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Natural Resource Stewardship and Science

Woodland Succession After Multiple Intense Disturbances

Manley Woods, 1998–2017

Natural Resource Report NPS/HTLN/NRR—2019/1919

ON THE COVER
Monitoring site 4 in Manley Woods at Wilson's Creek National Battlefield, 2006. The image was taken three years after a tornado and less than one year after a fuel reduction burn.
Photography by Heartland I&M Network, NPS

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Contents

Page

Figures

Tables

Executive Summary

Natural community management at Wilson's Creek National Battlefield (NB) is shaped by our understanding of the woodlands and prairies at the time of the Civil War battle in 1861. This report is focused on the Manley Woods unit of the Battlefield, which is an oak-hickory woodland in the Springfield Plain subsection of the Ozarks. Canopy closure for Missouri oak woodlands can be highly variable and can range from 30-100% across the spectrum of savanna, open woodland, and closed woodland types. In 1861, the woodland was likely a savanna community. Over time, woodlands at Wilson's Creek NB, as well as across the Ozarks, began to increase in tree density, transitioning to a closed canopy woodland because of changes in land use history, including fire exclusion. Management plans eventually included restoring the area to a savannah/open woodland structure using fire. Prescribed fire was eventually reintroduced to Wilson's Creek NB in 1988, and managers have been working towards open woodland targets using fire as a primary mechanism to reduce the canopy over time.

The Manley Woods unit of Wilson's Creek NB has been subject to intense natural and anthropogenic disturbance events such as a tornado in 2003, timber removal in 2005, prescribed fires in 2006 and 2009, an ice storm in 2007, and periodic drought. The Heartland Inventory and Monitoring Network (hereafter, Heartland Network) installed four permanent monitoring sites within the Manley Woods area of the park in 1997. Initially, we assessed ground flora and regeneration within the sites (1998–1999). We added fuel sampling after the 2003 tornado. Although overstory sampling occurred prior to the tornado, the protocol was not yet stabilized and those data were not included in these analyses.

Manley Woods has undergone substantial change in the monitoring period (1997–2017). Manley Woods continues to have characteristic open oak woodland structure, but it is at a tipping point towards a forest community type rather than the more open target structure (i.e., savanna). The 2003 tornado introduced considerable heterogeneity to Manley Woods that continues to persist. Managers were concerned about oak and hickory regeneration in Manley Woods so a fire-free interval of about seven years was recommended to allow young oak and hickory trees to reach a fire tolerant stage. The eight-year long break in fire application successfully supported recruitment of saplings and class 1 trees (midstory trees; 5–14.9 cm diameter at breast height [DBH]), but fuels and canopy closure are elevated. The expansion of class 1 trees may have exceeded expectations and may be contributing to current canopy closure. Tree species composition indicates an increase in some mesophytic species.

The ground flora layer of the woods also responded to the changes in structure and disturbance. Ground flora species richness increased in the last monitoring period. Remarkably, few exotic species have been observed in the woodland. Continued dominance of the woodland by oak species will require that prescribed fire be restarted soon and periodic fire implemented to thin the midstory layer. To achieve a savanna-like (open woodland) structure, shorter fire return intervals may be needed in the short-term.

Acknowledgments

We are grateful for the contributions of previous staff who helped to monitor vegetation at Wilson's Creek National Battlefield. J. Thomas provided botanical support in 2017. Some of the language of this report was taken from James et al. (2009), particularly the introduction and methods. J. Haack-Gaynor provided maps and C. Young assisted with manuscript focus. We appreciate statistical insights provided by L. Morrison as well.

Introduction

Natural community management at Wilson's Creek National Battlefield (NB) is focused on returning the woodlands and prairies to their structure at the time of the Civil War battle in 1861 (John Milner Associates 2004; Gremaud 1986). John Milner Associates (2004) provided targets for plant community maintenance and restoration in addition to describing the historic scene of the park. This report is focused on the Manley Woods unit of the Wilson's Creek NB, which is an oak-hickory woodland in the Springfield Plain subsection of the Ozarks (Nigh and Schroeder 2002).

Canopy closure for Missouri oak woodlands can be highly variable, ranging from 30–100% across the savanna, open woodland, and closed woodland types (Nelson 2005). In 1861, Manley Woods was considered a savanna community (<30% canopy closure) more than an open woodland (Gremaud 1986). Due to changes in land use history over time, including fire, woodlands at Wilson's Creek NB, as well as across the Ozarks, began transitioning to closed canopy woodlands as tree densities increased. (Gremaud 1986; Guyette et al. 2002; John Milner Associates 2004). Management plans eventually included restoring the area to an oak-hickory savanna type community using prescribed fire (Gale et al. 2004; John Milner Associates 2004). Prescribed fire was reintroduced to Wilson's Creek NB in 1988 (Gale et al. 2004), and managers have been working towards savanna/open oak-hickory woodland targets using fire as a primary mechanism to reduce the canopy over time (Gale et al. 2004).

