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Natural Resource Stewardship and Science

Assessment of Vegetation in Six Long-Term Deer Exclosure Investigations at Morristown National Historical Park

Data Synthesis & Management Recommendations

Natural Resource Report NPS/MORR/NRR—2020/2176

The production of this document cost $16,413, including costs associated with data collection, processing, analysis, and subsequent authoring, editing, and publication.

ON THIS PAGE
Native herbaceous vegetation protected in an exclosure along the Primrose Brook Trail
(RU/JEAN N. EPIPHAN)

ON THE COVER
Current condition of a 32 year old exclosure along the New York Brigade Trail
(RU/JEAN N. EPIPHAN)

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Data Synthesis & Management Recommendations

Natural Resource Report NPS/MORR/NRR—2020/2176

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Executive Summary

Countless habitats in the Northeast region of the United States are being threatened by stresses that lower native biodiversity and natural resource quality. The main stressors near developed areas are waves of invasive plants and the overabundance of white-tailed deer (*Odocoileus virginianus*). One common solution to protecting native plants is the exclosure fence, which eliminates deer herbivory and potentially the spread of some introduced plants. Twenty-four long-term deer exclosures have been established in Morristown National Historical Park for six differing research purposes. The long-term data from these exclosures, collected for over thirty years, provide a wealth of information to the National Park Service as well as other professionals in conservation management.

The goals of this study were to synthesize the long-term data sets and reveal the dynamics and successes of these exclosures as tools in ecological conservation. As built structures in a changing landscape, how have these exclosures performed as protection tools over time? How successful have they been in protecting native vegetation for up to thirty years and with limited funding? The lessons learned here can inform managers and professionals throughout parks where deer herbivory and invasive plants pose serious concerns.

We found that the majority of exclosures have been able to preserve native species (herbaceous and woody shrubs and trees) that have important ecological services. Location within MNHP played an important role in their success. Exclosures within intact mid- to late succession mixed oak-beech-birch forests had more native species and higher floristic quality than those in tulip-ash or black locust successional forests or areas near field edges. The smaller exclosures (3.7 x 3.7 m) were less likely to break open and provide deer access, even if damaged. Larger exclosures, such as the two-acre exclosure or the 10 x 10 m exclosures, had higher risk of tree limb fall and subsequent failure. This is due to the greater chance of damage because of larger ground coverage. (Any fence damage opens up the entire exclosure to deer herbivory). Distance from high density introduced species invasions was correlated with success. Exclosures intentionally placed in or adjacent to invasive plant colonies were more likely to be infiltrated by invasive plants in comparison to exclosures placed intentionally in areas free of invasive plants. The invaded exclosures provided insights on introduced species dynamics. In particular, woody invasive plants dominated in specific locations that were previously dominated by Japanese stiltgrass (*Microstegium vimineum*). This has implications for management and control strategies into the future as these populations of invasive plants demonstrate a novel form of succession.

We recommend that with limited resources, investments should be directed to exclosures located in high quality forest sites as they are most beneficial to native habitat conservation over time. Exclosure fences must have a continual repair management protocol to be effective, such as regularly scheduled and frequent visits, especially after storms. The care needed to maintain the exclosures is much more time intensive than was expected over the years and cannot be managed by just one devoted employee as in the past. If funding does not allow for more people-hours devoted to exclosure maintenance, we recommend focus on small exclosures (such as 3.7 x 3.7 m) that require

less frequent and costly maintenance and experience less frequent damage. Although fewer acres would be protected, the success of more secure exclosures overtime would be improved.

Acknowledgments

Thank you to R. Masson, the Biologist of Morristown National Historical Park, for endless and invaluable assistance in field work coordination, logistics for the months of data collection, institutional memory of past investigations and ecological conditions, and managing and retrieving much archived data files. This all was done in addition to his completing his regular NPS professional activities as a senior member of the MNHP staff. This report could not have been done without his help, encouragement, and constant enthusiasm.

Thank you to T. Grimm for valuable assistance in data organization.

Thank you to K. Miller and W. Thompson whose careful reviewing and thoughtful edit suggestions helped to refine this report.

Introduction to the Six Exclosure Studies

Countless habitats in the Northeast region of the United States are being threatened by stresses that lower native biodiversity and natural resource quality. The main stressors in developed areas are waves of invasive plants and overabundance of white-tailed deer (*Odocoileus virginianus*). One common solution to protecting native plants is the exclosure fence, which eliminates deer herbivory and potentially the spread of some introduced plants. The enclosed native flora can then grow and reproduce, potentially enriching the surrounding areas eventually by dispersal. Native flora preservation is vital for wildlife habitat, other ecological services, and conservation of regional natural heritage, all important goals for the USNPS.

Over the years, several exclosures have been erected in the Jockey Hollow and New Jersey Brigade sections of Morristown National Historical Park for various related, yet different, research purposes (Table 1). These studies tested conservation concepts such as: if preventing deer herbivory would allow for native forests plants to exist and regenerate; if specific planted natives would succeed and reproduce in exclosures; if exclosure from deer helps to prevent invasive plant infiltration; and how species compositions change after specific invasives were physically removed. The findings of each study have been independently evaluated in published reports (Russel, 2002; Ruhren and Handel, 2003; Tartaglia and Handel 2007; Ehrenfeld et al., 2010). However, the data collection in some cases continued as the exclosures remained on site. The National Park Service is left with the main question of what is the next management step for these exclosures?

Their fate lies in their efficiency to support native flora (trees, shrubs, and herbs) over the years balanced with the requirement to keep the exclosures intact. This study re-examines long-term data of 24 exclosures, of which 23 remain (Figure 1). New data have been collected on the vegetation in and around the exclosures, as well as exclosures' structural integrity. The following report examines each original study (six in total) to see if they have been successful and to determine whether management lessons can be extracted.

Table 1. Exclosure Studies 1987 to 2003. Exterior Control refers to the presence or absence of an open control site next to the exclosure.

Name of study	Year of inception	Size	Total # of exclosures	Individual exclosure identification	Exterior control	Research purpose
Deer Exclosure	1987 & 1988	6.1 x 6.1m	5	1, 2, 3, 4, 5	Yes	Observe differences in vegetation in exclosures protected from deer to adjacent areas open to deer herbivory under a range of forest cover types.
Biotic	1995	10 x 10m	2	6, 7	Yes	Preserve native seed reservoirs in specific areas of significant native plant biodiversity and measuring the success of preservation in an exclosure
Exotics	1995 (monitoring began in 1998)	10 x 10m	4	SHT, GLT, CR, NJB (CR no longer exists)	No	Assess whether nearby Japanese barberry and Japanese stiltgrass would spread into the exclosure if protected from deer, if native could reestablish if protected by deer, and if native plants reestablishment could reduce invasive plant infiltration.
Jack-in-the-Pulpit	1997	3.7 x 3.7m	4	j1, j2, j3, j4 (j3 & j4 no longer exist)	No	Evaluate effect of deer herbivory on jack-in-the-pulpit.
Herbaceous	1997	3.7 x 3.7m	10	h1, h2, h3, h3, h4, h5, h6, h7, h8, h9, h10	Yes	Evaluate feasibility of restoring native herbs, compare reproduction with and without deer herbivory, test if pollinators and seed dispersers visit the restored species.
Restoration	2003	90 x 90m	1	2ac	Yes	Evaluate effectiveness of restoration treatments in an exclosure

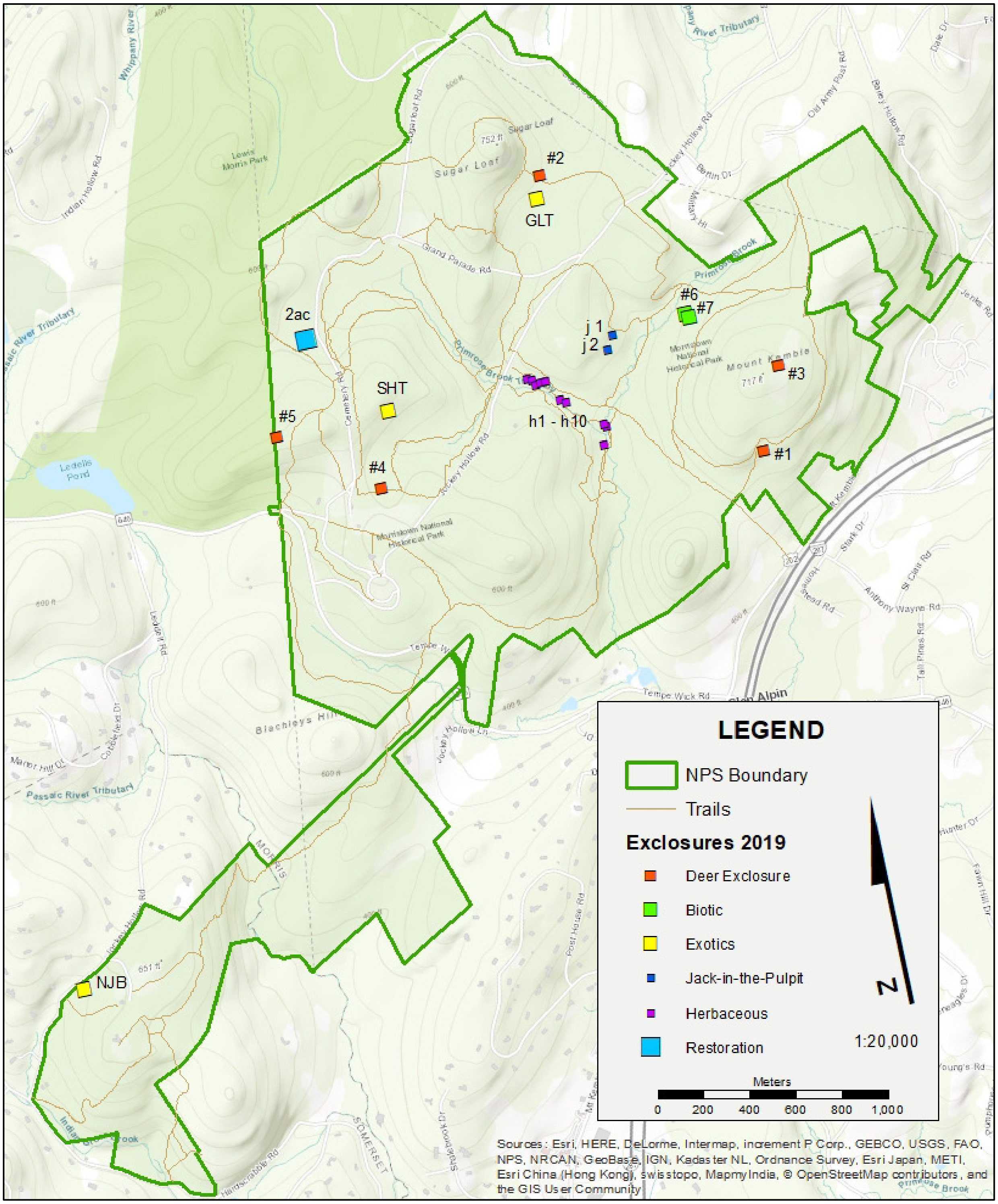

Figure 1. 2019 map of existing exclosures in the Jockey Hollow Section of Morristown National Historical Park. Exclosures are labeled by their identification codes. Exclosure symbolized by exclosure study. The digital location of the site where Exclosure CR once stood could not be found in 2019 during field searches and is not included in this map of existing exclosures.

Methodology

Each of the following studies had original sampling methodologies that differed from one another. We replicated each of the original methods when possible. Then we performed our overall data collection. Data synthesis and analysis was in many similar between studies, yet in many ways different. The complete and comprehensive methods are included in each chapter for clarity.

Data Collection 2019

We found and visited each of the existing 23 exclosures at Morristown National Historical Park and mapped their locations in GIS (geographical information systems) (Figure 1). The status of each exclosure structure was noted as well as the vegetative condition. If exclosures or control areas experienced tree or limb fall damage, deer browse, or excessive overgrowth, each was noted. Some exclosures could not be entered or assessed in detail because entry would have been hazardous.

As a complete census we recorded the species list in each exclosure and control where-ever possible. The percent cover within the entire exclosure and control were recorded (except for the 2 ac exclosure). Then we followed each of the particular and original sampling protocols for each study if available. These specific details are explained in the methods section of each chapter.

Data Synthesis

We received and reviewed all available raw data files from each of the six studies. Some of the data were not available or complete. However, we were able to perform an adequate data synthesis and produce results as explained in detail in the following chapters. We then evaluated the current quality of vegetation at each exclosure by using the adjusted floristic quality index as it considers the contributions of introduced species as well as native species and it eliminates the sensitivity to species richness that helps to more accurately express condition for low richness high quality sites (Miller and Wardrop 2006).

Adjusted Floristic Quality Index Formula:

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

I' = Adjusted floristic quality index $\quad$ C = Coefficient value

N = Native species $\quad$ A = Introduced species

The complete results are reported in each of the following chapters' results section. Likewise, the specific conclusions and recommendations for each study and exclosure are at the end of each chapter.

Chapter 1. The First Deer Exclosures in Jockey Hollow

Introduction

In the 1980s, white-tailed deer (*Odocoileus virginianus*) populations were increasing throughout the region (Paddock and Yabsley, 2007). Native plant populations in old fields and forests were experiencing detrimental changes and severe losses of species richness due to white-tailed deer herbivory (Alverson et al., 1988, Healy 1997, Bowers, 1997). National Park Service employees decided to build five exclosures in different forest covertypes to observe how vegetation responds when protected from deer herbivory over time (R. Masson, personal communication, 31 August 2018). This was a pioneering concept in the late 1980s as the deer population surge was a novel occurrence.

Since 1987, NPS employees and volunteers collected data in these five exclosures. Their sampling detail, intensity, and methods evolved over the many years. Data were assessed in a 2002 report (Russell, 2002) after which more data have been collected through 2007 and again in 2019. This chapter reveals the results and conclusions to a 32-year study of vegetation in and outside of five deer exclosures. In addition, this study demonstrates how exclosures function in the landscape in forests and edge habitats.

Methods

1987–2007 Establishment and Data Collection

Five 6.1 x 6.1m deer exclosures were erected in 1987 and 1988, each with a paired adjacent control area of the same size. The five exclosures were placed in different forest cover types (Ehrenfeld 1977).

- Exclosure #1 – mixed oak (*Quercus* spp.) – black birch (*Betula lenta),* – tulip poplar (*Liriodendron tulipifera*) forest cover
- Exclosure #2 – tulip poplar – ash (*Fraxinus* spp.) forest cover
- Exclosure #3 – edge of old field with an open canopy
- Exclosure #4 – near an open field under successional black locust (*Robinia pseudoacacia*) forest cover
- Exclosure #5 – American beech (*Fagus grandifolia*) – black birch forest cover

From 1987–1990, percent cover data per vascular plant species were recorded in one 1m^2 subplot for each exclosure and control. In 1991, percent cover data were collected in categories (Epiphan and Handel, 2020) and subplots were chosen at random. From 1991–1997, sample size per site varied from one to four in each exclosure and control. In 1998 and onward, nine subplots were sampled in most cases. Some years a census was performed instead of samples and in some years, data were not collected. These changes make a direct comparison among years inappropriate.

2019 Data Collection

The GPS location of each exclosure was recorded. Condition of each exclosure fence and site was recorded. Openings in the fences and deer browse intensity was recorded for each exclosure.

In all five exclosures and adjacent control plots, a census of percent cover of each vascular plant species under three meters tall was performed within the entire 6.1 m^2 area. Then, percent cover per vascular plant species under three meters tall was recorded in each of the 1 m^2 subplots inside the exclosure and each of nine 1 m^2 subplots in the adjacent control area. Some species identification could not be verified due to lack specific characteristics needed for differentiation. Therefore, the genus was recorded in few cases such as in ash (*Fraxinus* sp.). Exclosures #2, #3, and #4 were severely damaged and hazardous to enter, therefore subplot information could not be accurately surveyed and was not recorded.

2019 Data Synthesis

Vegetation data in all the exclosures were compiled with past years' data. Sampled species percent cover was averaged per species in each exclosure and each control area per year. When percent cover categories were used in place of exact percent cover, the median of the percent cover category was used to represent the sample before averages were calculated (Table 1.1).

Table 1.1. Translation used to determine percent cover values from percent cover categories.

Median of % cover category	NPS code for % cover category	Description of NPS % cover category
0.5	r	Solitary with small number.
1	t	Few with small cover or solitary with < 5% cover
3	1	Numerous with < 5% cover
15	2	5 to 25% cover
38	3	26 to 50% cover
63	4	51 to 75% cover
85.5	5	76 to 95% cover
98	6	96 to 100% cover

Species cover averages were totaled into two groups, native and introduced. Nativity was verified by the USDA plants database (USDA NRCS, 2006). Blackberry species (*Rubus* spp.) were often dropped from the totals because in many years they were not identified to species and introduced wineberry (*Rubus phoenicolasius*) was not differentiated from other native blackberry species. The few unknown species data were dropped from the synthesis. The census data were compiled in the same manner as the sampled data except the exact percent cover or the median of the category were used to represent the species cover. No averages were calculated for the census. Species richness data were compiled for each year and separated into native and introduced categories.

A floristic quality assessment was performed for the 2019 data to determine the current vegetative condition. We used the New Jersey 2019 coefficient values (Freyman et al., 2016). We utilized the adjusted floristic quality because it was adapted to consider the contributions of introduced species as well as native species and it eliminates the sensitivity to species richness that helps to more accurately express condition for low richness high quality sites (Miller and Wardrop 2006).

Adjusted Floristic Quality Index Formula:

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

I' = Adjusted floristic quality index C = Coefficient value
N = Native species A = Introduced species

Results

Exclosure #1

<u>Assessment of Sampled Data Over Time</u>
In the exclosure and control area for the first several years, data were not comparable as the sample size and continuity varied in the first decade (Figure 1.1). In 1998, when the sample size grew to nine subplots, the averaged native percent cover was 90%, far above the control's native percent cover. The fence was found open to deer in 1999 and 2000 and native cover in the exclosure declined. It was later repaired, but the native species cover in the exclosure resurged to only 40%. The native species cover in the control declined over time and with very low observations in 2019. Native species richness fluctuated over the years but was greater in the exclosure every year (Table 1.2).

The control area experienced a steady growth of invasive species coverage surpassing 90% in 2003 and remained above 90% in 2019 (Figure 1.1). This growth was mainly due to the invasion of Japanese barberry (*Berberis thunbergii)* that had an average cover of 81% in the control subplots. In the exclosure, coverage of Japanese barberry and other introduced species remained low. The introduced species richness in the exclosure and control remained below 6 species (Table 1.2). The slight increases or decreases of species richness in 1991, 1993, 1994 and again in 1998 may have been due to the changes in sampling intensity.

<u>2019 Census</u>
The only year census data were collected was in 2019, where the entire exclosure and control were surveyed. The native species richness in the exclosure was 12 and the total native cover in the exclosure was 52.75%. The main native species found in the exclosure were spicebush (*Lindera benzoin*), maple-leaf viburnum (*Viburnum acerifolium*), tulip poplar (*Liriodendron tulipifera*), Virginia creeper (*Parthenocissus quinquefolia*), and Jack-in-the-pulpit (*Arisaema triphyllum*). In the control area, four native species were found occupying only 2% cover.

Seven introduced species were found in the exclosure and cohesively had a cover of 50%. However, 48% of that cover was from Asiatic bittersweet (*Celastrus orbiculatus*) that was climbing the fence and spreading outward at 2 m, arching above the native cover below. In the entire control area, the introduced species richness was seven and was dominated by Japanese barberry that had 98% cover.

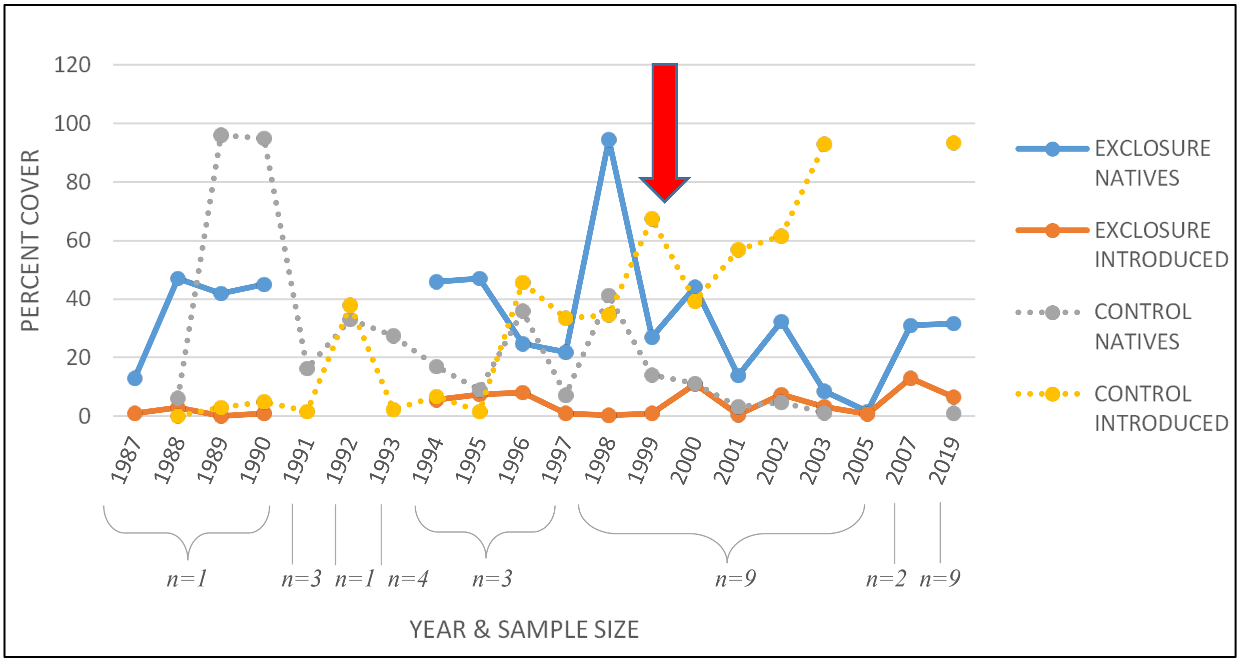

Figure 1.1. Sampled percent cover of native and introduced species in 1m^2 subplots over time in Exclosure #1 and the adjacent control. The red arrow denotes when the fence was found open and deer herbivory was evident on native species in the exclosure. The breaks in data lines indicate when data were not collected. In 1991–1993, the exclosure was not sampled, but the control was. In 1987, 2005 and 2007 the control was not sampled, but the exclosure was.

Table 1.2. Native and introduced species richness over time in the sampled subplots of Exclosure #1 and the adjacent control. Note the sample size generally increased over the years (a few years it decreased) as shown in the second column.

Year	Sample size	Exclosure native	Exclosure introduced	Control native	Control introduced
1987	1	5	1	–	–
1988	1	9	2	2	0
1989	1	8	0	4	2
1990	1	3	1	1	1
1991	2	–	–	5	3
1992	1	–	–	5	1
1993	4	–	–	8	5
1994	3	15	2	5	2
1995	3	12	2	9	3
1996	3	13	5	9	4
1997	3	10	2	5	4
1998	9	12	2	9	6
1999	9	11	5	9	6
2000	9	16	5	13	6

Table 1.2 (continued). Native and introduced species richness over time in the sampled subplots of Exclosure #1 and the adjacent control. Note the sample size generally increased over the years (a few years it decreased) as shown in the second column.

Year	Sample size	Exclosure native	Exclosure introduced	Control native	Control introduced
2001	9	14	3	11	4
2002	9	13	4	10	4
2003	9	11	4	7	4
2005	9	9	4	–	–
2007	2	8	5	–	–
2019	9	12	4	4	3

Exclosure #2

Assessment of Sampled Data Over Time

In the exclosure, native species percent cover fell in 1989 and remained low for over two decades until it resurged to 39% in 2002 (Figure 1.2). In 2019, sampled native species cover was 34% even though the fence was found wide open on one side. In the control area, sampled native percent cover remained low after 1989.

Introduced species cover in the exclosure and control surged in 1989 to over 90% which was due to Japanese stiltgrass (*Microstegium vimineum*). Japanese stiltgrass cover was gradually replaced with the introduced shrubs Japanese barberry, multiflora rose (*Rosa multiflora*), and wineberry (*Rubus phoenicolasius*) by 2002. Since then, the new invasions of common privet (*Ligustrum vulgare*) and burning bush (*Euonymus alatus*) dominated the introduced species cover. In the control, the introduced cover also shifted from Japanese stiltgrass dominance to Japanese barberry.

Native species richness in the exclosure was low except for in 2002 (Table 1.3). Native species richness in the control was low except between 1999 and 2003. The slight increase of native species richness from 1997 to 1998 could likely have been due to the increase in sampling intensity from three subplots to nine subplots. Sometime between 2003 and 2019 the exclosure fence fell open on one side, it was subject to deer browse, and native species richness fell. Introduced richness gradually increased.

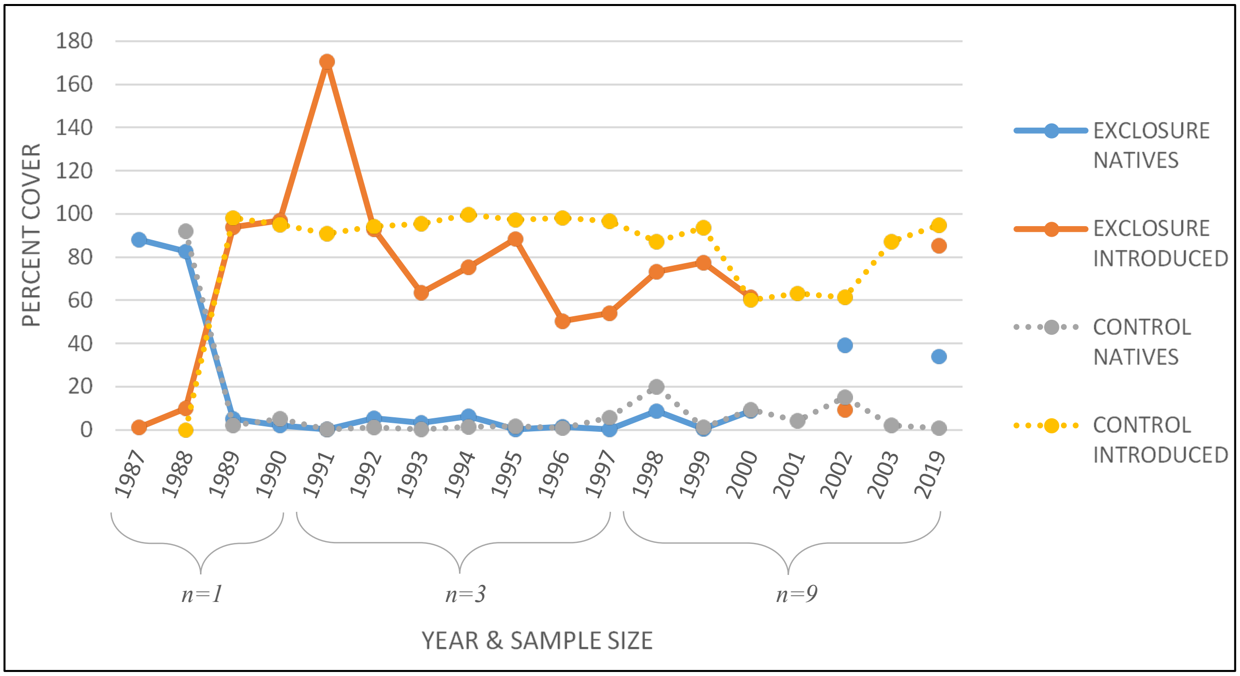

Figure 1.2. Sampled percent cover of native and introduced species in 1 m2 subplots over time in Exclosure #2 and the adjacent control. The breaks in data lines indicate when data were not collected. In 1987 the control was not sampled. In 2001 and 2003 the exclosure was not sampled.

Table 1.3. Native and introduced species richness over time in the sampled subplots of Exclosure #2 and the adjacent control. Note the sample size increased over the years as shown in the second column.

Year	Sample size	Exclosure native	Exclosure introduced	Control native	Control introduced
1987	1	5	1	–	–
1988	1	3	2	2	0
1989	1	1	3	1	2
1990	1	2	3	1	1
1991	3	2	5	1	3
1992	3	3	4	2	2
1993	3	4	5	1	2
1994	3	4	3	3	2
1995	3	1	5	3	3
1996	3	3	4	4	1
1997	3	1	5	4	4
1998	9	5	4	4	4
1999	9	3	4	9	6
2000	9	3	4	12	4
2001	9	–	–	8	5
2002	9	13	4	10	5

Table 1.3 (continued). Native and introduced species richness over time in the sampled subplots of Exclosure #2 and the adjacent control. Note the sample size increased over the years as shown in the second column.

Year	Sample size	Exclosure native	Exclosure introduced	Control native	Control introduced
2003	9	–	–	9	4
2019	9	3	5	2	7

Census Over Time

In 2001, the exclosure vegetation was so thick it could not be entered to sample subplots, therefore it was assessed as a census; both the control and exclosure were surveyed as a census in 2005 (Figure 1.3). A notable increase in introduced species coverage in both the exclosure and control area occurred from 2005 to 2019. The native percent cover in the exclosure increased to 36% while the native species in the control was suppressed.

In 2019, the vegetation in and outside of the exclosure was extremely thick. The exclosure fence was down on one side and open to deer. A dense thicket of common privet (*Ligustrum vulgare*) proliferated and ended up blocking access to deer browse in some sections. A few larger spicebush shrubs were able to persist and grow above the deer browse line. Six species of natives were recorded in the exclosure as well as six introduced species. Outside the exclosure, Japanese barberry dominated the control area where eight total introduced species were found and only four native species.

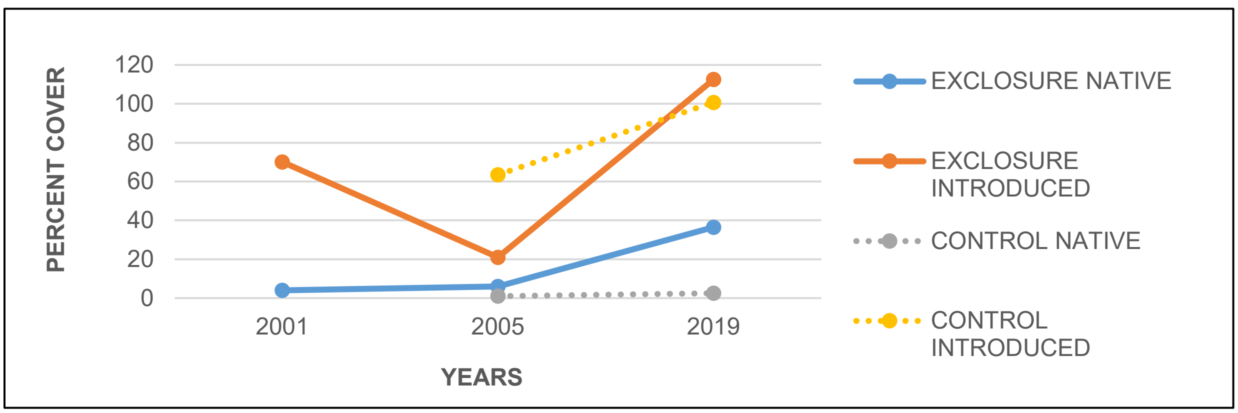

Figure 1.3. Percent cover census of native and introduced species over time in the entire 6.1 m2 Exclosure #2 and the adjacent control. The breaks in data lines indicate when data were not collected. In 1987 the control was not sampled. In 2001 and 2003 the exclosure was not sampled.

Exclosure #3:

Assessment of Sampled and Census Data

Early on the shrubs and vines grew so thick that subplot sampling was no longer possible; therefore, for a few years, census data were collected instead (Figure 1.4 & Figure 1.5). In the first couple years, Japanese stiltgrass grew to be a dominant species in the exclosure and was up to 50% cover in the control. It was quickly replaced by introduced vines and shrubs. Native cover dropped early on and remained lower than introduced species cover throughout the site. In 2019, the census revealed many layers of introduced vegetation well exceeding 100% cover inside the exclosure and the control. At some point between 2003 and 2019, the exclosure collapsed from limb fall damage and the weight of climbing vegetation.

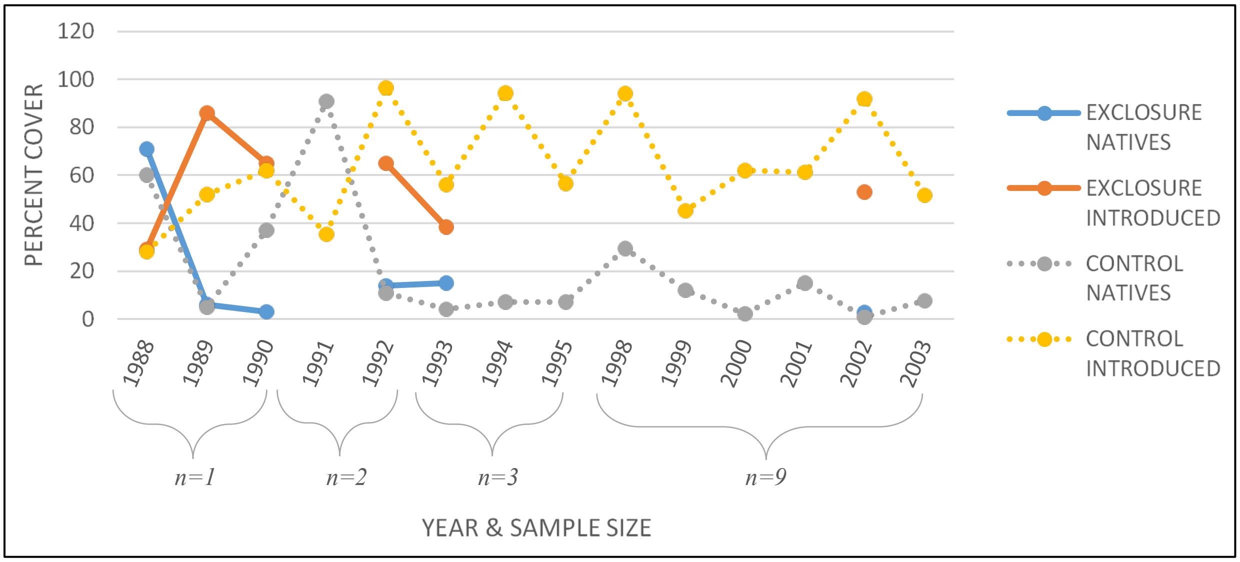

Figure 1.4. Sampled percent cover of native and introduced species in 1 m2 subplots over time in Exclosure #3 and the adjacent control. The breaks in data lines indicate when data were not collected. In 1991, 1994–1995, 1998–2001, and 2003, the exclosure was not sampled.

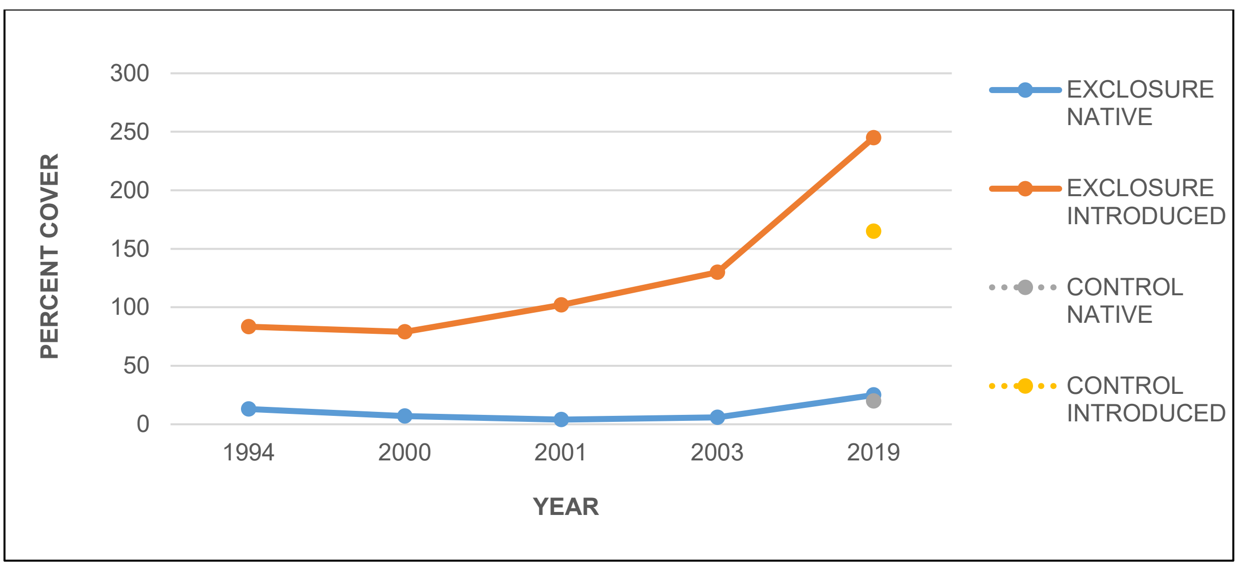

Figure 1.5. Percent cover census of native and introduced species over time in the entire 6.1 m^2 Exclosure #3 for five years. The adjacent control was sampled only in 2019.

Over the years, species richness gradually increased and then decreased (Table 1.4 & Table 1.5). The increase is sampling intensity in the control over the years could have influenced the initial increase in species richness, however between 1998 and 2003 of continuous sampling intensity the richness slightly decreased over time (Table 1.4). Due to the thick vegetation the exclosure was not sampled like the control, rather a census was performed and over the years native richness plummeted (Table 1.5). In 2019, the only native species found at the site were Allegheny blackberry (*Rubus allegheniensis*) and Virginia creeper (*P. quinquefolia)*. The dominant introduced species were Japanese barberry, multiflora rose (*Rosa multiflora*), and Japanese honeysuckle (*Lonicera japonica*).

Table 1.4. Native and introduced species richness over time in the sampled subplots of Exclosure #3 and the adjacent control. Note the sample size increased over the years as shown in the second column.

Year	Sample size	Exclosure native	Exclosure introduced	Control native	Control introduced
1988	1	3	4	1	4
1989	1	3	3	3	2
1990	1	1	3	1	3
1991	2	–	–	10	3
1992	2	11	6	4	4
1993	3	9	5	4	3
1994	3	–	–	6	5
1995	3	–	–	6	4
1998	9	–	–	7	8
1999	9	–	–	7	7
2000	9	–	–	10	9
2001	9	–	–	11	8
2002	9	5	4	4	3
2003	9	–	–	7	5

Table 1.5. Census of native and introduced species richness in scattered years in Exclosure #3 and in 2019 in the exclosure and adjacent control.

Year	Exclosure native	Exclosure introduced	Control native	Control introduced
1994	12	7	–	–
2000	4	3	–	–
2001	4	3	–	–
2003	2	4	–	–
2019	2	5	1	4

Exclosure #4

Assessment of Sampled and Census Data

Exclosure #4 was placed in a rather open understory setting with high light conditions near an open field and under a black locust successional forest. In 1996, a tree fell on the exclosure but did not collapse the fence, however since then, recorded notes suggest that vegetation was extremely thick and sampling efforts were hazardous. In 2012, a large canopy gap was created by Super Storm Sandy which opened more light to exclosure area. In 2019, sampling was impossible due to thick vegetation and the fallen tree hazards on and around the exclosure and a census was performed.

Throughout the duration of the sampling, introduced species dominated (Figure 1.6), however, the dominant species changed though time. In the first few years, the dominant plant was Japanese stiltgrass, over 90% cover, and woody plant cover was low. By the mid-1990s, introduced woody plants, multiflora rose and Japanese honeysuckle (*Lonicera japonica*), and introduced herbs such as garlic mustard (*Alliaria petiolata*) and bittercress (*Cardamine impatiens*), grew in cover. By 2019, the census recorded that Japanese stiltgrass was absent while multiflora rose was dominant (>80%); introduced shrubs and vines together reached 245% cover in the exclosure area and 165% cover in the control (over 100% means that multiple layers were present).

Native cover in most years was lower than introduced cover (Figure 1.6). The increase of native species in the exclosure in the late 1990's was due to high cover of spicebush, enchanter's nightshade (*Circea lutetiana*), Jack-in-the-pulpit (*Arisaema triphyllum*), violets (*Viola* spp.), and Virginia creeper (*Parthenocissus quinquefolia*), all of which were eventually outcompeted by introduced species. The adjacent control area maintained a low native cover throughout. In 2019, native percent cover was low overall; in the exclosure it was 12% and 0% in the control.

Over the years, species richness increased and then decreased in the 2000s (Table 1.6). The increased species richness from 1997 to 1998 could have been due to the increase in sampling intensity from five subplots to nine subplots. The 2019 census revealed a drop in native richness to two native species in the exclosure, zero natives in the control. Eight introduced species were found in the exclosure and six in the control.

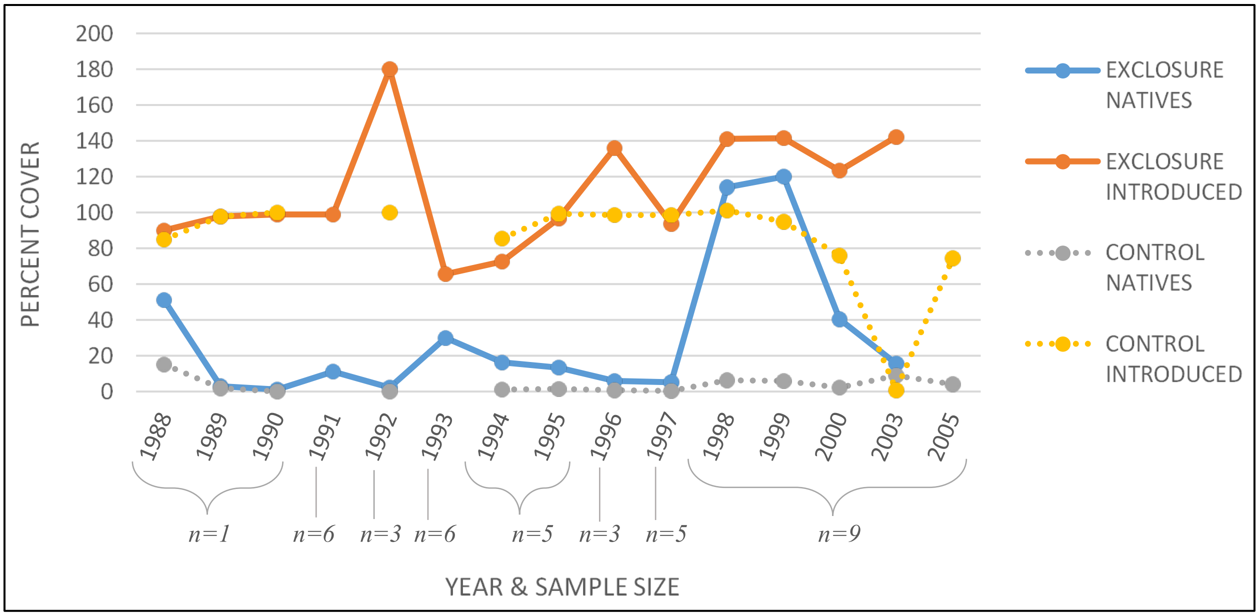

Figure 1.6. Sampled percent cover of native and introduced species in 1 m^2 subplots over time in Exclosure #4 and the adjacent control. The breaks in data lines indicate when data were not collected. In 1991 and 1993 the control was not sampled. In 2005 the exclosure was not sampled.