The Heartland Inventory and Monitoring Network provides long-term vegetation monitoring to Wilson's Creek NB. We collect data at permanent monitoring sites to determine the status of and track trends in woodland and restored prairie vegetation in Wilson's Creek NB. Woodland monitoring sites within the Manley Woods area of the park were first installed in 1997 (Appendix B). Initial data collection in 1998 included ground flora and tree regeneration components. Fuels monitoring was added in 2003, post-tornado. Overstory sampling was deployed in 1997, but the protocol was not yet stabilized so the data record begins in 2003.

Ecological disturbances other than fire are also common in this region. In 2003, 60 ha of the Manley Woods area of Wilson's Creek NB was struck by a northeasterly traveling tornado (Figure 1). Areas around two of the four long-term monitoring sites (sites 4 and 5) were most affected (Leis and James 2008). In the post-tornado years, three notable disturbances occurred (Appendix A). Increased fuel loads resulting from the tornado damage caused concern for increased wildfire risk, so park staff made plans to reduce fuel loads. In 2005, a contractor removed salvageable timber from Manley Woods, and in the following year, a prescribed fire was completed. The salvage and prescribed fire operations concentrated on the areas most affected by the tornado and thus received the greatest disturbance. In 2007, a severe ice storm further stressed natural communities in Manley Woods. Lastly, another prescribed fire was applied in 2009 to continue fuel reduction efforts. A fire-free period was then prescribed to allow regeneration of trees—specifically oaks and hickories (*Quercus* spp. and *Carya* spp.)—to grow to a more fire resistant stage (Dey and Hartman 2005).

In this report, we describe changes in Manley Woods through the monitoring record in light of severe disturbances and park natural community goals. Leis and James (2008) analyzed the four monitoring sites separately in an effort to understand the impact of the tornado and subsequent treatments. They concluded that the tornado affected each of the sites differently resulting in a heterogeneous woodland structure. This report seeks to understand Manley Woods as a community. As a result, analyses combine sites in an attempt to reveal woodland-wide trends. Furthermore, current and planned treatments are applied across the whole woodland to achieve community level objectives. Management goals for Manley Woods include fuel reduction and restoration of historically appropriate vegetation structure, diversity, and function. Oak woodland restoration dynamics are complex and a variety of metrics were needed to understand the trends over time. Nevertheless, we hope to provide information to Wilson's Creek NB natural resource and fire managers to guide future treatments in Manley Woods.

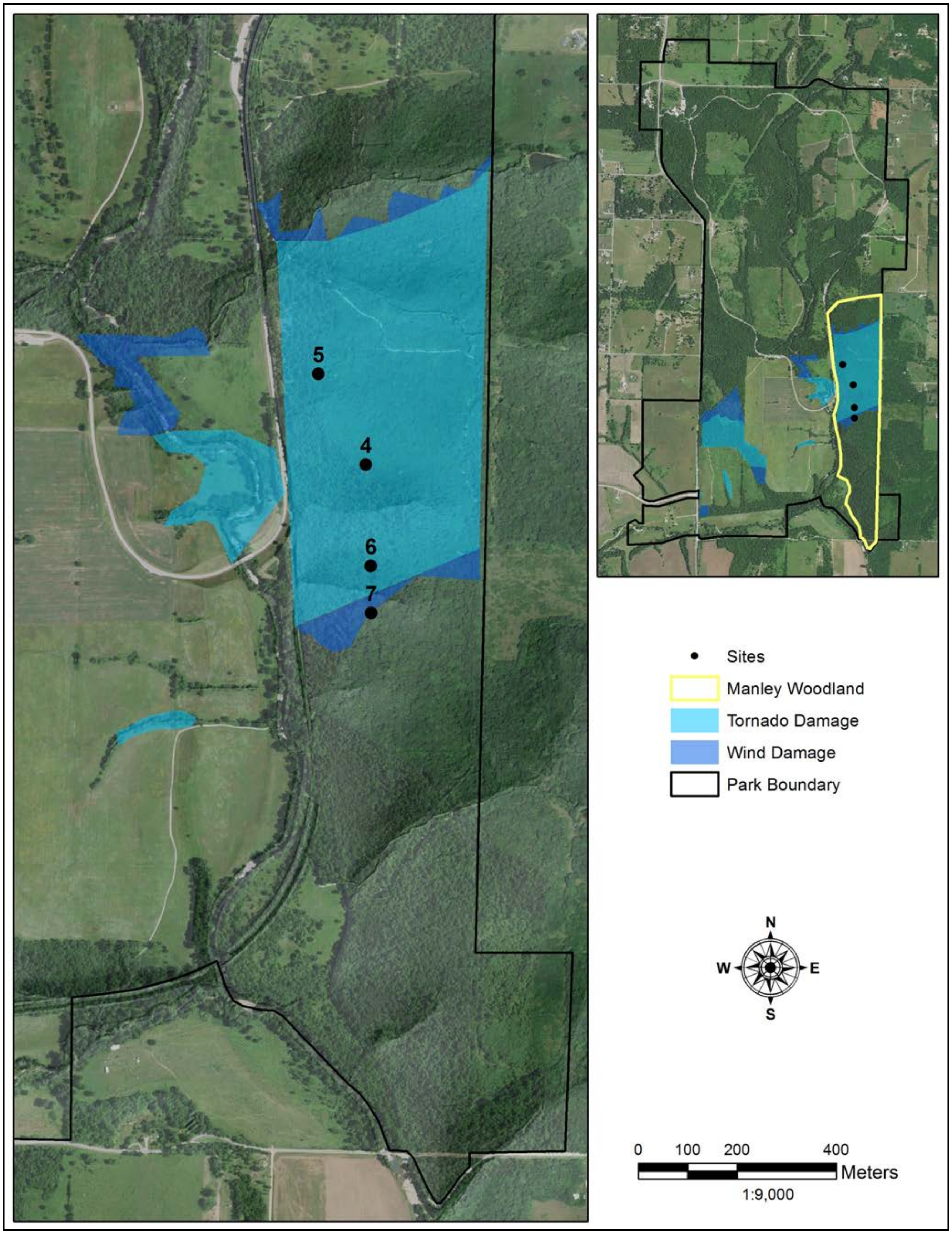

Figure 1. Inset of Wilson's Creek National Battlefield on the right and magnification of Manley Woods unit with sample sites labeled on the left (2016 image).

Methods

Study Site

Wilson's Creek NB was created in 1960, and the park was later directed to restore the historic battlefield scene as well as to interpret the events of the battle (Gale et al. 2004). The park is in the ecotone of the Ozarks Highlands and Osage Plains regions where the prairies meet the woodlands (Nelson 2005). Schoolcraft (1821) described highly variable ecosystems within this area including prairies, glades, savannas, and woodlands. Later, Civil War soldiers at Wilson's Creek NB described an open savannah scene interspersed with agricultural fields, but at the time of the park's creation, many of the upland savannas and glades had become closed canopy woodlands (Gremaud 1986; John Milner Associates 2004).

Manley Woods is located along the southeastern border of the park (Figure 1). A recent mapping project (Diamond et al. 2012) underscored the heterogeneity resulting from the 2003 tornado. They classified three of the monitoring sites as "Manley shrubland and woodland" community types because they were in a highly disturbed state. The remaining site was characterized as "upland deciduous woodland and forest" type within the South-Central Interior Oak Forest Group (Figure 2). Appendix B documents the sampling and recent disturbance history for each sampling site. The series of disturbances described above most affected two of the four long-term monitoring sites in Manley Woods (sites 4 and 5). Sites 6 and 7 received less intense disturbance (G. Sullivan, NPS Supervisory Resource Management Specialist, interview, 2008; Leis and James 2008).

Although there is natural community heterogeneity within this part of the park including shrubland, woodland, glade, and eastern redcedar community types (Diamond et al. 2012), the monitoring sites were initially more similar in nature (open oak woodland). All four monitoring sites within the woodland were aggregated for these analyses despite this heterogeneity, to provide an understanding of the Manley Woods unit as a whole.

Design

We established the four vegetation monitoring sites in the Manley Woods unit of Wilson's Creek NB in 1997 (Figure 1). Because the overstory methods were still in development at the time of the 1997 sampling, 1997 data were not included in these analyses.

See James et al. (2009) for details on sampling design. Monitoring methods followed the woodland standard operating procedures outlined in the vegetation community monitoring protocol (James et al. 2009). Monitoring sites were 50 m x 20 m (0.1 ha) in size with two focal transects bounding the site on the 50-m sides (Figure 3). For this protocol, overstory tree data were collected within the entire 0.1 ha area, while all other metrics were collected within 10 subplots located along the site boundaries. Each subplot consisted of a series of nested frames (0.01 m^2, 0.1 m^2, 1 m^2, and 10 m^2), but only observations at the 10-m^2 scale were summarized to the site scale (0.1 ha) for this study. Woodland monitoring consisted of a suite of sampling methods for characterizing overstory tree composition, canopy cover, regeneration, understory herbaceous species composition, and ground cover.

Monitoring components were added at different times. A full timeline is in Appendix B. Understory species composition and tree regeneration were implemented first (sampling twice annually from 1998 to 2000). In 2003, sampling resumed with both understory, overstory, and regeneration components completed between May and June, post-tornado. The next sample event was in September 2006 with all three elements. In the following year, only understory flora and regeneration were sampled. An attempt to conduct monitoring in 2012 yielded data only for site 7 because of safety concerns (those data were not included in this report). No additional vegetation sampling occurred until 2017 when all three vegetation components were again sampled. Fuels were added to the sampling suite in 2003, 2009, 2012, and 2017.