Table 1.6. Native and introduced species richness over time in the sampled subplots of Exclosure #4 and the adjacent control. Note the sample size generally increased over the years (a few years it decreased) as shown in the second column.

Year	Sample size	Exclosure native	Exclosure introduced	Control native	Control introduced
1988	1	5	3	2	3
1989	1	2	3	1	2
1990	1	1	3	0	2
1991	6	9	4	–	–
1992	3	5	5	1	4
1993	6	9	7	2	2
1994	5	6	6	4	4
1995	5	6	4	3	2
1996	3	5	6	1	3
1997	5	5	4	5	5
1998	9	9	6	5	5
1999	9	7	7	7	5
2000	9	10	7	3	2
2003	9	7	7	–	–
2005	9	5	5	2	5

Exclosure #5

Assessment of Sampled and Census Data

At Exclosure #5 and its control, sampling over the years demonstrated very low or absent introduced species percent cover (Figure 1.7). The native species percent cover remained below 15% in the control area and below 40% cover in the exclosure. The fluctuations of native percent cover in the exclosure in the first decade may have been due to differences in sampling intensity and random locations of subplots. A few large shrubs existed in the exclosure, whereas other parts remained mostly bare. When nine subplots were consistently sampled after 1998, the native percent cover grew until 2003 when a hole was found in the fence and deer herbivory was noted. In 2012, Hurricane Sandy caused a large tree to fall on the site and opened the exclosure to deer permanently. In 2019, the species with the greatest percent cover were pignut hickory (*Carya glabra*), witch hazel (*Hamamelis virginiana*), and native sedge (*Carex* sp.) which is mostly likely Pennsylvania sedge (*Carex pensylvanica*).

Species richness follows the same trend as the percent cover (Table 1.7). The native richness increased overtime and then decreased after the fence was found open in 2003. The increase of native species richness from 1997 to 1998 could likely have been due to the increase in sampling intensity from three subplots to nine subplots. The introduced richness remained low or absent. In 2019, the census revealed more species than the sampling: twelve native species were found in the exclosure and six native species in the control even though the fence was completely down; no introduced species were recorded.

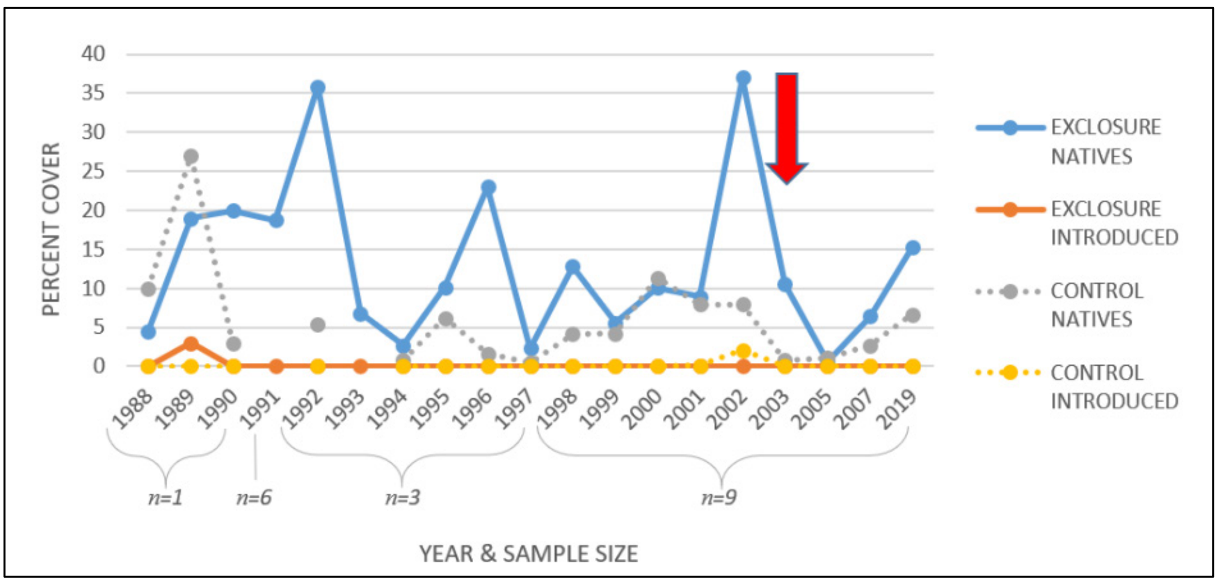

Figure 1.7. Sampled percent cover of native and introduced species in 1 m^2 subplots over time in Exclosure #5 and the adjacent control. The breaks in data lines indicate when data were not collected. In 1991 and 1993 the control was not sampled. The red arrow displays when a hole was found in the exclosure fence allowing deer to enter.

Table 1.7. Native and introduced species richness over time in the sampled subplots of Exclosure #5 and the adjacent control. Note the sample size generally increased over the years as shown in the second column.

Year	Sample size	Exclosure native	Exclosure introduced	Control native	Control introduced
1988	1	4	0	2	0
1989	1	4	1	3	0
1990	1	3	0	3	0
1991	4	6	0	–	–
1992	3	6	0	2	0
1993	3	4	0	–	–
1994	3	5	0	2	0
1995	3	8	0	4	0
1996	3	8	0	5	0
1997	3	6	0	2	0
1998	9	10	0	4	0
1999	9	11	0	6	1
2000	9	10	0	5	0
2001	9	10	0	4	1
2002	9	12	0	8	2
2003	9	9	0	7	0
2005	9	5	0	6	0
2007	9	7	0	5	0
2019	9	5	0	7	0

Exclosures #1–5 Comparison and Condition 2019

Exclosure #1 was erected under a mixed oak, black birch, and tulip poplar canopy on a slope half-way between the toe-slope and upland summit (see Figure 1). In 2019, the exclosure was intact and closed off to deer. Over the years, barberry has been mostly excluded in the exclosure, while it completely dominated the control and surrounds the entire area (Appendix B). Native species in the control were suppressed, but in the exclosure, natives have been allowed to grow and survive by 2019 (Figure 1.8). The dominant introduced species in the exclosure was the vine Asiatic bittersweet that was perched on the fence, thriving at a height of 2–3 meters. The adjusted floristic quality index (FQI) in the exclosure was 34.4, which is much higher than in the control, 21.1 (Table 1.8).

Exclosure #2 was established at a moist toe-slope east of Sugar Loaf Hill (see Figure 1) under a canopy of tulip poplar and ash where the groundcover layer was mostly comprised of Japanese stiltgrass. This general area was rapidly invaded with introduced shrubs that pushed out native species and Japanese stiltgrass. The exclosure fence failed in time as the introduced shrub cover increased beyond 100% (Figure 1.8). In 2019, some native species persisted but remained suppressed

(Figure 1.8 & Figure 1.9). The adjusted FQI was 26.9 in the exclosure and 18.3 in the control (Table 1.8).

Exclosure #3 was placed under full sun on the edge of an old field. Japanese stiltgrass and native species were outcompeted by introduced shrubs and vines. In 2019, the fence was down and it had the highest overall introduced cover in the exclosure area and the control (Figure 1.8). The dominance of introduced species reduced the overall richness (Figure 1.9). In 2019, the adjusted floristic quality index was lowest of all the exclosures at 13.4 and as 10 in the control (Table 1.8).

Exclosure #4 was subject to similar site influences as #3. It is very near an open field to the south and subject to edge effects. It was established under light shade of a successional black locust cover type where many trees failed over the years and opened more canopy gaps (Shaw and Farrell, 2013). Introduced species cover flourished in the exclosure especially because multiflora rose was able to dominate by growing up and all over the fence and downed trees (Appendix B). Native species were very suppressed (Figure 1.8). In 2019, the adjusted FQI was 14.3 in the exclosure and 0 in the control because no native species were recorded there (Table 1.8).

Exclosure #5 was established in a dry upland area under a canopy of American beech and black birch trees. The understory remained sparse through the years and in 2019 was completely native in the exclosure and in the control (Figure 1.8 & Figure 1.9). The location of site is also farther from the dense invaded areas rather than amidst them, like the other exclosures. The adjusted FQI was highest at this site because no invasive species were recorded; in the exclosure it was 48 and the control was 53 (Table 1.8).

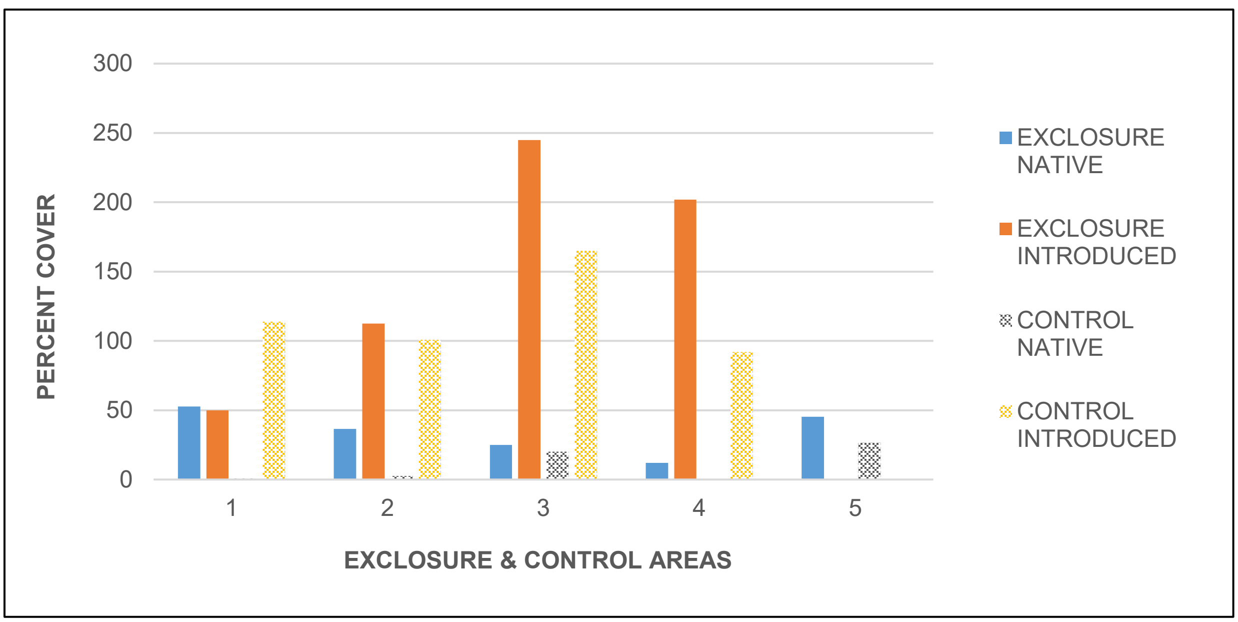

Figure 1.8. Percent cover census of native and introduced vegetation in five exclosures and their paired controls in 2019.

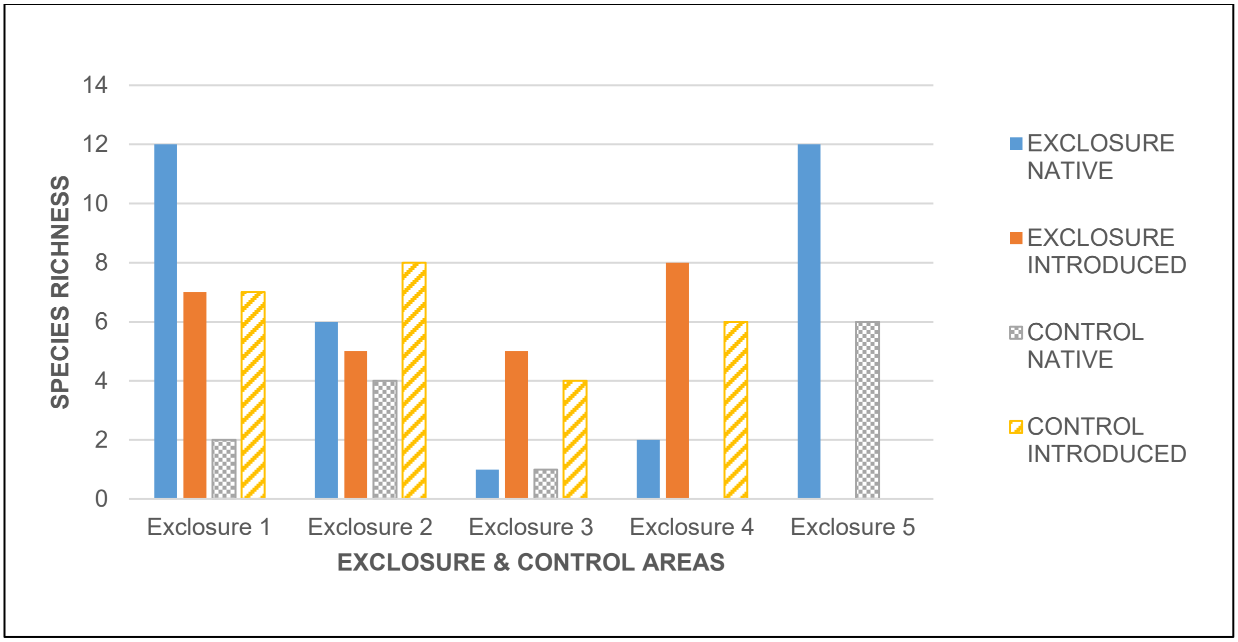

Figure 1.9. Richness census of native and introduced vegetation in five exclosures and their paired controls in 2019.

Table 1.8. Floristic quality assessment of exclosures #1–5 and paired control areas in 2019. Total mean C equals the mean coefficient value for native and introduced species. Native mean C is the mean coefficient value for native species. FQI is the floristic quality index.

Conservatism-based metrics:	**Exclosure #1**	**Control #1**	**Exclosure #2**	**Control #2**	**Exclosure #3**	**Control #3**	**Exclosure #4**	**Control #4**	**Exclosure #5**	**Control #5**
Total Mean C:	2.7	1.3	1.9	1	0.7	0.5	0.6	0	4.8	5.3
Native Mean C:	4.4	3.5	3.8	3.3	2.5	2	3.5	0	4.8	5.3
Total FQI:	11.5	4.3	6.6	3.6	1.9	1	2.1	0	11.8	18.4
Native FQI:	14.6	7	9.3	6.6	3.5	2	4.9	0	11.8	18.4
Adjusted FQI:	**34.4**	**21.1**	**26.9**	**18.3**	**13.4**	**10**	**14.3**	**0**	**48**	**53**
% C value 0:	38.9	63.6	50	69.2	71.4	75	83.3	100	0	0
% C value 1–3:	16.7	18.2	16.7	15.4	28.6	25	8.3	0	16.7	8.3
% C value 4–6:	44.4	18.2	33.3	15.4	0	0	8.3	0	83.3	83.3
% C value 7–10:	0	0	0	0	0	0	0	0	0	8.3

Conclusion & Recommendations

Over the first decade (1987 to 1997), vegetation cover and richness fluctuations were the result of differences in sampling intensity. After 1998 when most exclosures had a sample size of nine or were recorded as a census, vegetation records were more constant. However, later openings in the fence allowed for deer herbivory in the exclosures and native species cover was impacted. Each of the five exclosures experience some degree of deer browse at some point in time.

Nonetheless, differences in native and introduced species cover across the sites strongly reflected the differences between each site. Exclosures #3 and #4 were severely impacted by edge effects and were quickly overcome by introduced shrubs and vines that outcompeted native plants over time. These two sites have the lowest floristic quality because of their location. Exclosure #5 had the highest floristic quality due to its distance from severe introduced plant invasions and potentially because of forest cover type. In Jockey Hollow, in areas with more mature American beech trees, less invasive plant infiltration has been experienced over the past few decades (R. Masson, personal communication, 15 August 2019). Exclosure #2, amidst a tulip poplar-ash canopy and moist toe-slope, was invaded by introduced species early on that flourished over time. Similarly, Exclosure #1 experienced a dense Japanese barberry invasion. Although, because the exclosure remained mostly intact over the years, it has been able to exclude or slow the invasion inside.

Last, the actual exclosure structures have influenced the species composition. The fence itself favors growth of vines as they have an available place to climb and reach towards light. This has given Asiatic bittersweet a competitive advantage over other species in Exclosure #1. In Exclosure #3 and #4, the structure allowed for vines and climbing shrubs, like multiflora rose, to gain a competitive advantage.

All in all, the exclosures had great potential to provide refuge for native plant species protected from deer herbivory (Russell, 2002). Exclosures #1, #4, and #5 had surges of native species growth before the fence was compromised. In Exclosures #2 and #3, the native cover dropped early on before the fence was compromised and invasive shrubs and vines moved in whether the fence was intact or not. Currently, the exclosure structures at sites #2–5 are collapsed or no longer serving as any protective barrier. These exclosures should be removed as they are eyesores in this national park landscape. Exclosure #5 has the highest adjusted FQI and should be re-installed to protect the high-quality species assemblage found there, but in this exact location, repair is almost impossible due to the large tree that fell in the area (Appendix B).

Exclosure #1 is still serving a purpose as it is protecting this 6.1m^2 area from being overcome by Japanese barberry. However, if this exclosure is going to be left standing, the Asiatic bittersweet should be cut at ground level and removed from the fence. The vine will eventually outcompete the native plants inside the exclosure. Last, the multiple standing dead trees around the exclosure have the potential to fail and destroy it. Appropriate precautions need to be taken for maintenance and data collection in the area.

Chapter 2. Biotic Exclosures

Introduction

In the 1990s, forests in New Jersey were experiencing record high populations of white-tailed deer (*Odocoileus virginianus*) (Kelly, 2018). The forests in the Jockey hollow section of Morristown National Historical Park were subject to severe browse from the over-abundant deer (R. Masson, personal communication, 31 August 2018). At the same time, invasive plants were spreading, dominating, and negatively impacting many habitats (Ehrenfeld, 1997, Kourtev et al., 1998, Ehrenfeld, 1999a, b).

The understory of Morristown National Historical Park was drastically changing and habitat for native species were being lost (Russell, 2002). A few high quality locations in the park were noticed by botanists and practitioners as “hot spots” of native vegetative biodiversity (R. Masson, personal communication, 31 August 2018). Under the council of Prof. Joan Ehrenfeld of Rutgers University, NPS employees placed two exclosures and adjacent control areas in two specific “hot spot” locations. The purposes of these exclosures were to preserve native seed reservoirs of significant native plant biodiversity and to measure the success of preservation in an exclosure over time.

Methods

1995–2003 Establishment and Data Collection

Two 10m x 10m deer exclosures were erected in 1995, each with a paired adjacent control area of the same size. For several years, vegetation data were collected by NPS employees and volunteers. In 1995 and 1997, the exclosures and control areas were sampled in five randomly selected 1m^2 subplots (Epiphan and Handel, 2020). Percent cover of vascular plants below three meters tall was recorded by percent cover category. From 1998 to 2003, data were collected in the same way, but as a census of the entire 10 x 10m area rather than in five subplots.

2019 Data Collection

The GPS location of each exclosure was recorded. Condition of each exclosure fence and site was recorded. Openings in the fences and deer browse intensity was surveyed in each exclosure. In the two exclosures and adjacent control plots, both a census and random sampling of five 1m^2 subplots were performed using the same methods as prior years, but exact percentages were used to record species percent cover rather than percent cover categories. Some species identification could not be verified due to lack specific characteristics needed for differentiation. Therefore, the genus was recorded for serviceberry (*Amelanchier* sp.), ash (*Fraxinus* sp.), azalea (*Rhododendron* sp.), and blueberry (*Vaccinium* sp.).

2019 Data Synthesis

Vegetation data in the exclosures and control were compiled with past years’ data. Percent cover categories used in previous years were translated to the median of the percent cover category (Table 2.1). In years when five subplots were sampled, the average per species was calculated per year in each the exclosure and control.

Table 2.1. Translation used to determine percent cover values from percent cover categories.

Median of % cover category	NPS code for % cover category	Description of NPS % cover category
0.5	r	solitary with small number.
1	t	few with small cover or solitary with < 5% cover
3	1	numerous with < 5% cover
15	2	5 to 25% cover
38	3	26 to 50% cover
63	4	51 to 75% cover
85.5	5	76 to 95% cover
98	6	96 to 100% cover

Species cover averages were totaled into to two groups, native and introduced. Nativity was verified by the USDA plants database (USDA NRCS, 2006). The few unknown species data were dropped from the synthesis. The census data over the years were compiled in the same manner as the sampled data except the percent cover values were not averaged. Species richness data were compiled for each year and separated into native and introduced categories.

A floristic quality assessment was performed for the 2019 data to determine the current vegetative condition. We used the New Jersey 2019 coefficient values (Freyman et al., 2016). We utilized the adjusted floristic quality because it was adapted to consider the contributions of introduced species as well as native species and it eliminates the sensitivity to species richness that helps to more accurately express condition for low richness high quality sites (Miller and Wardrop, 2006).

Adjusted Floristic Quality Index Formula:

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

I' = Adjusted floristic quality index C = Coefficient value
N = Native species A = Introduced species

Results

Biotic Exclosure #6

The biotic exclosure #6 was sampled only in the first year, 1995, and the last, 2019 (Figure 2.1). In 2019, the fence was open to deer and herbivory was evident. In both years, the percent cover of all vegetation was low, there were no introduced species found, and natives occupied less than 10% cover. The native species richness was seven in both the exclosure and control in 1995 and it was eight in each in 2019.