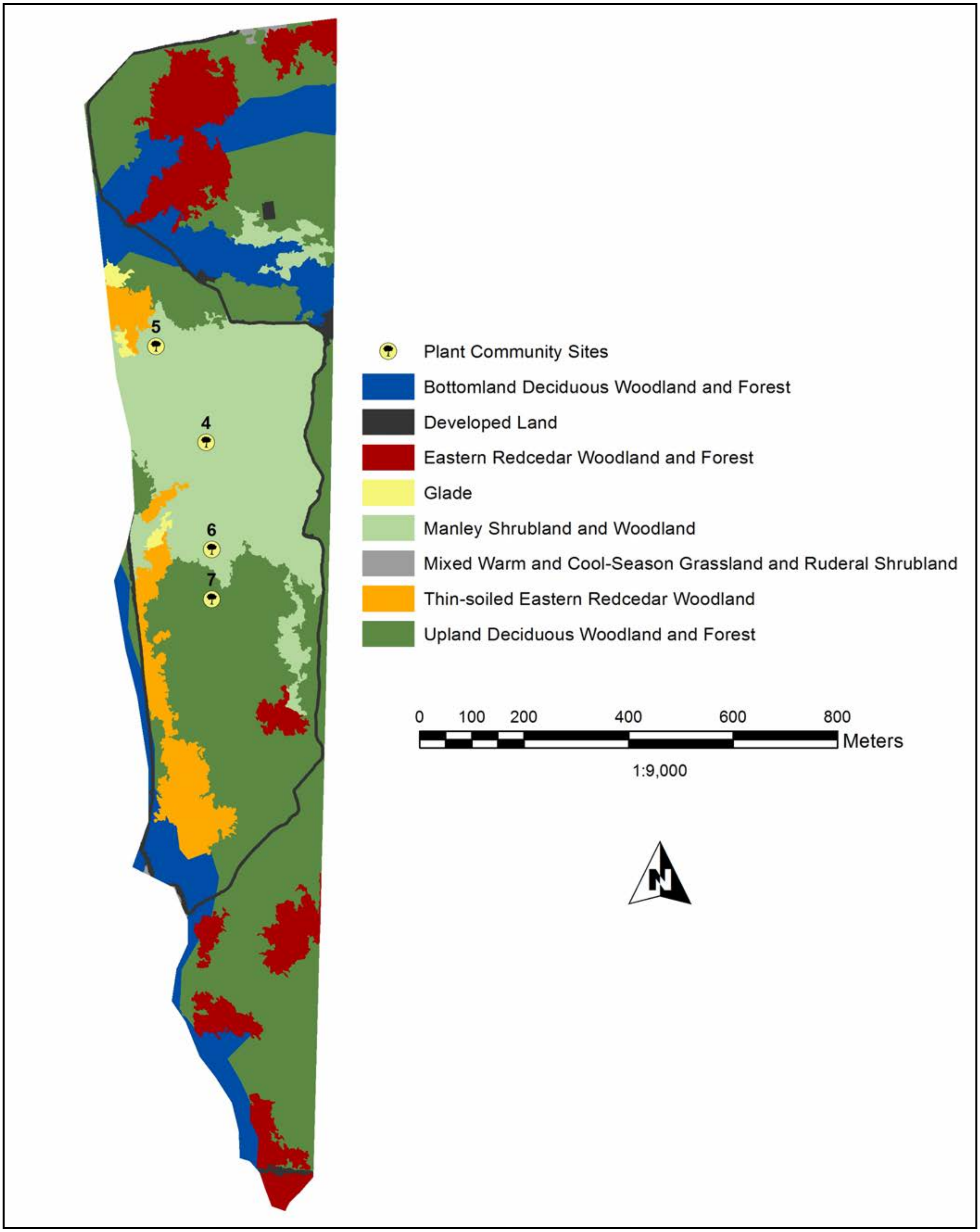

Figure 2. The Manley Woods unit of Wilson's Creek National Battlefield includes a variety of vegetation types (Diamond et al. 2013).

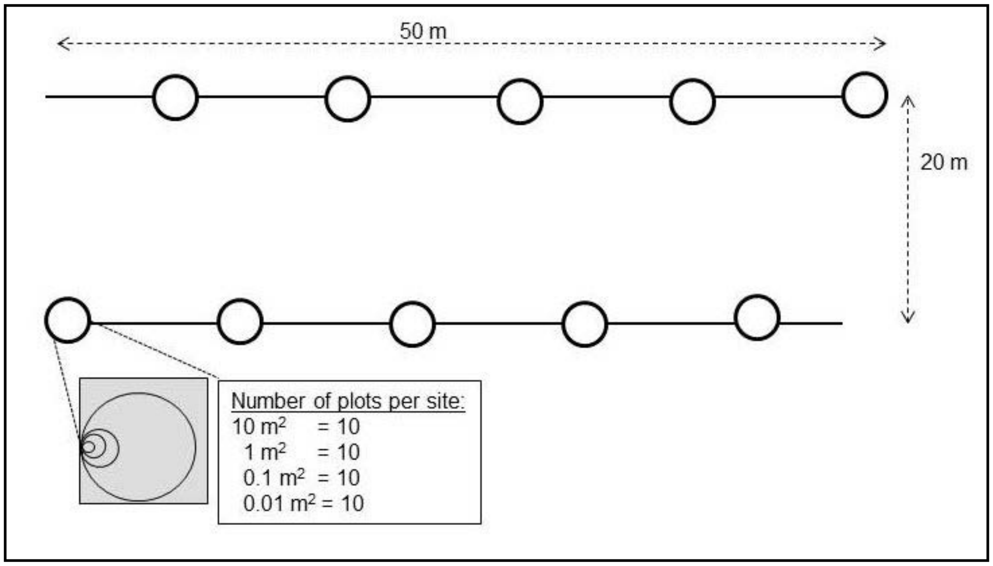

Figure 3. Plant community site monitoring design for Heartland Network parks.

Data Summary

SPSS (Version 24) was used for summary statistics (IBM 2016). All site means were calculated based on 10 subplots for each year (N = 4 sites with n =10 subplots each).

Recent Fire History

Fire history records are available for the park for the years 1988 through 2017, but spatial historical records of periodic disturbances like windthrows are not readily available. Recent fire history for the Manley Woods unit of Wilson's Creek NB was determined using a fire occurrence geodatabase for the park. Although our fire history data begins in 1992, we started the fire history for these analyses in 1994, the first year with known histories for all four Manley Woods monitoring sites (e.g., all sites were unburned in 1994; all sites burned in 1995). The history for site 4 was unknown until our first recorded fire on that site in 1994. A 30-m buffer was constructed from the center point of each monitoring site. If the buffered area was greater than 30% burned, the whole site was considered burned. Mean site fire return intervals (MFRI) were then calculated from this history:

$$MFRI = \frac{\textit{Number of years in dataset (23)}}{\textit{Number of burns at site}}$$

The site MFRI values were then averaged to find the MFRI for the whole unit and a standard deviation was calculated.

Fuel Load

Fuel loads were first measured in 2003, post-tornado. Downed woody fuel load, including 1-hour to 1000-hour, duff, and litter components, was estimated by using the planar intercept method (Brown et al. 1982; Leis et al. 2011). Four fuels transects are associated with each long-term vegetation monitoring site. Fuel loading was calculated with FFI (FEAT/FIREMON Integrated Version 1.05.04.00; FFI Ecological Monitoring Utilities 2018, Lutes et al. 2009). Red oak fuel constants (Table 1) were the most comparable for the dominant species in our study area. In 2009, fuel loads were measured both pre- and post-burn.

Table 1. Fuel constants used in loading calculations by fuel lag class: QMD (quadratic mean diameter), NHC (nonhorizontal correction factor), SG (specific gravity), and BD (Bulk density).

Factor	1-hr	10-hr	100-hr
QMD	0.28	0.1	2.82
NHC	1.13	1.13	1.13
SG	0.65	0.58	0.5
BD litter	0.9	–	–
BD duff	6.0	–	–

Precipitation

Palmer drought severity index (PDSI) data were obtained from the National Climate Data Center (https://www7.ncdc.noaa.gov/CDO/cdodivision-alselect.cmd, accessed August 15, 2018). The data are relative to the western Ozarks division of Missouri. Although this is a regionally derived metric, patterns are consistent with the precipitation record for the park through time (Vose et al. 2014).

Forest Overstory and Midstory

Tree composition in the forest was based on individual tree counts for each species and diameter at breast height (DBH) for each tree greater than 5.0 cm in the 0.1-ha site. Snags were calculated separately from live trees for overstory analysis. Basal area and stem density were calculated within size class categories (Table 2) as described in James et al. (2009). We distinguished class 1 (midstory trees) from classes 2 through 5 (overstory trees) for interpretation. In 2017, we measured a subplot (200 m^2) in three of the four sites because of the high volume of trees.

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

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

Basal area and stem density were used to calculate percent stocking using the metric stocking equation developed by Rogers (1980). This metric equation was derived from Gingrich's (1967) stocking equation for upland hardwood forests in the Central US, and allows parameter estimates to be made from data collected in the metric system. Taken together, all tree metrics were used to describe the forest composition and structure for the park focus area.

Canopy cover data were collected using a densitometer. Densitometer readings were collected in the four cardinal directions in each of the ten 10-m^2 plots and converted to canopy cover (multiplying by 1.04). Plot level mean canopy cover (n = 4 per plot) was used to calculate site-level mean canopy cover. A grand mean was then calculated for all sites (N = 4). Percent change was calculated using the following formula where CC is canopy cover:

$$\frac{2017\ CC - 2003\ CC}{2003\ CC} \times 100$$

Forest Understory

Woody regeneration and ground flora were measured within the ten 10-m^2 plots in each site. Foliar cover serves as an estimate of abundance for ground flora species. The cover class intervals are converted to median values to estimate percent cover for each herbaceous and shrub species (Table 3). Mean percent cover is then calculated as the species percent cover for a sampling unit, averaged for all plots in which the species occurs (n = 10). Sampling unit means were then used to calculate Manley Woods-level means (N =4).

Table 3. Modified Daubenmire cover value scale used to determine ground flora species cover for Heartland Network parks.

Cover Class	Cover Range (%)	Class Midpoint (%)
7	95-100	97.5
6	75-95	85.0
5	50-75	62.5
4	25-50	37.5
3	5-25	15.0
2	1-5	2.5
1	0-0.99	0.5

Tree Regeneration

Tree regeneration phase stems were tallied by species in the ten 10-m^2 subplots of each site and reported in three size classes: (1) seedlings = stems <0.5 m tall; (2) small saplings = stems ≥0.5 m tall, but <2.5 cm DBH; and (3) large saplings = stems ≥0. 5 m tall and DBH >2.5 cm and <5.0 cm. Summary was done by pooling species to look at total stems/ha and by calculating stems/ha for each individual species. In both cases, stems were summed and averaged by the number of sites (N = 4). To assess the park management goal of recruitment for oaks, stems for all oak species were summed by size class and averaged (N = 4), then converted to density. A 90% confidence interval was then calculated for the first three pre-tornado years as appropriate. This confidence interval was chosen to allow for evaluation of articulated goals.