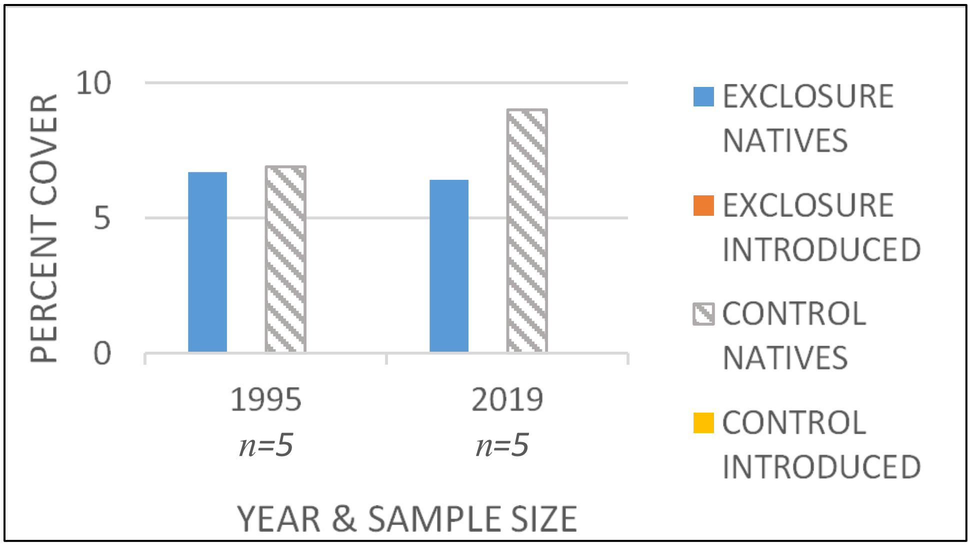

Figure 2.1. Sampled percent cover of native and introduced species in 1 m^2 subplots over time in Biotic Exclosure #6 and the adjacent control. Sample size (*n*) was five each year.

In the census each year from 1998 to 2019, the introduced percent cover was very low or absent (Figure 2.2). The native percent cover in the exclosure slightly decreased in 1999, then increased to over 100% in 2003, after which the fence broke open and exposed the plants to deer browse. In 2019, the fence was repaired, but the native percent cover was low and equal to the native cover in the control area. Correspondingly, the species richness over time follows the same trends as the percent cover (Table 2.2). Even though the native cover was reduced after it was open to deer, in 2019 the adjusted FQI was 49 in the exclosure, which was higher than the control at 43.4.

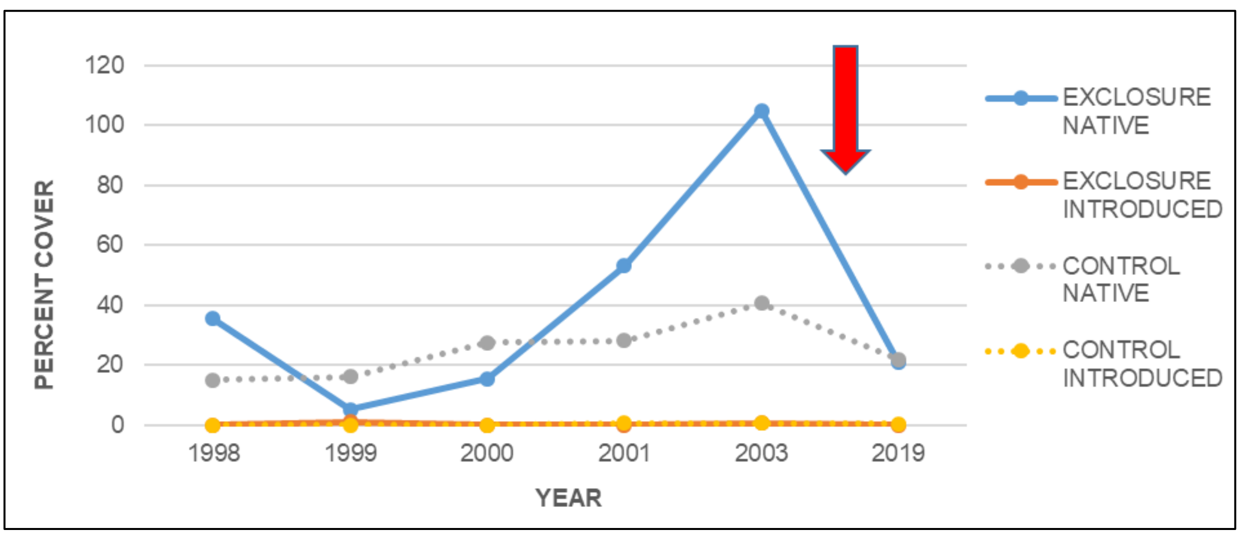

Figure 2.2. Percent cover census of native and introduced species over time in the entire 10 x 10 m Biotic Exclosure #6 and adjacent control. The red arrow denotes when the exclosure fence damaged and became open to deer.

Table 2.2. Census of native and introduced species richness in Biotic Exclosure #6 and the adjacent control.

Year	Exclosure native	Exclosure introduced	Control native	Control introduced
1998	12	0	10	0
1999	3	1	2	0
2000	7	0	9	0
2001	9	0	11	1
2003	21	1	20	1
2019	12	0	13	1

In the 2019 census, the native woody tree species covered 18% of the entire exclosure, which included 15% American beech (*Fagus grandifolia*) saplings and marginal cover of numerous small seedlings (below 30 cm in height) of red maple (*Acer rubrum*), black birch (*Betula lenta*), ash (*Fraxinus* sp.), tulip poplar (*Liriodendron tulipifera*), and black gum (*Nyssa sylvatica*). In the control area, the same species assemblage was observed (20.5% total cover); American beech covered 15% in the sapling layer and countless small native tree seedlings as in the exclosure, but with black cherry (*Prunus* serotina) and sassafras (*Sassafras albidum*) as well.

The only shrub species found in the exclosure in the 2019 census was blueberry (*Vaccinium* sp.) with a cover of only 1%. Herbaceous plants covered 5% of the exclosure, which included striped wintergreen (*Chimaphila maculata*), whorled loosestrife (*Lysimachia quadrifolia*), Canada mayflower (*Maianthemum canadense*), Indian cucumber-root (*Medeola virginiana*), and Indian pipe (*Monotropa uniflora*). The control area contained heavily browsed witch hazel (*Hamamelis virginiana*) and blueberry totaling less than 1%. The native herbs also were less than 1% cover, including only striped wintergreen, Canada mayflower, and beech drops (*Epifagus virginiana*). One small plant of Japanese stiltgrass (*Microstegium vimineum*) was observed at less than 1% cover.

Biotic Exclosure #7

In 1995, 1997, and 2019, subplots in the exclosure and control were sampled (Figure 2.3). Data records note that the exclosure was found with holes or entry pathways and evidence of deer herbivory in 1999 and 2004. It has since been repaired, has remained intact for over a decade, and the native species cover rose to more than double the control native cover in 2019. The introduced species percent cover remained very low or absent over the entire duration of the long-term survey.

In the 1995, 1997, and 2019, samplings the species richness remained comparable; native species richness in the exclosure and control ranged between ten and thirteen and introduced species richness was either zero or one. More accurate records of species richness were found in the census (Table 2.4). Dips in species richness were found in the exclosure in years when deer may have entered, but this trend is also found in the control. By 2019, the total native richness in the exclosure reached its highest point at 23 species and adjusted FQI of the exclosure was 50. The adjusted FQI was 43.5 for the control (Table 2.3).

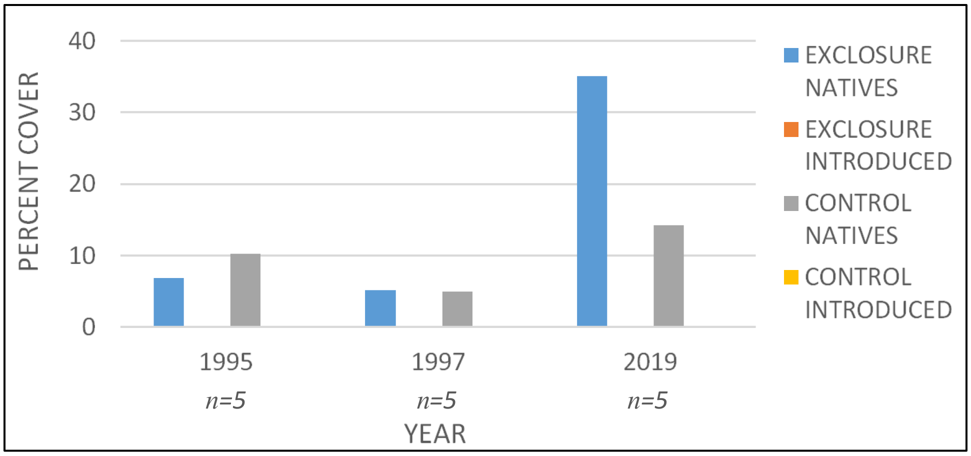

Figure 2.3. Sampled percent cover of native and introduced species in 1 m^2 subplots over time in Biotic Exclosure #7 and the adjacent control. Sample size (*n*) was five each year.

Table 2.3. Floristic quality assessment of the two biotic exclosures and controls in 2019.

Conservatism-based metrics:	**Exclosure #6**	**Control #6**	**Exclosure #7**	**Control #7**
Total Mean C:	4.9	4.2	4.8	4.1
Native Mean C:	4.9	4.5	5.2	4.6
Total FQI:	15.5	15.7	24.5	17.9
Native FQI:	15.5	16.2	25.5	19
Adjusted FQI:	**49**	**43.4**	**50**	**43.5**
% C value 0:	0	7.1	7.7	10.5
% C value 1–3:	10	21.4	7.7	21.1
% C value 4–6:	90	71.4	69.2	57.9
% C value 7–10:	0	0	15.4	10.5

Table 2.4. Census of native and introduced species richness in Biotic Exclosure #7 and the adjacent control.

Year	**Exclosure native**	**Exclosure introduced**	**Control native**	**Control introduced**
1998	16	0	11	1
1999	7	1	5	1
2000	15	0	13	0
2001	17	0	16	0
2003	11	0	8	0
2019	23	2	18	1

The percent cover of species in the census demonstrate the periods when the fence was opened, and deer had access (Figure 2.4). Native species cover dropped in 1999 to the same cover found in the control. Again, in 2003, the fence was open. Although, at some point after 2004, the fence was repaired and native species cover in 2019 surpassed 50% cover, which is more than double the control native cover in that year.

In the 2019 census, native tree species cover was 7.5% of the exclosure which included saplings of serviceberry (*Amelanchier* sp.), American beech, and black gum. Numerous seedlings between ground level and 50 cm height totaled 2% cover and included red maple, ash, tulip poplar, chestnut oak (*Quercus montana*), and black oak (*Quercus velutina*). One sprouting bigtooth aspen (*Populus grandidentata*), that had suffered deer browse in the past, covered less than 1% but is growing to over one meter in height now that the exclosure has been intact for a few years. The control area had very similar native tree species assemblage and cover (7.25%), however the only species above 10 cm in height was American beech that had evidence of frequent deer browse.

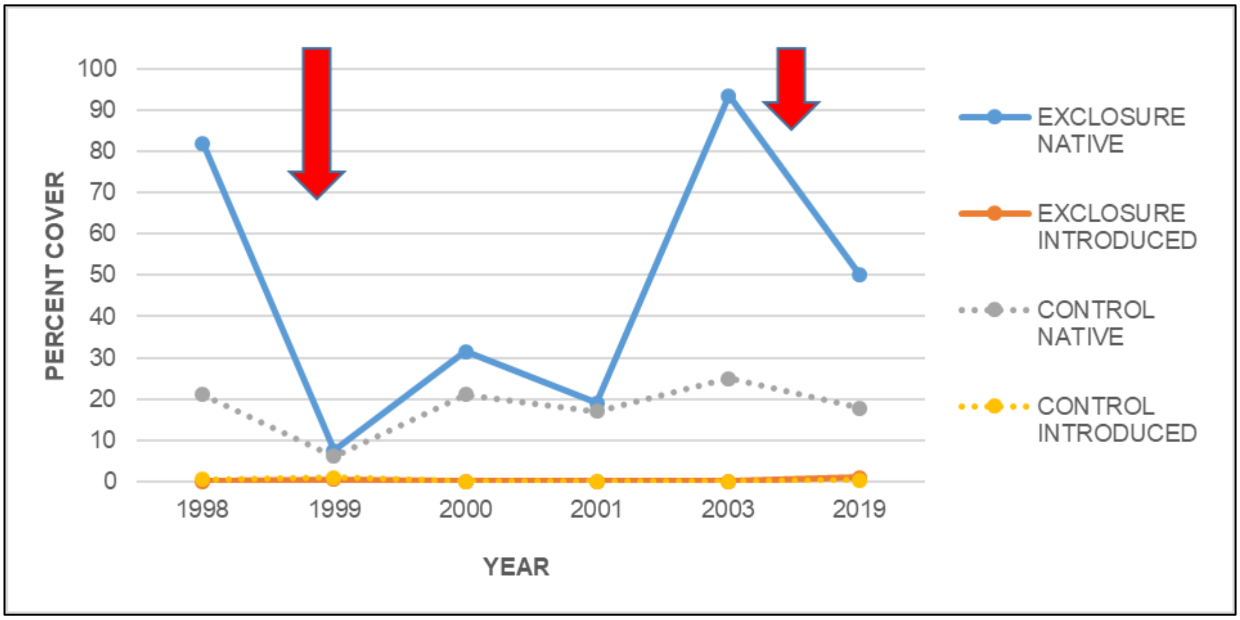

Figure 2.4. Percent cover census of native and introduced species over time in the entire 10 x 10 m Biotic Exclosure #7 and adjacent control. The red arrows denote when the exclosure fence was opened to deer, which was repaired afterwards.

In the 2019 census, the native shrubs, azalea and blueberry, covered 2.5% of the exclosure. In the control only blueberry was found at 2% cover with evidence of deer browse. Herbaceous plants in the exclosure together totaled 40% cover. The most abundant species were: white wood aster (*Eurybia divaricata*) (5%); Allegheny hawkweed (*Hieracium paniculatum*) (10%); Canada mayflower (10%); partridgeberry (*Mitchella repens*) (12%). The remaining species were present each with marginal cover Pennsylvania sedge (*Carex pennsylvanica*), Jack-in-the-pulpit (*Arisaema triphyllum*), striped wintergreen, whorled loosestrife, Indian cucumber-root, Indian pipe, and Round-leaf Pyrola (*Pyrola americana*). The control had 7% native herbaceous cover with American hogpeanut (*Amphicarpaea bracteata*), white wood aster, Canada mayflower, partridgeberry, Round-leaf Pyrola, and New York fern (*Thelypteris palustris*).

Conclusions & Recommendations

The difference in native cover in the intact exclosure (#7) in comparison to the control, showed that the exclosure successfully protects native species, allowing them to regenerate and grow. Exposed woody natives suffered heavy deer browse; seedlings remained stunted and saplings that were tall enough to escape browse, persisted. This is grim fate for exposed seedlings and there were many. In the exclosures, there is still potential to regenerate them if maintained frequently over time.

In general, over the past two decades, many native species in these exclosures have been allowed to persist, even though the fence was compromised a few times. After each fence repair, native cover increased (Figure 2.4). Meanwhile, since the 1990s, much of the Jockey Hollow understory has been taken over by invasive plants that are extirpating many species along with the heavy browse of over-abundant deer. As the severity of invasive plant cover and deer herbivory grow in the Park, the few protected areas of high biodiversity will become ever more valuable.

The protection of the biotic exclosures over time is imperative for natural heritage conservation at Morristown National Historical Park. A few species in these two exclosures are becoming very rare in the park, including: native azalea, Indian cucumber-root, whorled loosestrife, and Allegheny hawkweed. These species and others found in these two exclosures provide special value to native pollinators and wildlife. For example, whorled loosestrife is the host plant to the loosestrife borer moth (*Papaipema lysimachiae*) (Bird 1914) and provides specific floral oil and pollen resources for oligolectic melittid bees (*Macropis* spp.) (Simpson and Neff, 1983). Patridgeberry (*Mitchella repens*) and striped wintergreen provide resources for native bumble bees (Hicks et al., 1985, Standley et al., 1988). Many *Bombus* species occur in New Jersey and are vulnerable to extinction (IUCN Bumblebee Specialist Group, 2019).

Exclosures have been found to be the better method to stop deer from inhibiting native plant regeneration when compared to hunting in New Jersey (Kelly, 2018). We recommend that these two exclosures remain and are regularly maintained. Optimal visitation frequency to ensure fence integrity and protection of native plant populations should occur every 2 months in the winter and at least once a month in the growing season. This will help to increase the growth and abundance of all native species in each exclosure area. The current status of woody vegetation is shaped by deer browse; in deer exposed areas, the saplings taller than two meters escape browse, but the new seedlings never get the chance to grow past 30 cm. When the fence is damaged, the woody vegetation is set back many years in growth.

Scouting for new invasive plants (early detection – rapid response) in and near the exclosures will be essential in coming years. One individual plant of Japanese stiltgrass (*Microstegium vimineum*) was just found for the first time in 2019. But with just one individual, the invasion can quickly spread (Ehrenfeld, 1999a, b) and native seedlings will be outcompeted. Further monitoring every few years, as a census in the controls and exclosures, will be valuable into the future.

Chapter 3. Exotics Exclosures

Introduction

In the 1990s, exotic invasive plants were spreading very quickly through Morristown National Historical Park (Ehrenfeld, 1997; Ehrenfeld, 1999a, b). Of the several exotic plants found in this park, the most dominant and widespread invasives species were and still are Japanese Barberry (*Berberis thunbergii*) and Japanese stiltgrass (*Microstegium vimineum*) (Ehrenfeld, 1999a, Brittingham et al., 2014). When invasive species invade, they depress native plant populations (Aronson and Handel 2011). In areas of Japanese stiltgrass invasions, survival and growth of native tree seedlings are suppressed. When Japanese barberry invades and dominates, the species not only crowd native plants, but it changes soil characteristics such as raising pH over time (Kourtev et al., 1998), which make it even more difficult for native plants to acquire nutrients they need to thrive.

The dispersal methods of these species allow for them infiltrate quickly and flourish. Seeds of Japanese stiltgrass easily attach on animals and get transported through forests (Baiser et al., 2008). White-tailed deer can be a major disperser of seeds. Furthermore, as deer deposit seeds of invasive plants, they heavily browse on native vegetation. This reduces native plant integrity allowing both Japanese stiltgrass and barberry to dominate with ease.

Under the council of Dr. Joan Ehrenfeld, four exclosures were erected near to invasions of Japanese barberry and Japanese stiltgrass. The purposes of this study were to:

1. Test if areas dominated by Japanese barberry and Japanese stiltgrass could be reestablished by native understory plants if protected from deer browse.

2. Observe whether reestablishment of a native understory would effectively reduce populations of Japanese barberry and Japanese stiltgrass without need of active management.

3. Observe whether Japanese barberry and Japanese stiltgrass would continue to dominate the forest understory even in the absence of deer browse.

After 21 years many unexpected vegetation and landscape changes occurred at these four sites.

Methods

1998–2008 Establishment and Data Collection

Four 10 x 10 m deer exclosures were erected in 1995; one on the Soldier Hut Trail (SHT), the second on Cemetery Road (CR), the third on the Grand Loop Trail (GLT), and the fourth in the New Jersey Brigade Area (NJB) (see Figure 1). No control areas were originally established for this study.

Starting in 1998, vegetation data were collected through 2008. Three 1m^2 subplots were randomly selected for sampling per site each sampling year (Epiphan and Handel, 2020). Percent cover of vascular plants below three meters tall was recorded by percent cover category.

2019 Data Collection

The GPS location of each exclosure was recorded. Condition of each exclosure fence and site were recorded. Openings in the fences and deer browse intensity were surveyed in each exclosure. The

Cemetery Road Exclosure was severely damaged after 2003 and dismantled. In the three remaining exclosures both a census of each entire 10 x 10 m exclosure and random sampling of three 1 m^2 subplots was performed using the same methods as prior years, but exact percentages were used to record species percent cover rather than percent cover categories. A new 10 x 10 m control was randomly selected adjacent to each existing exclosure. In each control area, a census was performed. Some species identification could not be verified due to lack specific characteristics needed for differentiation. Therefore, the genus was recorded for serviceberry (*Amelanchier* sp.) and ash (*Fraxinus* sp.).

2019 Data Synthesis

Vegetation data in the exclosures were compiled with past years' data. Percent cover categories used in previous years were translated to the median of the percent cover category (Table 3.1). For the sampling data, the average per species was calculated per year in each the exclosure. Species cover averages were totaled into to two groups, native and introduced. Nativity was verified by the USDA plants database (USDA NRCS, 2006). The few unknown species data were dropped from the synthesis.

Table 3.1. Translation used to determine percent cover values from percent cover categories.

Median of % cover category	NPS code for % cover category	Description of NPS % cover category
0.5	r	solitary with small number.
1	t	few with small cover or solitary with < 5% cover
3	1	numerous with < 5% cover
15	2	5 to 25% cover
38	3	26 to 50% cover
63	4	51 to 75% cover
85.5	5	76 to 95% cover
98	6	96 to 100% cover

The census data from 2019 in the exclosure and controls were compiled and totaled into two groups, native and introduced. Species richness data were compiled for each year and separated into native and introduced categories.

2019 Data Analysis

The native and introduced sampled cover totals per site per year were then averaged across all four sites and standard error was used to show the standard deviation of the sampling distribution of the mean.

A floristic quality assessment was performed for the 2019 data to determine the current vegetative condition. We used the New Jersey 2019 coefficient values (Freyman et al., 2016). We utilized the adjusted floristic quality index because it was adapted to consider the contributions of introduced species as well as native species and it eliminates the sensitivity to species richness that helps to more accurately express condition for low richness high quality sites. (Miller and Wardrop, 2006).