Understory Species Diversity Indices

Diversity indices describe the number of species and their abundances (based on foliar cover measurements) and can be compared across monitoring sites in the park. Mean site cover for all non-tree species was calculated using all plots within each site (n = 10). For each site within the community, species richness (S), Shannon diversity index (H′), and evenness (J′) were calculated. S represents the number of species observed. PC-ORD (version 7.02) was used to calculate the diversity indices (IBM 2016; McCune and Mefford 2016). A grand mean was then calculated for all sites (N = 4).

Initial plant diversity for each site was calculated using the Shannon diversity index:

$$\text{Shannon Index:} \quad H' = -\sum_{i=1}^{n} p_i \ln p_i$$

where p_i is the relative cover of species i (Shannon 1948).

Species distribution evenness (J′) is calculated by site according to Pielou (1977):

$$\text{Evenness:} \quad J' = \frac{H'}{\ln(S)}$$

where H′ is the Shannon index and ln(S) is the maximum possible Shannon diversity for a given number of species if all species were present in equal numbers. Evenness is a measure of distribution of species within a community as compared to equal distribution and maximum diversity (Pielou 1969).

Understory Community Diversity Metrics

Community richness metrics evaluate how species richness differs across study sites and the park. We limited these calculations to understory herbaceous species. *Alpha* diversity is synonymous with species richness at the site scale (i.e., mean number of species per monitoring site). This is equivalent to species richness used to calculate the diversity measures described previously. *Gamma* diversity is the park richness (i.e., total number of species in the park) observed across all our monitoring sites. *Beta* diversity is a measure of variation in species richness across monitoring sites such that small values (near 0) indicate a high degree of similarity in species occurrence across monitoring sites and greater values (>5) indicate a higher degree of variation in species between sites (more differentiated communities; McCune and Grace 2002).

$$\textit{Beta Diversity} = (\textit{gamma}/\textit{alpha}) - 1$$

Understory Guild Abundance

Understory species were also summarized by guilds, aka functional groups (designations per the USDA Plants database; James et al. 2009; USDA, NRCS 2017). Guild assignments were grasses, forbs, sedges/rushes, ferns, and woody species. A complete species list along with guild assignment is provided in Appendix A. Mean cover values were calculated for each guild-site-year combination. A grand mean was then calculated across all sites (N = 4).

Ground Cover

Ground cover was assessed using cover classes (Table 3). A site mean was calculated by averaging the cover class midpoints for plots (n = 10) in each site. We observed aerial cover of grass litter, leaf litter (deciduous plant leaves), rock (exposed rock), bare ground (soil), and the cover of woody debris (e.g. branches and sticks). Total unvegetated area reflects space unoccupied by stem basal area in the plots (James et al. 2009).

Confidence levels were calculated and displayed to illustrate trends relative to established goals. The default level was the 95% confidence interval, however, occasionally goals were set to the 90% confidence level and the summary figures reflect those goals.

Results

Recent Fire History

We recorded prescribed fires in 1995, 1998, 2006, and 2009. Using the geodatabase calculation methods, we found the mean fire return interval for the monitoring sites in Manley Woods to be 6.2 (±1.0 SD) years. As of the last vegetation monitoring event in 2017, three sites burned eight years prior and site 7 had not been burned in 11 years. Fire severity varied between the most recent burns. The 2006 fire was noted to be severe based on satellite imagery (Leis and James 2008). The 2009 fire was a patchy and low severity fire (Leis 2008 unpublished report).

Fuel Load

We reported fuel loading as a function of disturbance events (post-tornado or time since fire). Fuel loads were the greatest (mean = 36 tons/acre) and most variable immediately post-tornado (Figure 4). Fuel loading was reduced by the 2006 and 2009 prescribed fires, but loading began to recover during the recent fire-free interval (2017; mean = 21 tons/acre [± 2.7 SE]).

Climate

Palmer drought severity index (PDSI) varied annually across the monitoring record, ranging from "unusually moist" to "moderate drought." Precipitation was unusually low in 2000, at the time of the 2006 fuel reduction prescribed fire, and again in 2012. Moist conditions were seen in 1994 and from 2008 to 2010 (Figure 5).

Ground Cover

Ground cover patterns in the Manley Woods unit of Wilson's Creek NB reflect the 2003 tornado and 2006 prescribed fire (Figure 6). Woody debris was consistent with fuel load data in that it was greatest in the three years following the tornado, but cover estimates were lower from 2007 to 2017. Bare ground was highest and deciduous leaf litter was lowest after the 2006 burn. Total unvegetated cover was variable through the monitoring record but peaked in 2003 and 2006 coinciding with the disturbance history.

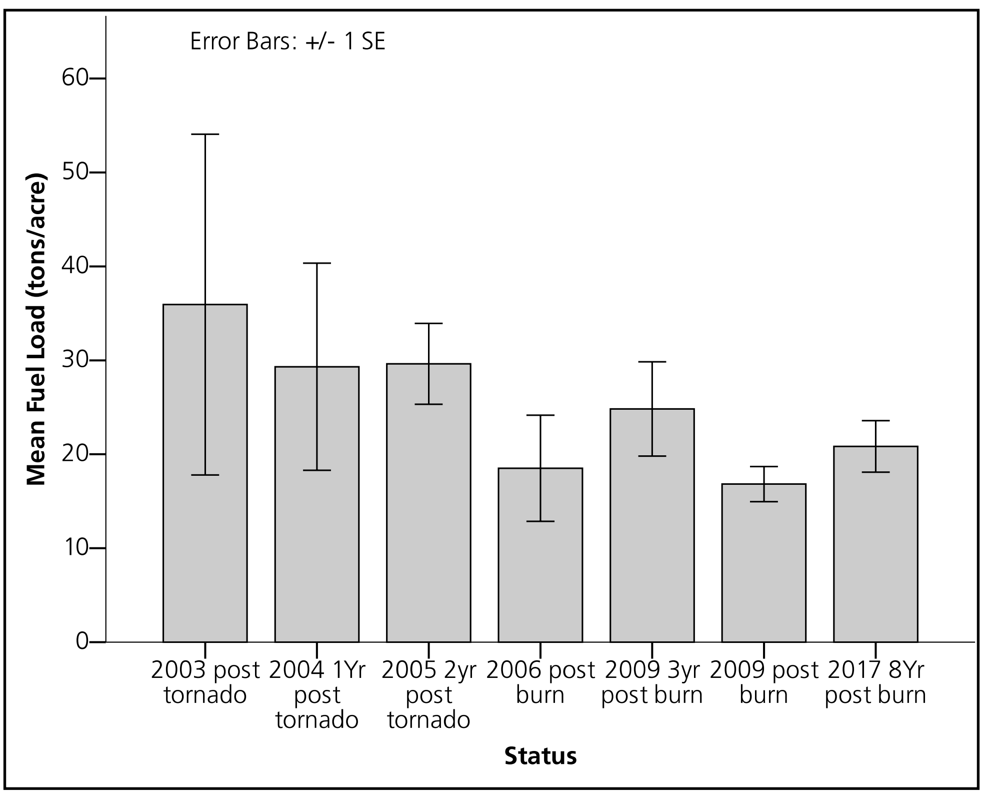

Figure 4. Fuel loading measured in monitoring sites in Manley Woods unit, Wilson's Creek National Battlefield, 2003–2017 (N = 4).

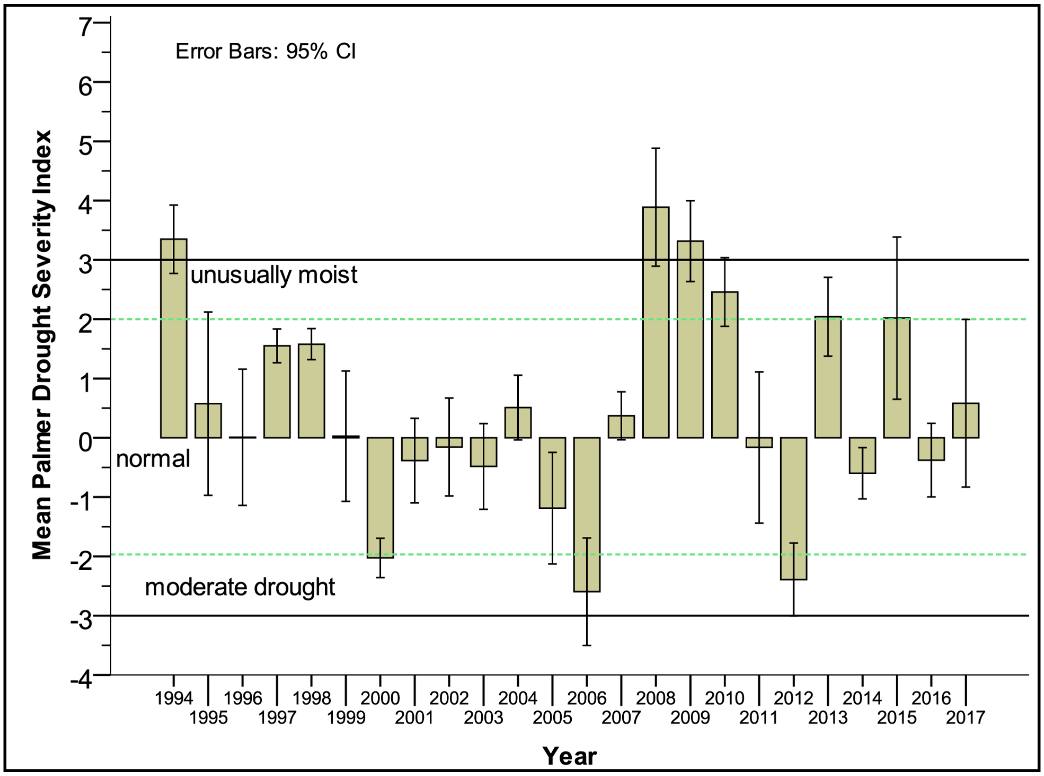

Figure 5. Palmer drought severity index for the Ozarks division of Missouri. The dashed lines represent normal range of conditions. The area between the dashed line and solid line represents moderate drought or unusually moist conditions.