Adjusted Floristic Quality Index Formula:

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

I' = Adjusted floristic quality index C = Coefficient value
N = Native species A = Introduced species

Results

Soldier Hut Trail Exclosure (SHT) Assessment of Sampled Data

Since 1998, three subplots were sampled for several years. The introduced species cover dropped in 2000 and 2001 and gradually increased past 50% in 2019 (Figure 3.1). This increase was found primarily due to the Asiatic bittersweet vine and a new invader, an exotic chokeberry (*Photinia* sp.), which has yet to be accurately identified to species (not Oriental Photinia, *Photinia villosa,* that is also found in Jockey Hollow). The sampled native percent cover has remained low, but native species richness increased during the years when introduced species cover was lower (Table 3.2). Recorded notes in 2003 revealed the deer fence had a new hole and deer may have entered. In 2019, part of the fence was down, and deer were able to enter easily.

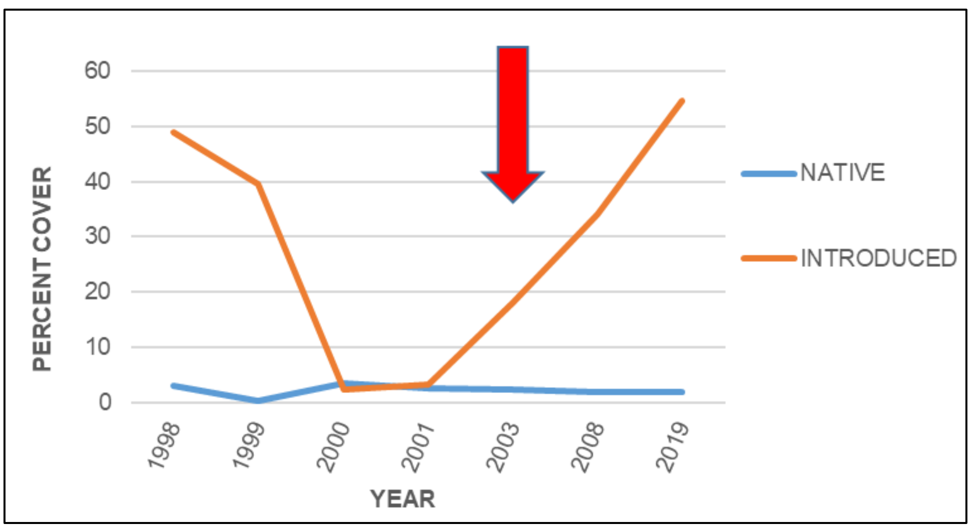

Figure 3.1. Sampled percent cover of native and introduced species in 1 m^2 subplots over time in the 10x10m Soldier Hut Trail Exclosure. Sample size was three for each year. The red arrow denotes when the exclosure fence was found open.

Table 3.2. Native and introduced species richness over time in the sampled subplots of the Soldier Hut Trail Exclosure.

Year	Exclosure native	Exclosure introduced
1998	4	2
1999	1	4
2000	9	2
2001	6	4
2003	5	2
2008	5	4
2019	3	4

Cemetery Road Exclosure (CR) Assessment of Sampled Data

The Cemetery Road Exclosure no longer exists. Data were collected in only three years (Figure 3.2). After 1999, the percent cover of introduced species increased while the native cover remained low. Native richness remained low, between two and three species, and introduced species richness remained between five and seven species. This exclosure was removed sometime after 2003 because the amount of Japanese barberry inside and outside the exclosure grew to the point where it became too difficult to maintain or collect data (R. Masson, personal communication, January 13, 2020).

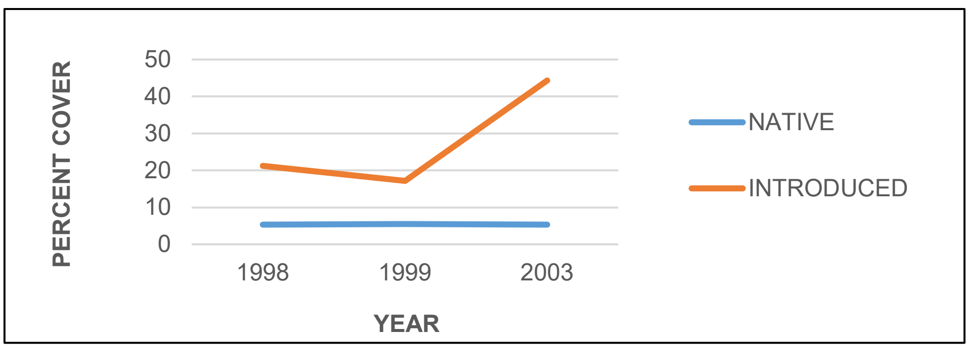

Figure 3.2. Sampled percent cover of native and introduced species in 1m^2 subplots over time in the 10x10m Cemetery Road Exclosure. Sample size was three for each year.

Grand Loop Trail Exclosure (GLT) Assessment of Sampled Data

In 1999, all sampled species percent cover decreased (Figure 3.3); native percent cover remained low thereafter. Introduced cover fluctuated but increased especially after 2003 when a tree fell on the fence and deer were able to enter. In 2019, the introduced cover surpassed 100% and the fence was completely down and the exclosure area was exposed to deer herbivory. The sampled native species richness decreased over time and introduced cover increased (Table 3.3).

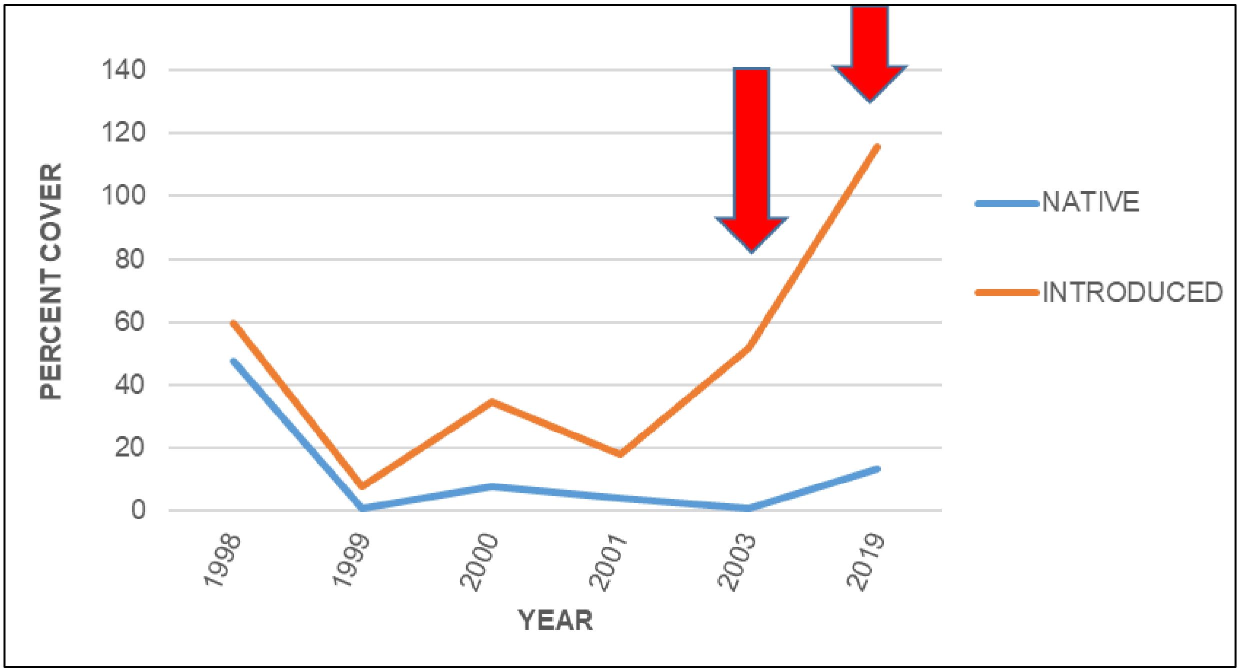

Figure 3.3. Sampled percent cover of native and introduced species in 1 m^2 subplots over time in the 10x10 m Grand Loop Trail Exclosure. Sample size was three for each year. The red arrows denote when the exclosure fence was found open.

Table 3.3. Native and introduced species richness over time in the sampled subplots of the Grand Loop Trail Exclosure.

Year	Exclosure native	Exclosure introduced
1998	7	4
1999	3	4
2000	6	5
2001	6	4
2003	3	3
2019	3	5

New Jersey Brigade Exclosure (NJB) Assessment of Sampled Data

Both native and introduced species cover has been very low (below 8%) in all averaged samples throughout the years (Figure 3.4). In previous years, there was no indication that deer entered the exclosure, but in 2019 the fence was found slightly opened and herbivory was evident on American beech (*Fagus grandifolia*) branches. Even so, highest species richness of both native and introduced species was found in 2019 (Table 3.4).

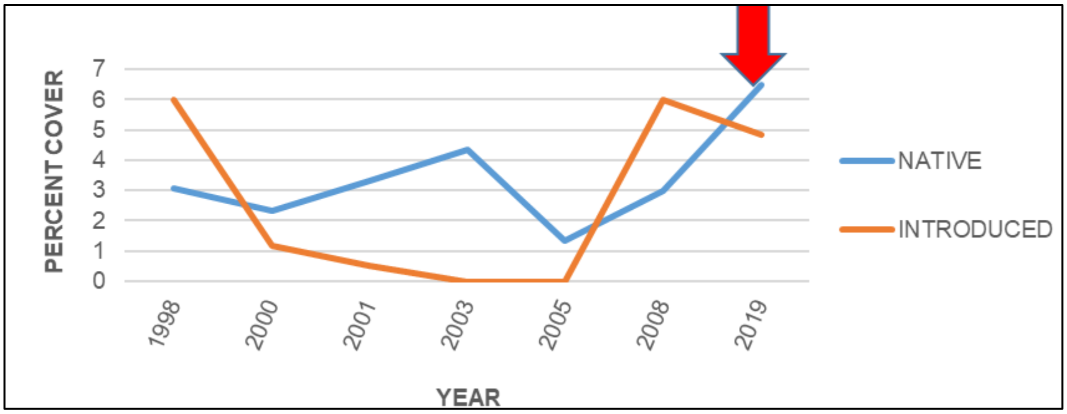

Figure 3.4. Sampled percent cover of native and introduced species in 1 m^2 subplots over time in the 10x10 m New Jersey Brigade Exclosure. Sample size was three for each year. The red arrow denotes when the exclosure fence was found open.

Table 3.4. Native and introduced species richness over time in the sampled subplots of the New Jersey Brigade Exclosure.

Year	Exclosure native	Exclosure introduced
1998	6	1
2000	7	2
2001	5	2
2003	7	0
2005	4	0
2008	5	1
2019	9	5

Sampled Data Analysis Across the Four Exotic Exclosures

The native and introduced species per year were then averaged across the sites (Figure 3.5 & Figure 3.6). Native species across all sites had lower percent cover in the samples than introduced species every year except in 2005 where the only sampled site was NJB. NJB had much fewer introduced species in the samples throughout the years than the other sites which is expressed in the standard error.

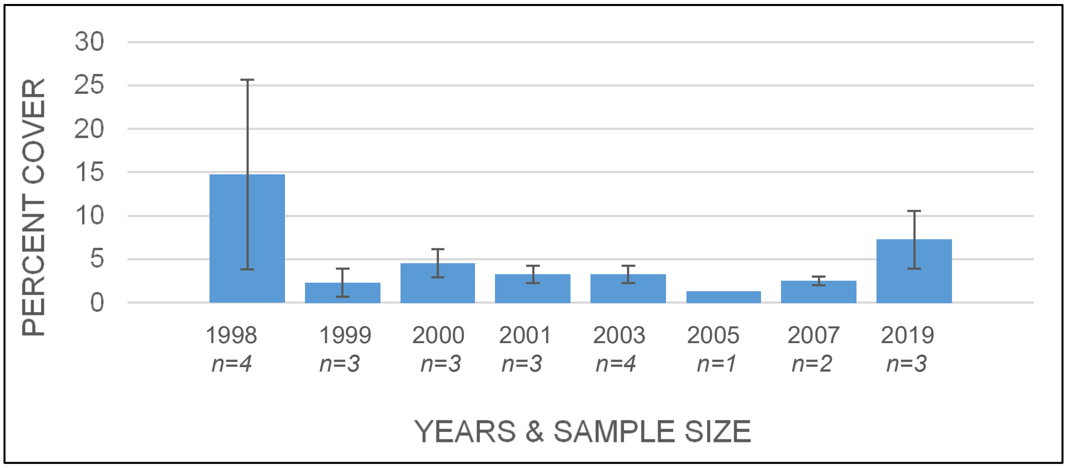

Figure 3.5. Native species sampled percent cover averaged across all sites for each year sampled. Sample size (*n*) changed each year. The error bars represent standard error of the mean.

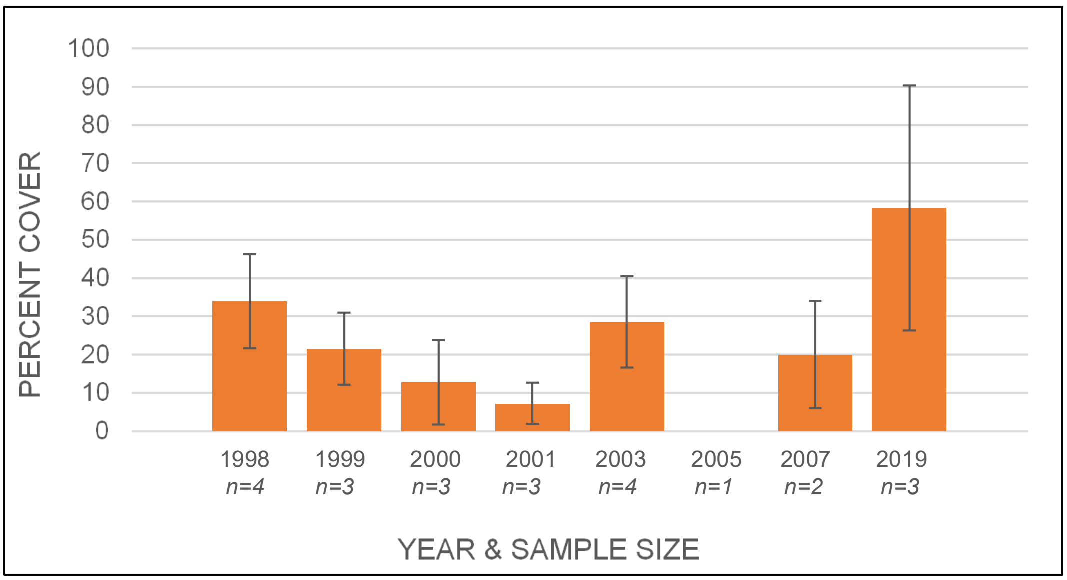

Figure 3.6. Introduced species sampled percent cover averaged across all sites for each year sampled. Sample size (*n*) changed each year. The error bars represent standard error of the mean.

Exotic Exclosures 2019 Census

A census of each entire 10 x10 m exclosure was performed in 2019 along with a new adjacent control. Native percent cover in the exclosures were higher than the paired controls (Figure 3.7). The New Jersey Brigade (NJB) site was the only site to have higher native cover in the exclosure than introduced cover. The dominant species in the exclosure at NJB were the native American beech and introduced exotic chokeberry (Table 3.5 & Table 3.6). The dominant species in the control were Japanese barberry and Japanese stiltgrass.

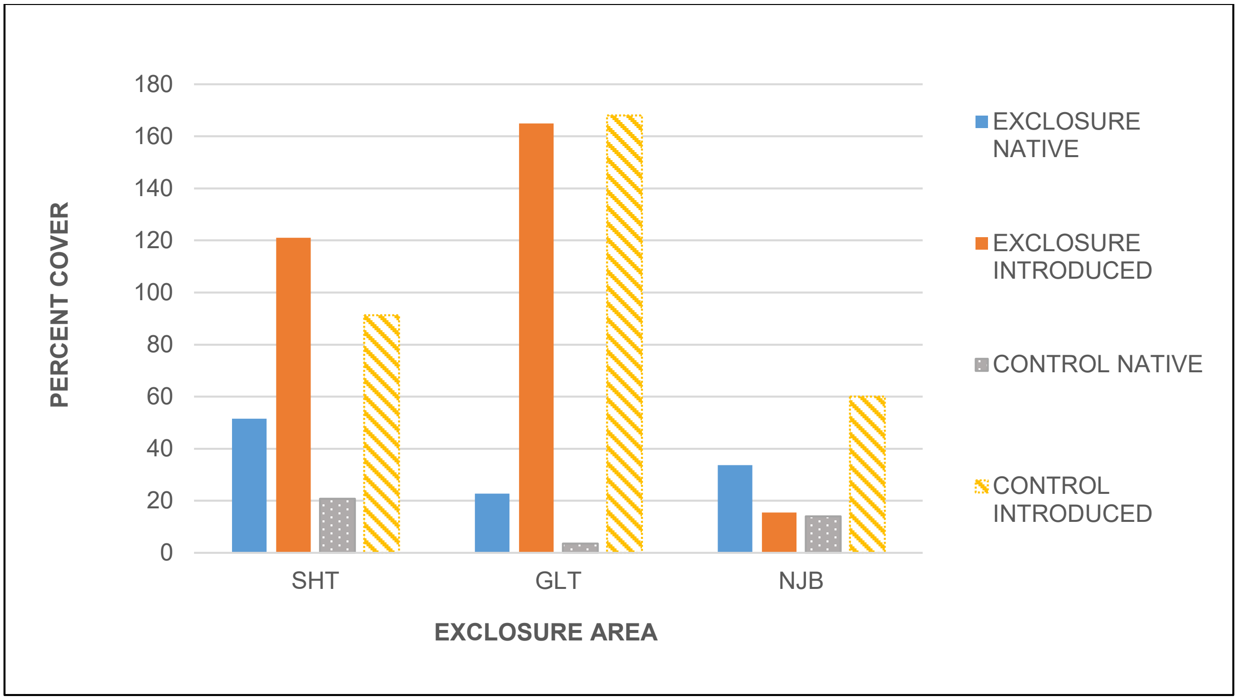

Figure 3.7. Percent cover census of native and introduced species in 2019, in each entire 10 x 10 m Exotic Exclosure and a new adjacent control. The Cemetery Road (CR) Exotic Exclosure was destroyed and dismantled prior to 2019.

Table 3.5. Percent cover census of key native species in the 2019 exotics exclosures and the new controls.

Common name	Species name	Exclosure SHT	Control SHT	Exclosure GLT	Control GLT	Exclosure NJB	Control NJB
American beech	*Fagus grandifolia*	2	0	0	0	28	0
Ash (seedlings)	*Fraxinus* sp.	12	8	0	0	0.25	1
Spicebush (>2m in height)	*Lindera benzoin*	0	0	4	0	0	0
Virginia creeper	*Parthenocissus quinquefolia*	13	5	5	0	1	2
Allegheny blackberry	*Rubus allegheniensis*	18	0	0	0	0	0
Poison ivy	*Toxicodendron radicans*	5	4	1	0	0.25	1
Blackhaw viburnum (>2m in height)	*Viburnum prunifolium*	0	1	12	0	0.25	1

Table 3.6. Percent cover census of dominant introduced species in the 2019 exotics exclosures and the new controls.

Common name	Species name	Exclosure SHT	Control SHT	Exclosure GLT	Control GLT	Exclosure NJB	Control NJB
Japanese barberry	*Berberis thunbergii*	30	40	5	10	1	20
Asiatic bittersweet	*Celastrus orbiculatus*	55	5	15	5	0.25	0.5
Common privet	*Ligustrum vulgare*	0	0	60	30	0	0
Japanese honeysuckle	*Lonicera japonica*	0	1	15	5	0	0
Japanese stiltgrass	*Microstegium vimineum*	0.25	1	0	78	1	24
Exotic chokeberry	*Photinia* sp.	35	35	0	0	12	0
Multiflora rose	*Rosa multiflora*	0	6	30	30	1	0.25
Wineberry	*Rubus phoenicolasius*	0	3	40	10	0	6

In both the Grand Loop Trail (GLT) and Soldier Hut Trail (SHT), the incidence of introduced species was much higher in general (Figure 3.7 & Table 3.8). At SHT exclosure, the introduced species cover was over 120% and comprised mostly of Asiatic bittersweet, exotic chokeberry, and barberry. The native cover was just over 50% and mostly comprised of Allegheny blackberry (*Rubus allegheniensis*) (Table 3.5). There were less natives in the control, but much introduced cover dominated by Japanese barberry and exotic chokeberry. At the GLT exclosure, native cover was 22.75% inside and 3.5% in the control. The introduced cover in the exclosure was 165% and 168% in the control. In the exclosure the dominant species were common privet (*Ligustrum vulgare*), wineberry (*Rubus phoenicolasius*), and multiflora rose (Table 3.6). Japanese stiltgrass was absent in the exclosure, but dominant in the control at 78%.

Both GLT and SHT were wide open to deer herbivory for several years and introduced species dominated the exclosure areas and controls. Even though the NJB site had a small hole in the fence in 2019, and deer entered, it was more protected over the years from deer than the other sites. It had much lower introduced species cover inside the exclosure, than the other sites. Even though the control introduced cover at NJB was much higher than the exclosure introduced cover, it was still much lower than the other sites.

Overall, the GLT exclosure and control areas had the lowest richness and the lowest adjusted FQI (Table 3.7 & Table 3.8). Native species richness was highest in the SHT exclosure where the adjusted FQI was highest at 41.6. The SHT exclosure and control and the NJB exclosure and control each had a few high coefficient value species such as a sapling of serviceberry (*Amelanchier* sp.) (SHT) and round-leaf Pyrola (*Pyrola americana*) (NJB).

Table 3.7. Native and introduced species richness census in 2019 in the three remaining exotic exclosures.

Site	Exclosure native	Exclosure introduced	Control native	Control introduced
SHT	18	6	10	8
GLT	7	6	4	7
NJB	15	6	13	8

Table 3.8. Floristic quality assessment of the three remaining exotic exclosures and controls in 2019.

Conservatism-based metrics:	Exclosure SHT	Control SHT	Exclosure GLT	Control GLT	Exclosure NJB	Control NJB
Total Mean C:	3.6	2.6	1.6	1.7	2.9	2.5
Native Mean C:	4.8	4.3	3.3	4.8	4.1	4
Total FQI:	17.6	11.6	6	5.6	13.3	11.5
Native FQI:	20.4	14.9	8.7	9.6	15.9	14.4
Adjusted FQI:	**41.6**	**33.3**	**23.3**	**28.9**	**34.7**	**31.5**
% C value 0:	25	40	50	63.6	28.6	38.1
% C value 1–3:	20.8	25	28.6	9.1	28.6	33.3
% C value 4–6:	41.7	20	21.4	27.3	38.1	19
% C value 7–10:	12.5	15	0	0	4.8	9.5

Sampled Japanese Barberry and Japanese Stiltgrass Evaluation

Across all the sites the averaged sampled cover of Japanese stiltgrass decreased over time (Table 3.9). However, for Japanese barberry the results were variable (Table 3.10). This seems due to the small samples size of three 1m^2 plots which is only 3% of the 10 x10 m exclosures and the patchy coverage of these two species. Some years the cover was captured, whereas other years it may not have been. In comparing the sampled and census data from 2019, the Japanese barberry cover was not accurately represented in only three samples (Table 3.6 & Table 3.10). At SHT, the census cover was 30%, whereas the sampled cover was 5.3%. For GLT the census cover was 5%, whereas the sampled cover was 49.333%.

Table 3.9. Sampled percent cover averages of Japanese stiltgrass (*Microstegium vimineum*) across all exotic exclosures over time. Standard error (SE) of each average percent cover value are in the gray columns. A dash (-) represents no sample data.

Year	SHT Ave.%	SHT SE	CR Ave.%	CR SE	GLT Ave.%	GLT SE	NJB Ave.%	NJB SE
1998	30.3	7.7	17.6	11.1	34. 7	17.4	6	4.6
1999	0.3	0.3	12. 7	12.7	1.5	0.8	–	–
2000	2	1	–	–	0	0	0.2	0.2
2001	0.3	0.3	–	–	1	0	0.3	1
2003	0	0	5	5	0	0	0	0
2005	–	–	–	–	–	–	0	0
2008	0	0	–	–	–	–	6	4.6
2019	0	0	–	–	0	0	0.2	0.2

Table 3.10. Sampled percent cover averages of Japanese barberry (*Berberis thunbergii*) across all exotic exclosures over time. Standard error (SE) of each average percent cover value are in the gray columns. A dash (-) represents no sample data.

Year	SHT Ave. %	SHT SE	CR Ave. %	CR SE	GLT Ave. %	GLT SE	NJB Ave. %	NJB SE
1998	0	0	0.2	0.2	0	0	0	0
1999	12.6	12.7	0.2	0.2	0.3	0.3	–	–
2000	0	0	–	–	0	0	1	1
2001	0.3	0.3	–	–	0	0	0	0
2003	0.2	0.2	33	32.5	0	0	0	0
2005	–	–	–	–	–	–	0	0
2008	33	32.5	–	–	–	–	0	0
2019	5.3	4.8	–	–	49.3	25.5	0	0

Conclusions

In the 2019 census, the NJB stood apart from the rest. In this exclosure all percent cover was lower than the other sites, but native cover was double the introduced cover. This exclosure contains mature American beech (Photo in Appendix A), which could be why the invasive species cover and even the cover of all species is lower than the other site. American beech leaves have been found to be phytotoxic and suppress growth of certain species (Hane et al., 2003). Also, researchers suggest that the slow decomposition of beech leaf litter and deep shade of beech canopies can also suppress germination and growth of understory species (Cale et al., 2003). Therefore, one can theorize that existing native species, and American beech in particular, did prevent infiltration of Japanese barberry and Japanese stiltgrass. More research is needed to understand if American beech leaf leachate actually effects the germination or growth of Japanese barberry and Japanese stiltgrass.

At the other three sites, SHT, GLT, and CR, the native species cover remained lower than the introduced cover. Native plants did not succeed to reduce populations of Japanese barberry, Japanese stiltgrass, or other introduced species. Japanese barberry did continue to invade these three exclosures, but they did not dominate. In 2019, other introduced species including Asiatic bittersweet, common privet, and exotic chokeberry dominated the exclosures.

The sample size of three subplots for each site was only 3% of each exclosure. There was not enough replication to understand specific species dynamics over time. However, it was enough to understand grouped native versus introduced species metrics across the sites. With NJB included in the analysis, the averaged sampled cover overtime demonstrates that native plant species could not reestablish when protected from deer browse (Figure 3.5 & Figure 3.6). Nor did the native plants overall reduce population of Japanese barberry or Japanese stiltgrass. Barberry continued to invade but not dominate. Other introduced shrubs and vines dominated the sites.

Japanese stiltgrass across all the sites did decrease over time, but it was not due to reestablishment of native plants. In the exclosures, the stiltgrass cover from 1998 was outcompeted by introduced shrubs and vines. Although, in 2019, the census in the new control areas at GLT and NJB revealed high percentages of stiltgrass. The deer exclosure could have prevented new invasions of stiltgrass inside the exclosures. More research and higher replication is needed to fully understand this dynamic over time.

Recommendations

The CR site has already been lost. The SHT and GLT sites are heavily invaded and the exclosures are open. These exclosures should be removed and sites abandoned. The NJB site provides opportunities for the investigation of intriguing theories about beech litter and prevention of invasion. If the NJB exclosure will remain, it needs to be visited regularly to maintain the fence integrity.

Chapter 4. Jack-in-the-Pulpit Exclosures

Introduction

The original Jack-in-the-pulpit (*Arisaema triphyllum*) study monitored specific plant populations of this common woodland species that could switch between male and female expression over time (Ruhren and Handel 2000). Jack-in-the-pulpit was found to be an abundant understory herb in the Jockey Hollow section of Morristown National Historical Park. In the New York Brigade area and along Primrose Brook, 28 populations were delineated and monitored for stem count, amount of males and females, percentage that was browsed by deer in 1995. Then, four 3.7 x 3.7 m deer exclosures were placed over a subset of the population in the New York Brigade area to prevent deer browse and other specific populations outside were used as the control. In 1996 through 1998, monitoring continued. Results showed that over four years the majority of Jack-in-the-pulpits did not flower, there were no new seedlings, and the relative sexual expression did not change inside the deer exclosure.

Since then, the four exclosures were left intact for further different studies. Over time, two exclosures were destroyed by tree or limb failure during storms. None of the original raw data from 25 years ago could be found. The recorded locations of the control populations were no longer available. However, in the following new study, we were able to observe the remaining exclosures managed to protect native species, including Jack-in-the-pulpit, and prevent introduced species invasion after 24 years.

Methods

2019 Data Collection

The GPS location of the two exclosures were recorded. Condition of each exclosure fence and site were recorded. Openings in the fences and deer browse intensity were surveyed in each exclosure. Two new adjacent control sites of the same size as the exclosure (3.7 x 3.7 m) were randomly assigned to each exclosure. In the two exclosures and adjacent control plots, a census was performed to determine percent cover of each vascular plant species. Jack-in-the-pulpit stems were counted, and sexual status was noted.

2019 Data Synthesis

No data prior to 2019 were available to evaluate trends over time. 2019 vegetation data in the exclosures and control were compiled and separated into native and introduced species cover. Nativity was verified by the USDA plants database (USDA NRCS, 2006). Species richness was compiled. A floristic quality assessment was performed for the 2019 data to determine the current vegetative condition. We used the New Jersey 2019 coefficient values (Freyman et al., 2016). We utilized the adjusted floristic quality index because it was adapted to consider the contributions of introduced species as well as native species and it eliminates the sensitivity to species richness that helps to more accurately express condition for low richness high quality sites. (Miller and Wardrop, 2006).

Adjusted Floristic Quality Index Formula:

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

I' = Adjusted floristic quality index C = Coefficient value
N = Native species A = Introduced species

Results

The two remaining exclosures were labelled j1 and j2. Exclosure j1, which was found partially collapsed, still was able to prevent deer access. It had a native species cover over 120%, which was far greater than natives in the control area (Figure 4.1). The dominant native species found were spicebush (*Lindera benzoin*), black gum (*Nyssa sylvatica*) saplings, and American elm (*Ulmus americana*) saplings. Jack-in-the-pulpit had a coverage of 7% in the exclosure; there were seven stems, all were vegetative. The total native species richness was eight in the exclosure and eight in the control. The introduced species cover was low both inside and outside of the exclosure. The introduced species richness was three in each the exclosure and control. There was no Jack-in-the-pulpit found in the j1 control area. The adjusted floristic quality index in the j1 exclosure was 36.7 and 31.9 in the j1 control.

In exclosure j2, the native species cover was higher than natives in the control (Figure 4.1). The native cover in the exclosure was dominated by black gum at 45%; in total, eight native species were found in the exclosure and eight in the control. Jack-in-the-pulpit was found in the exclosure at 2% cover with three vegetative stems. None were found in the control. The introduced cover was higher in the control than in the exclosure where Japanese stiltgrass (*Microstegium vimineum*) dominated. Six introduced species were found in the control and four in the exclosure. The adjusted floristic quality index for the j2 exclosure was 33.6 and 29.9 in the control.

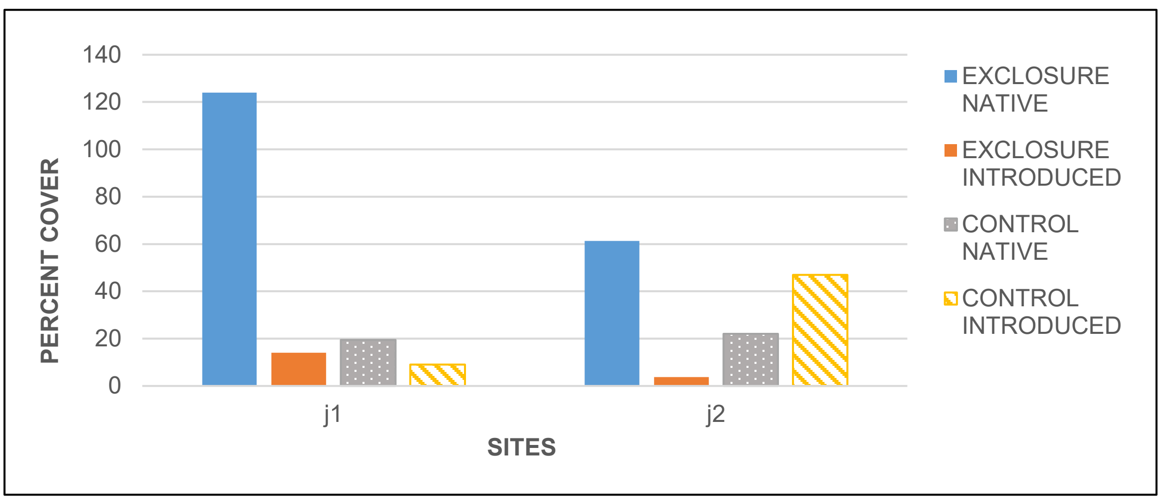

Figure 4.1. Percent cover census of native and introduced species in 2019, in each 3.7 x 3.7 m Jack-in-the-Pulpit Exclosure and a new adjacent control.

Conclusion & Recommendations

In these two 24-year-old exclosures, native species percent was much higher than in the exposed control areas. The natives were able to flourish over the years in the absence of deer browse. The floristic quality of the exclosures were only slightly higher than the controls because native species richness was equal but less introduced species were in the exclosures. Finally, few Jack-in-the-pulpits remain inside the exclosures, whereas none were found in the exposed control areas.

Exclosures in New Jersey have been found to be the most successful protection for native plant species (Kelly, 2018). These two exclosures serve as small refuges where natives can be preserved in to the future. The j1 exclosure can be repaired and both can be visited regularly to maintain their integrity overtime. These two exclosures are relatively near to the two Biotic Exclosures and the ten Herbaceous Exclosures. In the future, these two can be part of a long-term study across these three sites that are less invaded than other areas of the park.

Chapter 5. Herbaceous Exclosures

Introduction

The Primrose Brook trail (formerly named the wildflower trail) was well known for its abundance of many of native herbaceous plants (The Jockey Hollow Wildflower Trail, 1935). Over time many historic wildflowers disappeared from the landscape (R. Masson, personal communication, 15 August 2019). White-tailed deer (*Odocoileus virginianus*) populations surged (Kelly, 2018) and the understory of Morristown National Historical Park was drastically changing (Russell, 2002). Restoration potential of the wildflower trail was dwindling.

In the 1990s, the National Park Service was interested in restoring native forest herbs (Ruhren and Handel, 2003). Nine species of wildflowers were selected to test their restoration potential inside and outside of deer exclosures along Primrose Brook. These species were chosen as a variety of plants from different families and varying presence in the landscape (common, or previously abundant but rare or extirpated). In 1997, ten 3.7 x 3.7 m exclosures and six nearby control plots were established, and these native forest herbs were planted.

The objectives of this project were to:

1. evaluate the feasibility of restoring native forest herbs by testing if restoration would be influenced by white-tailed deer.

2. compare plant reproduction with and without white-tailed deer herbivory by evaluating if plant fitness would be correlated with white-tailed deer herbivory.

3. test if pollinators and seed dispersers visit the restored species in the exclosures.

This study demonstrated that deer herbivory did limit survival, reproduction, and restoration success (Ruhren and Handel, 2003). After one year, about half the individual plants survived in the exclosures, but frequency of inflorescence significantly dropped. Activity of pollinators and seed dispersers were present, which affected overall plant fitness and reproductive success.

In 2007, a second round of investigation took place in the same exclosures (Tartaglia and Handel, 2007). Ten years after the original plantings, survival was measured once again on the remnant fraction that had persisted. More native herbs were planted and measured in 2008.

Since then, more studies in the region found that exclosures provide the best chances for native plant survival under high deer browse pressure (Russell, 2002, Abrams and Johnson, 2012, Kelly, 2018). In 2019, the Primrose Brook area still maintained areas of lush native herbs in comparison to other areas of Jockey Hollow (Epiphan, Photo documentation, Appendix A). Therefore, we decided to test the long-term success of the ten Herbaceous Exclosures after 22 years by:

1. surveying the survival of plant forest herbs.

2. measuring all the vegetation inside the exclosures and in new control areas.

Methods

1997–2008 Establishment and Data Collection

In 1997, ten 3.7 x 3.7m exclosures were constructed along the Primrose Brook Trail (Ruhren and Handel, 2003) (Figure 5.1). A total of 399 individual plants of nine species were planted: 277 in the ten exclosures and 122 in the six nearby control sites. The nine species were: wild ginger (*Asarum canadense*), wild geranium (G*eranium maculatum*), false Solomon's seal (*Maianthemum racemosum*), miterwort (*Mitella diphylla*), Jacob's ladder (*Polemonium reptens*), bloodroot (*Sanguinaria canadensis*), foamflower (*Tiarella cordifolia*), large-flower bellwort (*Uvularia grandiflora*), and a mix of violet species (*Viola* spp.). In 1998, survivorship was monitored along with reproductive status. The control areas were not permanently marked.

In 2007, the control areas were not monitored. In the ten exclosures, the surviving planted species were tallied (Tartaglia and Handel, 2007). In the same year, three new species were planted in nine of the ten exclosures, omitting the h5 exclosure. The species were: red columbine (*Aquilegia canadensis*), swan's sedge (*Carex swanii*), and bluestem goldenrod (*Solidago caesia*). In 2008, the survivorship was tallied.

2019 Data Collection

The GPS location of each exclosure was recorded. Condition of each exclosure fence and site were recorded. Openings in the fences and deer browse intensity were surveyed in each exclosure. Tallies of all the planted species were performed in each exclosure. Swan's sedge was tallied with other sedges (*Carex* spp.) as they could not be differentiated in the field without taking several reproductive samples, which would have been detrimental to their survival. A percent cover census of all vegetation in the ten exclosures were performed as well as in ten new randomly chosen adjacent control sites outside of the exclosures. Percent cover of all vascular species below 3 meters in height was recorded. Some species identification could not be verified due to lack specific characteristics needed for differentiation. Therefore, the genus was recorded for serviceberry (*Amelanchier* sp.), ash (*Fraxinus* sp.), azalea (*Rhododendron* sp.), and blueberry (*Vaccinium* sp.). This census was performed in August 2019, and consequently was not able to record data on spring ephemerals.

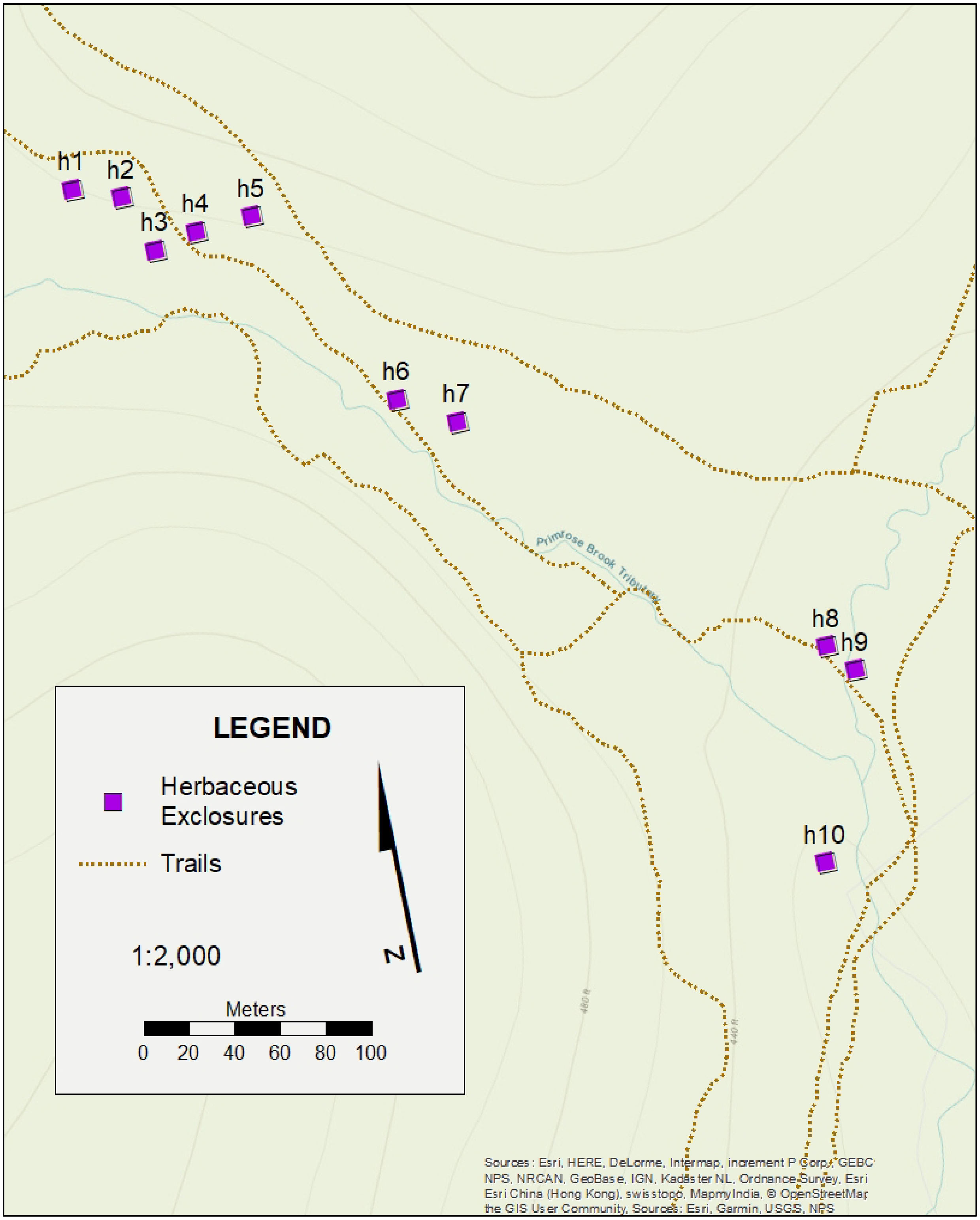

Figure 5.1. Map of the ten Herbaceous Exclosures along the Primrose Brook Trail in Jockey Hollow of Morristown National Historical Park.

2019 Data Synthesis & Analysis

The planted species survival was compiled for 2007 and 2019, survival percentages per species and average survival rates were calculated. Standard error was used to determine the standard deviation of the sampling distribution of the mean.

In the vegetation census, native species and introduced species percent cover and richness was compiled at each exclosure and control. Nativity was verified by the USDA plants database (USDA NRCS, 2006). Average native and introduced cover and standard error was calculated.

A floristic quality assessment was performed using the New Jersey 2019 coefficient values, to determine the vegetative condition. We utilized the adjusted floristic quality index instead of the traditional floristic quality index, because the former was adapted to consider the contributions of introduced species as well as native species and eliminates the sensitivity to species richness that helps to more accurately express condition for low richness high quality sites (Miller and Wardrop, 2006).

Adjusted Floristic Quality Index Formula:

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

I' = Adjusted floristic quality index C = Coefficient value
N = Native species A = Introduced species

Results

Planted Herbs

After the original planting of nine forest herbs in 1997, 48% ± 7.8 (SE) of the plants in the exclosures survived and only 23% ± 5.0 (SE) of the plants outside the exclosures in the control areas survived in 1998 (Ruhren and Handel, 2003). Of the nine species, the worst performers in both the exclosures and control were wild ginger, miterwort, and the violets. In 2007, wild ginger, miterwort, the violets, and jacob's ladder were not found at all in the exclosures (Tartaglia and Handel, 2007). The average percent survival in the exclosures of the nine planted species was 17.14% ± 6.60 (SE). Of the five surviving species, a small fraction remained in 2007 (Table 5.1); the average percent survival of these five remnant species was 30.85% ± 7.14 (SE).

In a few exclosures in 2019, some species counts increased from 2007, whereas in other exclosures losses were observed. There were four more false Solomon's seal found in 2019 than in 2007. However, the other four species experienced overall losses. Of the five remnant species of wild geranium, the long term averaged percent survival in the exclosures from 1997 to 2019 was 27.44% ± 10.62 (SE). Likewise, the average percent survival of the nine planted forest herbs from 1997 to 2019 was 15.24 ± 7.39 (SE).

In 2019, nineteen of the blue-stem goldenrods survived and zero red columbine survived (Table 5.2). The sedge counts may have included other species of sedge that look very similar in August when no reproductive parts were observed to help discern exact species. This count is likely inflated.

Table 5.1. Five planted species counts in 1997 and their surviving counts in 2007 and 2019 in the ten Herbaceous Exclosures along Primrose Brook. Percent survival in 2007 and 2019 is calculated from the original count planted in 1997.

Common name	Species name	1997	2007	% Survival 2007	2019	% Survival 2019
Wild geranium	*Geranium maculatum*	50	17	34%	13	26%
False Solomon's Seal	*Maianthemum racemosum*	20	9	45%	13	65%
Bloodroot	*Sanguinaria canadensis*	50	18	36%	9	18%
Foamflower	*Tiarella cordifolia*	39	14	35.9%	11	28.2%
Large-flower bellwort	*Uvularia grandifolia*	30	1	3.3%	0	0%

Table 5.2. Planted species counts in 2007 and their surviving counts 2008 and 2019 in nine of the ten Herbaceous Exclosures along Primrose Brook.

Common name	Species name	2007	2008	2019
Red columbine	*Aquilegia canadensis*	56	51	0
Swan's sedge	*Carex swanii*	53	52	52[a]
Bluestem goldenrod	*Solidago caesia*	52	52	19

[a] count of all sedge species (Carex spp.); species could not be discerned at the time of sampling.

Exclosures, New Controls, and All Vegetation Types

In 2019, herbivory in the exclosures was not noticed even though small holes where deer could enter were found in exclosures h2, h3, and h5. At exclosure h5, the original fence was replaced with a plastic fence; it was mostly likely damaged and open for an unknown period of time. In 2018, the h8 exclosure was found open and damaged, but was repaired.

Native species percent cover and richness were higher than introduced cover and richness (Figure 5.2, Table 5.3). In seven sites, native percent cover was higher in the exclosures than in the controls and native richness was higher in six exclosures than in the controls. Introduced species were only found in five of the ten sites, h1–h5. The h2 exclosure was near to a new invasion of exotic chokeberry (*Photinia* sp.) and subsequently more cover of this species was found at this site. The lowest native species cover was found in the h5 exclosure which was damaged for an unknown period of time and rebuilt before 2019.

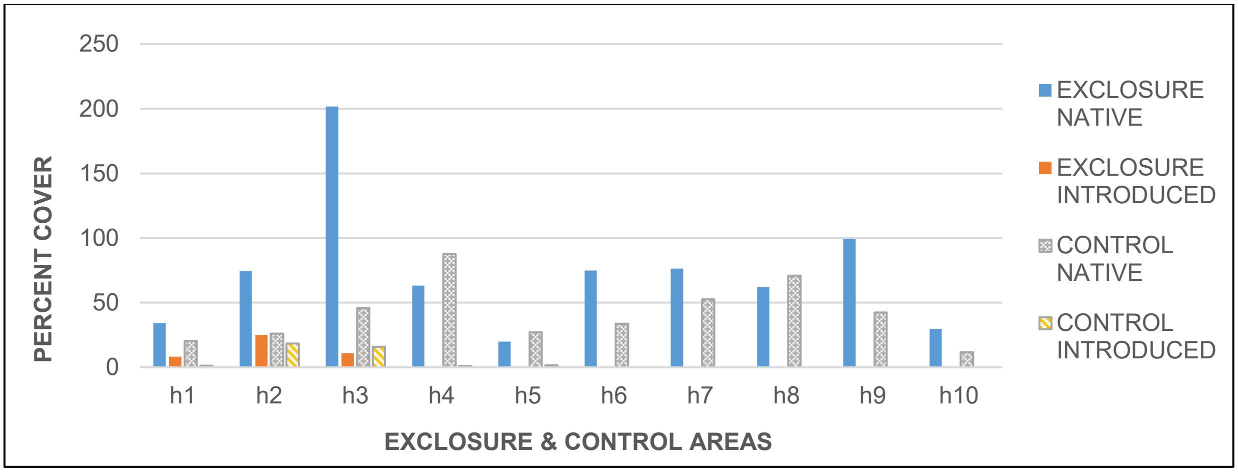

Figure 5.2. Percent cover census of native and introduced species in 2019, in each 3.7 x 3.7 m Primrose Brook Trail Herbaceous Exclosure and a new adjacent control.

Table 5.3. Census of native and introduced species richness in the ten Herbaceous Exclosures and the adjacent controls.

Site	Exclosure native	Exclosure introduced	Control native	Control introduced
h1	14	2	9	2
h2	11	4	7	4
h3	13	2	13	2
h4	12	2	14	2
h5	12	2	10	4
h6	13	0	9	0
h7	10	0	11	0
h8	12	0	13	0
h9	11	0	7	0
h10	16	0	15	0

The vegetation census in 2019 found that the average native percent cover of all ten exclosures was significantly greater than in the controls (Table 5.4). The averaged introduced percent cover in the ten exclosures was low and not statistically different from the control average.

Table 5.4. Averaged percent cover of all vegetation types in the ten herbaceous exclosures and controls areas. Standard error (SE) is displayed in the row immediately below the averaged % cover.

Vegetation type	Exclosure native	Exclosure introduced	Control native	Control introduced
Trees averaged % cover	21.3	0	24.2	0
Trees ± (SE) Shrubs	7.2	0	5.7	0
Shrubs averaged % cover	6.9	2.7	2.4	1.9
Shrubs ± (SE)	3.8	1.7	1.7	1.6
Vines averaged % cover	0.7	1.9	0.2	1.9
Vines ± (SE)	0.6	1.2	0.1	1.7
Flowering herbs averaged % cover	27.2	0	6.0	0
Flowering herbs ± (SE)	9.1	0	1.6	0
Graminoids averaged % cover	17.6	0	9.0	0.03
Graminoids ± (SE)	8.9	0	6.8	0.03
All vegetation averaged % cover	73.7	4.5	41.9	3.8
All vegetation ± (SE)	16.2	2.6	7.4	2.3

Native tree species averaged percent cover in the exclosures and controls were comparable (Table 5.4) as well as their species assemblages. In the exclosures, American beech (*Fagus grandifolia*) was dominant in the sapling layer with 13.1% ± 7.2 (SE) averaged cover and ash (*Fraxinus* sp.) had the greatest average cover of trees in the seedling layer (2.5% ± 1.0 (SE). Other tree species found growing in the exclosures include (from most to least % cover): black gum (*Nyssa sylvatica*), flowering dogwood (*Cornus florida*), blue beech (*Carpinus caroliniana*), chestnut oak (*Quercus montana*), red maple (*Acer rubrum*), tulip poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), red oak (*Quercus rubra*), black oak (*Quercus velutina*), sugar maple (*Acer saccharum*), white oak (*Quercus alba*), serviceberry (*Amelanchier* sp.), bigtooth aspen (*Populus grandidentata*), and elm (*Ulmus* sp.). Similarly, in the control areas, American beech saplings (some clonal sprouts) had an average cover of 18.35% ± 5.6 (SE). The tree seedling composition was similar to those found in the exclosures but were stunted by deer browse. There were no observations of introduced trees species in the exclosures or controls.

The averaged percent cover of native shrubs in the exclosures was greater than in the controls (Table 5.4). In a few exclosures, blueberry (*Vaccinum* sp.) and azalea (*Rhododendron* sp.) had notable percent covers (11–15% cover). The control areas had much less native shrub cover except for one site where witch hazel (*Hamamelis virginiana*) have 18% cover; the few other native shrubs species had covers less than 2%. Averaged introduced shrub cover in the exclosures and controls were very low; observations were sporadic and small, with the exception of exotic chokeberry at h2 and h3 exclosures (8–10% cover) and the h2 control (17% cover).

Native vine cover was very low in the exclosures and the controls (Table 5.4); the only species observed were seedlings of Virginia creeper (*Parthenocissus quinquefolia*) and catbrier (*Smilax* *glauca*). Introduced vine cover was also sporadic in the exclosures and controls. Asiatic bittersweet (*Celastrus orbiculatus*) was the only species that had notable presence in the exclosures h1 and h2 (8–10%) and in the h2 control (17%).

Averaged cover of native flowering herbs was significantly greater in the exclosures than the controls (Table 5.4). The success of the planted herbs in the exclosures added greatly to the total flowering herb cover already reported in the prior section. Many naturally occurring herbs in the exclosures were successfully protected as well. The three species with greatest averaged cover were: white wood aster (*Eurybia* divaricata) at 11.4% ± 7.6 (SE); Canada mayflower (*Maianthemum canadense*) at 4.2% ± 2.6 (SE); and partridgeberry (*Mitchella repens*) 3.5% ± 1.7 (SE). Across the ten exclosures, 13 species of not planted native flowering herbs were found. In the control areas, there were 8 species of naturally occurring native flowering herbs found. The averaged percent covers of each were much lower than in the exclosures, for example, white wood aster had 0.2% ± 0.2 (SE), Canada mayflower had 1.6% ± 0.8 (SE), and partridgeberry had 2.6% ± 1.1 (SE) averaged cover. No introduced flowering herbs were recorded in the exclosures or controls.

Native graminoids were primarily sedges, in the genus *Carex*, and more individuals with greater percent cover were observed in the exclosures than the controls (Table 5.4). The only introduced graminoid found was Japanese stiltgrass (*Microstegium vimineum*) that was recorded with less than 1% cover in only one control area.

Floristic Quality Assessment

The average adjusted FQI for the exclosures was 50.21 ± 1.34 (SE). The exclosure with the highest adjusted FQI was h3 at 55.4 because the native richness was high and it included species with high conservation coefficient values such as rue anemone (*Thalictricum thalictricoides*), aster sp. (*Symphiotrichum* sp.) and the planted foamflower and bloodroot. The lowest adjusted FQI was in exclosure h2 at 42.8, which had more introduced species than the other exclosures.

The average adjusted FQI for the control sites was 48.5 ± 1.43 (SE). The highest adjusted FQI was found in control h10 at 54 where no introduced species were recorded and the high coefficient value species round-leaf pyrola (*Pyrola americana*) and striped wintergreen (*Chimaphila maculata*) were found. The lowest adjusted FQI in a control was at h2 where native species richness was low along with relatively high introduced richness.

Conclusions

The adjusted FQI values were mostly high throughout both the exclosures and controls because the entire Primrose Brook area contains rather high native richness. Differences in adjusted FQI were mostly due to the surviving planted species with high coefficient values and presence or absence of introduced species. More introduced species were found in the sites nearer to newly invaded areas that were closer to the trailhead and Jockey Hollow Road. In addition, microsite differences could have played roles in the species assemblage, richness, and percent covers. Such potential difference are: elevation, moisture, closeness to specific plant populations and native seed pools, and proximity to species like American beech (*Fagus grandifolia*), which has been found to suppress growth of some species (Hane et al., 2003). More research needs to be performed to understand how these factors influence each exclosure location.

In general, the exclosures were successful after 22 years. They allowed for many native planted species to survive in comparison to the exposed control areas; zero plant species were found outside the exclosures. Five of the nine species were found to be poor performers as planted individuals: wild ginger, miterwort, Jacob's ladder, violets, and large-flowered bellwort; zero survived in 2019. However, this is not to say that natural populations would perform poorly as, for example, many violet species are still found around the Primrose Brook Trail (Epiphan, photo documentation 2019, Appendix A). The best performing species after 22 years was false Solomon's seal. Furthermore, some of the individuals of false Solomon's seal and foamflower spread by sexual or asexual reproduction in the exclosures. Even some of the bluestem goldenrod was found to have spread outside the exclosures in areas nearby. These protected individuals that have survived have the potential to spread and re-establish in the local area especially if deer populations will be controlled in the future.

The exclosures were successful at protecting native naturally occurring (not-planted) species of trees, shrubs and herbs. Much of their success can be attributed to location. This area is further from severe introduced species invasions, in comparison to many other exclosures in the park. Moreover, the integrity of the exclosure structures lasted and were maintained as they were all found to be mostly intact in 2019 and no evidence of deer herbivory inside was seen. The setting of the exclosures, most of which are amid dense stands of intermediate and mature trees, help catch and hang up falling stems and limbs before they reach the exclosure, and small size plays into the low incidence of damage as well. But most importantly, the locations of these exclosures along a regularly visited trail close to a parking area helped to facilitate frequency of visitation and ease of maintenance and repairs by NPS employees.

Recommendations

Given the success of the planted native herbs and preservation of native vegetation (herbs and woody shrubs and trees), these exclosures should remain and monitoring and maintenance should continue. The species preserved in exclosure serve as native seed reservoirs for the surrounding Primrose Brook area that is becoming more and more impacted by deer browse and invasive plant infiltration. Monitoring the vegetation in and outside of the exclosures into the future will prove ever more valuable as predicted species assemblages and climatic changes ensue (Dawson et al., 2011).

The most essential factor in ensuring the future success of these exclosures is regular maintenance. We recommend regularly visiting each exclosure at least once a month in the growing season, at least every other month in winter, and soon after severe wind and storm events.

These ten Herbaceous Exclosures along with the two Jack-in-the-Pulpit and two Biotic Exclosures serve invaluable purposes: to preserve native flora, seed reservoirs, and habitat for years into the future as well as further the long-term studies of biological conservation in the Jockey Hollow section of Morristown National Historical Park.

Chapter 6. Restoration Exclosure

Introduction & Background

Much insightful research on invasive plants and vegetation of the Jockey Hollow and New Jersey Brigade Sections of Morristown National Historical Park have been performed by the late Dr. Joan Ehrenfeld and her graduate students (Ehrenfeld, 1997; Ehrenfeld, 1982; Ehrenfeld, 1997; Kourtev et al., 1998; Kourtev et al., 1999; Ehrenfeld, 1999a, b; Ehrenfeld et al., 2001; Kourtev et al., 2002a, b; Russell, 2002; Ross, 2008). One of her largest projects in Jockey Hollow was the establishment of the two-acre Restoration Exclosure. The site originally had a canopy of tulip poplar (*Liriodendron* tulipifera), oaks (*Quercus* sp.), and hickories (*Carya* spp.) intermixed with stems of black locust (*Robinia pseudoacacia*). The understory was inundated with dense Japanese barberry (*Berberis thunbergii*) (Ehrenfeld et al., 2020). In 2002, a two-acre zone of Japanese barberry was cleared and fifteen black locust removed. An eight-foot-tall exclosure was erected around the two acres. Then, native flora was planted in the exclosure and soil treatments were applied. Monitoring was performed in several methodologies (Ehrenfeld et al., 2020) to determine whether the soil treatments affected the growth and spread of the following in the absence of deer impacts:

1. Remaining exotic species in the plots
2. Planted native species in the plots
3. Recruitment of unplanted native species
4. Recruitment of exotic species

Data were recorded from 2003 to 2008 in the exclosure and in a section outside the exclosure once in 2004.

Data were statistically analyzed, results thoroughly compiled, and conclusions drawn by Ehrenfeld et al., 2020. The basic findings were that the soil manipulations did modify the soil, but no significant changes in vegetation were evident. There were some overall differences between the exclosure and control. In the exclosure, Japanese stiltgrass (*Microstegium vimineum*) became dominant in the ground layer, in the absence of barberry, and other new introduced plant species moved in as well. In both the exclosure and control, introduced species remained dominant. Yet, many recruits of native generalist species were observed amid the stiltgrass in the exclosure. Native richness and cover increased in the exclosure in comparison to the nearby control, where native species richness and cover remained low. In essence, the restoration efforts in the exclosure were not effective in reducing overall introduced species cover but were effective in increasing native species richness and cover.

More long-term monitoring in the restoration exclosure would have been needed to see how the native vegetation stood up against these invasives over time. Unfortunately, in 2011 the hard-working and brilliant Dr. Joan Ehrenfeld sadly passed away. Later that fall, and again in 2012, hurricanes wreaked havoc on this area. Very large tulip poplars tipped up and many large limbs failed which damaged the exclosure fence, opening the plot up to deer. Repairs of minor continual damage were performed as time permitted over the years, but deer still gained access. The current status has some damaged fence portions where deer enter, and recent signs of browse and tracks were evident.

Methods 2019

We determined that Dr. Ehrenfeld's draft report, which was submitted to the NPS for review, had a thoroughly complete analysis of vegetation data over time (Ehrenfeld et al., 2020). Nonetheless, the reviewers' comments related to data analysis that have been left unaddressed, since Dr. Ehrenfeld had passed. Subsequently, the final report was never officially submitted; performing final edits were not in the scope of this report. Therefore, we decided to visit the two-acre exclosure to see if the previous monitoring could be replicated in 2019 and if it were even valuable.

Exclosure Condition

We found that there were multiple openings in the fence. The trees and branches were still across the broken fence areas and throughout the interior of the exclosures. The large downed debris became covered in several dense colonies of multiflora rose (*Rosa multiflora*) and several blackberry species (*Rubus* sp.) and many intertwined woody vines. Traversing the exclosure area was impossible in some sections and very dense and hazardous in others. Deer herbivory, trails, and tracks were observed throughout.

Data Collection

Due to the condition of the site, there was no way to successfully replicate previous monitoring protocols and no reason to as the site has been open to deer herbivory for several years. We decided to collect the information that we could safely and considering the current condition and value of findings in a broken exclosure where deer have run rampant.

We collected general observations on native and introduced species cover. We combed the areas of the exclosure that allowed safe passage and listed all species found inside the broken exclosure to provide the current status of vegetation. We then were able to compile species richness.

Data Analysis

A floristic quality assessment was performed using the New Jersey 2019 coefficient values, to determine the vegetative condition. We utilized the adjusted floristic quality index instead of the traditional floristic quality index, because the former was adapted to consider the contributions of introduced species as well as native species and eliminates the sensitivity to species richness that helps to more accurately express condition for low richness high quality sites (Miller and Wardrop, 2006).

Adjusted Floristic Quality Index Formula:

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

I' = Adjusted floristic quality index C = Coefficient value
N = Native species A = Introduced species

Results 2019

The dominant cover at the site was comprised of a few introduced species, including exotic chokeberry (*Photinia* sp.), oriental Photinia (*Photinia villosa*), Japanese Barberry (*Berberis thunbergii*), multiflora rose (*Rosa multiflora*), and wineberry (*Rubus phoenicolasius*). These woody introduced plants seemed to have suppressed the previously dominant Japanese stiltgrass (*Microstegium vimineum*) (Ehrenfeld et al., 2010). The total introduced species richness was 15 (Table 6.1). The native richness was much higher at 35 species, but their covers was small and sparse. The adjusted floristic quality index was 35.1 (Table 6.2).

Table 6.1. Census of native and introduced species richness in the 2ac Restoration Exclosure.

Species type	Species richness	Percent richness
Total Species:	50	100%
Native Species:	35	70%
Non-native Species:	15	30%

Table 6.2. Floristic quality assessment of the two biotic exclosures and controls in 2019.

Conservatism-based metrics:	Value
Total Mean C:	3
Native Mean C:	4.2
Total FQI:	21.2
Native FQI:	24.8
Adjusted FQI:	**35.1**
% C value 0:	30
% C value 1–3:	28
% C value 4–6:	32
% C value 7–10:	10

Even though many introduced species dominated, the native species assemblage was noteworthy (Table 6.3). There were 35 total native species found (Table 6.3). Some native species found in this exclosure, were not found in or around any of the other exclosures, such as grape fern (*Botrychium oneidense*), silvery glade fern (*Deparia acrostichoides*), Christmas fern (*Polystichum acrostichoides*), sensitive fern (*Onoclea sensibilis*), dogbane (*Apocynum cannabinum*), and wild yam (*Dioscorea villosa*). Among the many dominant introduced species a few emerging invasive species were found here that were not in other exclosure sites including glossy buckthorn (*Frangula alnus*), princess tree (*Paulownia tomentosa*), and linden viburnum (*Viburnum dilatatum*).

Table 6.3. Observed species list within the 2-acre Restoration Exclosure in 2019. Nativity has been verified by the USDA native plant database (USDA NRCS, 2006). Conservation coefficients are the 2019 New Jersey values (Freyman et al., 2016).

Common name	Scientific name	Nativity	Conservation coefficient	Family
Norway maple	*Acer platanoides*	introduced	0	Aceraceae
Red maple	*Acer rubrum*	native	3	Aceraceae
White snakeroot	*Ageratina altissima*	native	3	Asteraceae
Porcelain-berry	*Ampelopsis brevipedunculata*	introduced	0	Vitaceae
Indian-hemp	*Apocynum cannabinum*	native	2	Apocynaceae
Jack-in-the-pulpit	*Arisaema triphyllum*	native	5	Araceae
Japanese barberry	*Berberis thunbergii*	introduced	0	Berberidaceae
Blunt-lobe grape fern	*Botrychium oneidense*	native	8	Ophioglossaceae
Sedge	*Carex* sp.	native	7	Cyperaceae
Shagbark hickory	*Carya ovata*	native	6	Juglandaceae
Asiatic bittersweet	*Celastrus orbiculatus*	introduced	0	Celastraceae
Enchanters nightshade	*Circaea lutetiana*	native	3	Onagraceae
Silvery glade fern	*Deparia acrostichoides*	native	7	Dryopteridaceae
Wild yam	*Dioscorea villosa*	native	5	Dioscoreaceae
Burning bush	*Euonymus alatus*	introduced	0	Celastraceae
Glossy buckthorn	*Frangula alnus*	introduced	0	Rhamnaceae
Ash	*Fraxinus* sp.	native	5	Oleaceae
Stickywilly	*Galium aparine*	native	2	Rubiaceae
White grass	*Leersia virginica*	native	3	Poaceae
Spicebush	*Lindera benzoin*	native	5	Lauraceae
Tulip poplar	*Liriodendron tulipifera*	native	5	Magnoliaceae
Canada mayflower	*Maianthemum canadense*	native	4	Liliaceae
Japanese stiltgrass	*Microstegium vimineum*	Introduced	0	Poaceae
Partridge-berry	*Mitchella repens*	native	5	Rubiaceae
Sensitive fern	*Onoclea sensibilis*	native	3	Dryopteridaceae
Woodsorrel	*Oxalis* sp.	native	1	Oxalidaceae
Virginia creeper	*Parthenocissus quinquefolia*	native	2	Vitaceae
Princess tree	*Paulownia tomentosa*	introduced	0	Scrophulariaceae
Exotic chokeberry	*Photinia* sp.	introduced	0	Rosaceae
Oriental photinia	*Photinia villosa*	introduced	0	Rosaceae
Jumpseed	*Polygonum virginianum*	native	4	Polygonaceae
Christmas fern	*Polystichum acrostichoides*	native	5	Dryopteridaceae
Sweet cherry	*Prunus avium*	introduced	0	Rosaceae
Black cherry	*Prunus serotina*	native	2	Rosaceae
Chestnut oak	*Quercus montana*	native	5	Fagaceae

Table 6.3 (continued). Observed species list within the 2-acre Restoration Exclosure in 2019. Nativity has been verified by the USDA native plant database (USDA NRCS, 2006). Conservation coefficients are the 2019 New Jersey values (Freyman et al., 2016).

Common name	Scientific name	Nativity	Conservation coefficient	Family
Black locust	*Robinia pseudoacacia*	introduced	0	Fabaceae
Multiflora rose	*Rosa multiflora*	introduced	0	Rosaceae
Allegheny blackberry	*Rubus allegheniensis*	native	3	Rosaceae
Bristly dewberry	*Rubus hispidus*	native	5	Rosaceae
Black raspberry	*Rubus occidentalis*	native	3	Rosaceae
Wineberry	*Rubus phoenicolasius*	introduced	0	Rosaceae
Sassafras	*Sassafras albidum*	native	2	Lauraceae
Aster	*Symphyotrichum* sp.	native	7	Asteraceae
Rue anemone	*Thalictrum thalictroides*	native	7	Ranunculaceae
New York fern	*Thelypteris noveboracensis*	native	4	Thelypteridaceae
Poison ivy	*Toxicodendron radicans*	native	1	Anacardiaceae
Linden viburnum	*Viburnum dilatatum*	introduced	0	Caprifoliaceae
Blackhaw viburnum	*Viburnum prunifolium*	native	5	Caprifoliaceae
Violet	*Viola* sp.	native	6	Violaceae
Grape	*Vitis* sp.	native	5	Vitaceae

Conclusions

The high native richness in the exclosure area was a positive discovery. Even though introduced species dominate the site, the native species are still holding on. However, it is likely that most of the native species will not last very much longer under the high deer pressure they have been subject to since the fence broke open. The many ferns found here are relatively unpalatable to deer because of their toxicity (Rooney, 2009) and they may persist; but the ferns and the other native flora have to contend with the growing waves of introduced flora. The introduced species cover will only expand and slowly work to reduce native cover and richness as we have observed in the other invaded exclosures in Jockey Hollow (Ch.1. Exclosure #3 & #4, Ch.3 SHT & GLT). Without any intervention, the fate of the vegetation in this damaged exclosure is grim.

Recommendations

This compromised, abandoned exclosure was built with quality materials and originally meant for long term data assessments. The current condition is terribly unfortunate. Ideally, repair of this grand exclosure would be best so it can be used once again for experiments in restoration. Currently, there are new introduced species flourishing here like the exotic chokeberry, oriental Photinia, and linden viburnum that are in emerging stages in Morristown National Historical Park. Research on the dynamics of these invasive species in this exclosure, if it were repaired, would be valuable. There are also native species here that do not occur in any other exclosure in this park. They could provide several valuable botanical research opportunities as well as preservation for natural heritage and wildlife habitat.

If researchers or the National Park Service are interested in the preservation of this exclosure for the potential research opportunities it would provide or the natural heritage that can be saved, this exclosure should be restored. However, the biggest hurdle is the cost; the cost in creating safe access, the cost of materials, of labor, and planning will be higher and more complex than the other exclosures at this park. There are large tree debris and prolific dense vegetation in the way which needs to be cleared for access which may be costly. The same or similar quality fence materials should be used in the repairs, which could be costly as well. The time and labor required needs to be planned out and costs estimated. This is no small feat.

Very importantly, if repaired, long term maintenance of the fence needs to be a scheduled priority. The frequency of fence monitoring must be at least once a month and after every strong storm. The long linear extent of the fence has a higher likelihood of being damaged by the many surrounding trees than the other smaller exclosures. Another key factor is the establishment of sufficient funding set aside to afford proper repair at any unpredictable time.

The repair and maintenance of this exclosure would be an expensive and long-term commitment that is well worth it, if the appropriate entities are interested and involved. This cannot be performed with limited funding, time, and personnel.

Discussion

The combination of white-tailed deer overabundance and invasion of introduced species has become a serious threat to native biodiversity in the region (Baiser et al., 2008, Aronson and Handel, 2011). The Baiser paper terms this a “perfect storm” of habitat destruction and this now challenges many NPS and other natural resource properties in the area. Exclosures have been utilized throughout the eastern forests afflicted with high deer populations and they have been successful (Webster et al., 2016, Kelly, 2018). Native plant regeneration was much higher in exclosures protected from deer browse. The data include both herbaceous and woody plant regeneration. We recorded all plants <3m height. Future studies may want to isolate the woody plant recruitment pattern to focus on the canopy species, for example, but this was not a goal of this particular study. Further, in areas where invasive plants are abundant, such as Morristown National Historical Park (Ehrenfeld, 1997, Ehrenfeld, 1999a, b), there are more challenges in native biodiversity conservation. Countless natural areas in New Jersey share similar challenges as well as other highly urbanized regions in the east.

The variety of research exclosures distributed throughout several plant community types in Morristown National Historical Park can provide valuable insight to exclosure utilization in New Jersey. Overall, 16 of the 24 exclosures were successful in protecting and regenerating some native flora. However, we found that the surrounding site quality and forest type influenced this success. Where the floristic quality was high in the control area, it was often higher in the adjacent exclosure as well as native plant cover and richness (Chapter 2, Chapter 4, Chapter 5). The introduced species cover was low or absent. In higher quality sites, invasive plants were less of a threat to exclosure success.

In Jockey Hollow and the New Jersey Brigade area, the higher quality sites were in mesic to dry mixed oak-beech-birch forests. In these forest patches with many American beech (Sneddon et al., 2008, Brittingham et al., 2014), the understory vegetation (herbaceous and woody seedlings) is rather sparse (R. Masson, personal communication, 15 August 2019) potentially due to phytotoxicity of beech leaf leachate (Hane et al., 2003) or slow leaf litter decomposition and deep shade (Cale et al., 2003). This microsite expression was observed in several exclosure locations: Exclosure #5, the New Jersey Brigade Exclosure, some of the Herbaceous exclosures, and part of the Biotic Exclosure areas (Chapter 1, Chapter 2, Chapter 3, Chapter 5). In these areas, introduced species cover and richness was low or absent. Native plant cover was often sparse, but the native richness and floristic quality were relatively high. More research is required to fully comprehend the mechanisms that influence understory cover and richness in beech dominated microsites. The finding could be valuable for natural heritage preservation and planning conservation strategies such as the use of exclosures in specific forest cover-types.

Fence damage by wind throws, tip-ups, and limb failures were main reasons why high site quality exclosures experienced declines in native plant cover. Maintenance of the exclosures is key, but size of the exclosures was important. The smaller exclosures had less incidences of damage and subsequent deer access and herbivory. Even when limbs fell on the structures, they often kept deer out anyhow, because the fence often collapsed inward and still protected the plants. It was beneficial to have a high fence height to exclosure width ratio, such as 2:3, which equates to rather small exclosures. Also, areas that had dense tree cover, in fact, helped to block limb fall damage because falling limbs would get caught in the trees above. This reduced the frequency of needed maintenance and repairs. Larger exclosures would protect more tree as well as herbaceous native plants, increasing population size, which has great demographic and genetic value. However, the value of protecting large areas depends on greater investment in fence management than has been funded in the past.

The areas that experienced the most damaging tree and limb failure were in successional tulip poplar and ash forests. The emerald ash borer (*Agrilus planipennis*) has spread through the park (Masson, personal communications, November 2017) and, along with widespread ash decline, these factors led to many dead ashes coming down. In addition, strong storms caused several mature, giant tulip poplars to come down throughout the park (J. Epiphan, observation during field research, 2017). These failures were very detrimental when they occurred on exclosures, such as the restoration exclosure (Chapter 6). They allowed for deer to enter, eat the native plants, and helped facilitate introduced plant invasions. In addition, the tree losses throughout this forest-type naturally opened more holes in the canopy, which has abetted the invasive plants species spread and dominance. The majority of the tulip poplar-ash forests had prolific understory invasions of introduced plants (Epiphan, observation in field research, November 2017). The exclosures in this forest-type experienced rapid growth of introduced species cover, far surpassing native species cover, such as in Exclosure #2 and the Grand Loop Trail Exclosure (Chapter 1, Chapter 3).

The successional black locust forests interspersed throughout the park (Sneddon et al., 2008) were planted by the National Park Service in the mid-twentieth century for afforestation of open areas (Masson, personal communication, November 2017). Ironically, the short-lived trees have been senescing over the past few decades and have re-opened canopy gaps in Jockey Hollow (Shaw and Farrell, 2013). In addition, black locust has allelopathic potential (Nasir et at., 2005), which may have favored invasion success in these areas and, compounded with high light gap conditions, the introduced species dominance in the understory was cataclysmically enabled. For example, this degraded condition has afflicted Exclosure #4, on the edge of a successional black locust forest and recent gap (Shaw and Farrell, 2013). These factors resulted in very low floristic quality (Chapter 1). Similarly, Exclosure #3 had the same fate and low floristic quality. It was on the edge of an old field and quickly overrun with invasive woody vines and shrubs. The vegetative condition at the exclosures and subsequent failure to preserve native plants were strongly influenced by their location. They were both placed in areas where rapid introduced plant invasion was very likely.

The locations of the exclosures were strong determinants of their fates. However, one exclosure in particular, Exclosure #1, was found in 2019 surrounded by thick colonies of Japanese barberry but managed to have less than 1% of this species inside the intact exclosure. This one location has been able to sustain native species inside and keep dense barberry invasions out. From this one incidence, it seems there is potential for barberry invasions to be stopped by a physical barrier. More research is needed to make any definite conclusion. In addition, the many other introduced shrub species, such as multiflora rose that can climb, and exotic chokeberry that spreads clonally, in other areas of the park may have other mechanisms that assist infiltration.

Interestingly, some of the exclosures in successional forests were installed in areas dominated by Japanese stiltgrass (Chapter 1, Chapter 3). These locations maintained a high introduced species cover over the years, but the introduced species assemblage shifted to predominantly woody shrubs and vines (Russell, 2002). In the restoration exclosure, the barberry was physically removed, then it was replaced by stiltgrass in 2003 (Ehrenfeld et al., 2010). In 2019, we found exotic chokeberry and multiflora rose dominating the site. More research is needed to understand the dynamics of succession and competition among introduced species. Morristown National Historical Park would be a great place for this type of investigation and would be of wide use to the National Park Service.

Final Conclusions

The first deer exclosures in Jockey Hollow were placed in differing forest cover-types that greatly influenced the levels of introduced and native species cover and richness as well as floristic quality. Exclosures in edge habitats, near gaps, and successional forests had greater cover of introduced species and lower floristic quality. Exclosures in mixed oak-beech-birch forests had greater success of native plant conservation. In the last remaining intact exclosure (#1), spread of Japanese barberry from the control to the exclosure was inhibited by the fence. Overall, when sampling intensity was higher and became more consistent, the results were more dependable and conclusive.

The exotic exclosures showed similar results as forest type influenced total cover and introduced species cover. In two exclosures, Japanese stiltgrass was replaced with introduced woody plants, which was also observed in Exclosure #4 from Chapter 1. In only one exclosure (NJB), the native cover was higher than the introduced cover, but the exact reasons why are still unknown, but likely due to microsite attributes.

The biotic exclosures had rather high floristic quality in general and fence damage was the greatest obstacle in the protection of native species in the exclosures. The preservation of native flora was successful but would have been greater if the fence were immediately repaired after damage events. The 10 x 10 m exclosures has 40 linear meters of fence to keep clear of fallen limbs. This requires regular frequent visitation and immediate repair as needed.

The Jack-in-the-Pulpit Exclosures and Herbaceous Exclosures were all successful at protecting native flora from deer herbivory. The majority of the adjacent control areas had less native percent cover and lower native richness. The planted species trials in the Herbaceous Exclosures revealed zero survival in the controls outside of the exclosures and poor performance of six of the twelve species. The surviving species: wild geranium, false Solomon's seal, bloodroot, foamflower, swan's sedge, and bluestem goldenrod had variable success rates. Nonetheless, they did elevate the overall floristic quality of the exclosures.

The large restoration exclosure revealed intriguing shifts of invasive plant dominance over time while enabling native plant richness to increase in comparison to the control. The severe storm damage to the exclosure structure and deer presence will continually degrade the site. Repair of this exclosure site is feasible with ample funding. If this is approved, a strict maintenance plan needs to be devised that includes frequent and regular maintenance of the 360-meter fence line, as well as adequate funding and dedicated personnel. Without a generous long-term management plan, ad hoc repair is not sustainable. The relatively new problems of many invasive species and super-abundant deer will require additional professional staff for successful management. This is not a minor scope of work that can be added to the tasks of existing personnel who have many other obligations. In preserved properties across many land holders (government and private environmental organizations), this type of modified staffing has become a modern requirement.

Exclosure fences must have a continual repair management protocol to be effective. The care needed to maintain the exclosures is much more time intensive than was expected over the years and cannot be managed by just one devoted employee as in the past. If funding does not allow for more people-hours devoted to exclosure maintenance, we recommend focusing on the small exclosures (3.7 x 3.7 m), which have high floristic quality and less chance of damage as well as the two biotic exclosures (10 x 10 m) that have high native biodiversity including a few rare plants.

The smaller exclosures had greater longevity and lower risk of failure. The larger exclosures had higher incidence of severe damage and failure. The larger the size of the exclosure, the greater the chance of damage was to the fence, which allowed in deer. Even though it is well understood that large contiguous forest tracts are better conserved as a whole, large exclosures bear a much higher risk for deer entry and are much more time intensive and costly for management. Many small exclosures scattered throughout the landscape, as observed in this study, are more likely to remain intact and can equate to the same area of a large tract with less maintenance concerns.

Location and forest type influenced storm damage potential as well as likelihood of introduced species invasions. Introduced species cover increased and native cover decreased when exclosures were severely damaged and deer had access. Deer presence may have facilitated invasion of some introduced plants. Exclusion of deer in some cases helped reduce introduced species presence in exclosures. In exclosures dominated by introduced plants, species assemblages shifted over time from herbaceous to mostly woody.

In summary, exclosures that most successfully conserved native species (herbaceous and woody) had the following qualities: less frequency of severe storm damage; were farther from extensive introduced plant colonies; were not in successional forests or edge habitats; were in higher quality forests such as mesic oak-beech-birch; and were smaller in size. The successful exclosures in high biodiversity areas are valuable tools for natural heritage preservation in Morristown National Historical Park. Monitoring of the exclosures should be performed regularly, by natural resource professionals, with high sampling intensity, and with a census to provide the most data for result interpretation. Recording information in additional data fields, such as canopy cover, canopy species assemblage, mid-story species assemblage, and proximity to invasive areas should be considered. Exclosure inspection and maintenance need to be regular and frequent by staff with this as a defined scope of work in order to successfully conserve native plant species inside. Regular visitation once a month and after each severe storm is highly recommended to maintain exclosure integrity and protect native flora. Without well-maintained exclosures, the natural heritage of these national priority areas will continually fail. The “perfect storm” of deer plus invasives will not end.

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Appendix A: Exclosure Photos

Figures A-1 through A-32 show the deer exclosures.

Figure A-1. Deer Exclosure #1 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-2. Deer Exclosure #2 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-3. Deer Exclosure #3 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-4. Deer Exclosure #3 Control Area in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-5. Deer Exclosure #4 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-6. Deer Exclosure #4 Control Area in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-7. Deer Exclosure #5 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-8. Deer Exclosure #5 Control Area in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-9. Biotic Exclosure #6 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A10. Biotic Exclosure #7 in 2019, with Steven N. Handel Holding 1m^2 Subplot Frames, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-11. Soldier Hut Trail Exotics Exclosure in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A12. Grand Loop Trail Exotics Exclosure in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-13. New Jersey Brigade Exotics Exclosure in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-14. New Jersey Brigade Exotics Exclosure area in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-15. Jack-in-the-Pulpit Exclosure j1 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-16. Jack-in-the-Pulpit Exclosure j2 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-17. Herbaceous Exclosure h1 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-18. Herbaceous Exclosure h2 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-19. Herbaceous Exclosure h3 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-20. Herbaceous Exclosure h4 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-21. Herbaceous Exclosure h5 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-22. Herbaceous Exclosure h6 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-23. Herbaceous Exclosure h7 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-24. Herbaceous Exclosure h8 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-25. Herbaceous Exclosure h9 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-26. Herbaceous Exclosure h10 in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

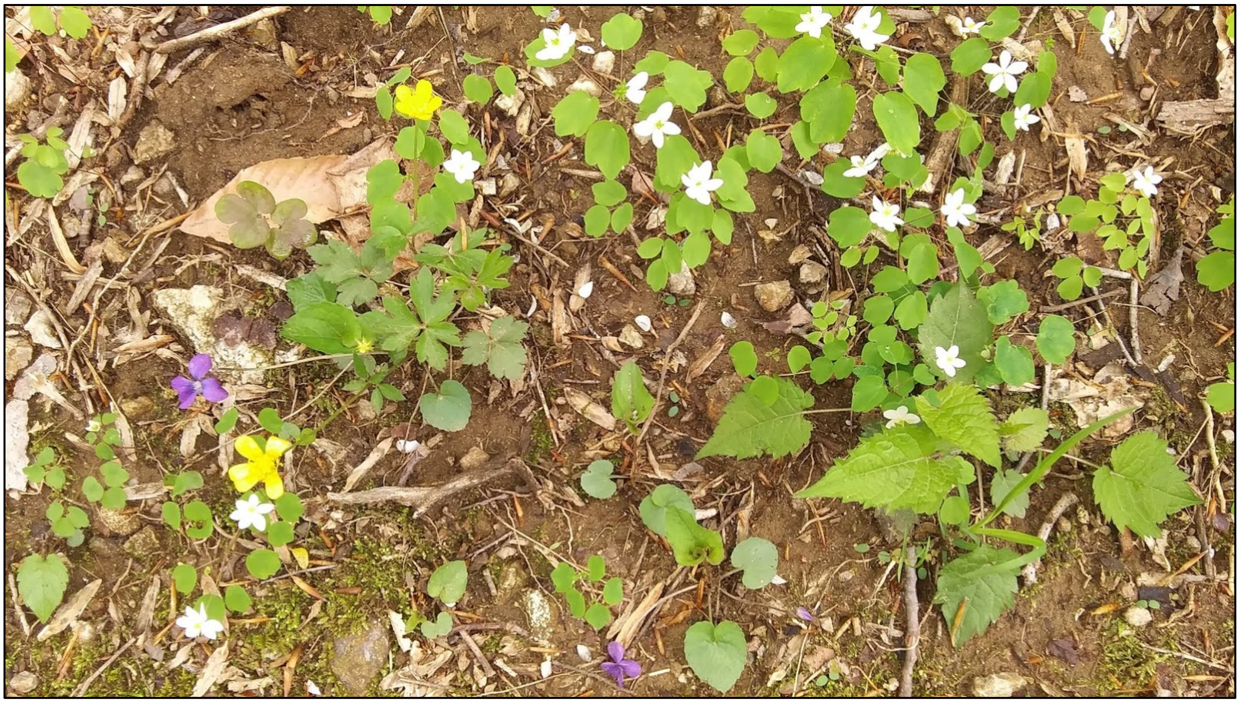

Figure A-27. Native Herbs along the Primrose Brook Trail in Spring 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-28. Violets along the Primrose Brook Trail in Spring 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-29. Native Herbs along the Primrose Brook Trail in Spring 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-30. Native Herbs along the Primrose Brook Trail in Spring 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-31. Entrance of the 2ac Restoration Exclosure in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

Figure A-32. Tip up and vegetation in the 2ac Restoration Exclosure in 2019, Morristown National Historical Park (JEAN N. EPIPHAN)

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