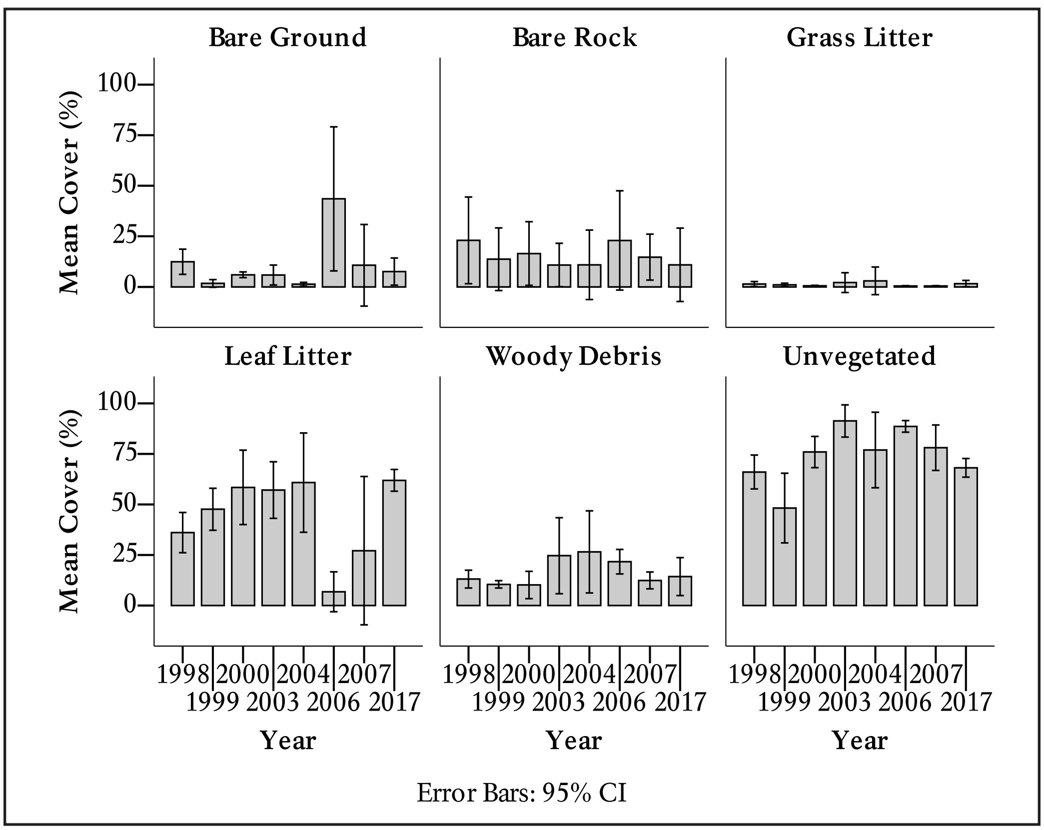

Figure 6. Elements of ground cover measured in monitoring sites in Manley Woods unit, Wilson's Creek National Battlefield, 1996–2017.

Midstory and Overstory Trees

Stand structure was assessed by calculating mean basal area (Figure 7) and density (Figure 8). Through the sampling period, there was a great deal of heterogeneity in the basal area and density of all size classes across the four monitoring sites. These two overstory metrics decreased for class 5 trees since 2003, and trees in this largest size class were not present in the 2017 sample. However, we only measured a subplot for three of the four sites that year and subsampling could have missed the rare class 5 trees. Despite only measuring a subplot in 2017, there appeared to be an increase in mean basal area of class 1 (midstory) trees. Mean density of midstory trees was also high in 2017, far surpassing the densities of all other size classes.

The species-wise analysis of overstory basal area and density shows the continued dominance of oak and hickory species in Manley Woods (Table 4 and 5). However, early successional species such as black cherry (*Prunus serotina*) and sassafras (*Sassafras albidum*) became more common in 2017. The 2017 average stem density of oaks was 57%.

Tree stocking measures the extent to which the growth potential of a site is utilized by trees. The level of stocking in a woodland is determined using both tree density and basal area (Table 6). At approximately 60% stocking, canopy closure occurs but growing space for trees is still available. A percent stocking value of 100% or greater represents an overstocked stand, where trees are utilizing all potential growing space (Gingrich 1967; Johnson et al. 2009). Percent stocking in woodlands ranges from 30–75%, with closed woodlands maintained at about 60–75% and open woodlands maintained between 30–60% (Hanberry et al. 2014; Dey et al. 2017). We determined the current stocking level to be 35.4% (± 18.7% SD), which is consistent with an open woodland community type.

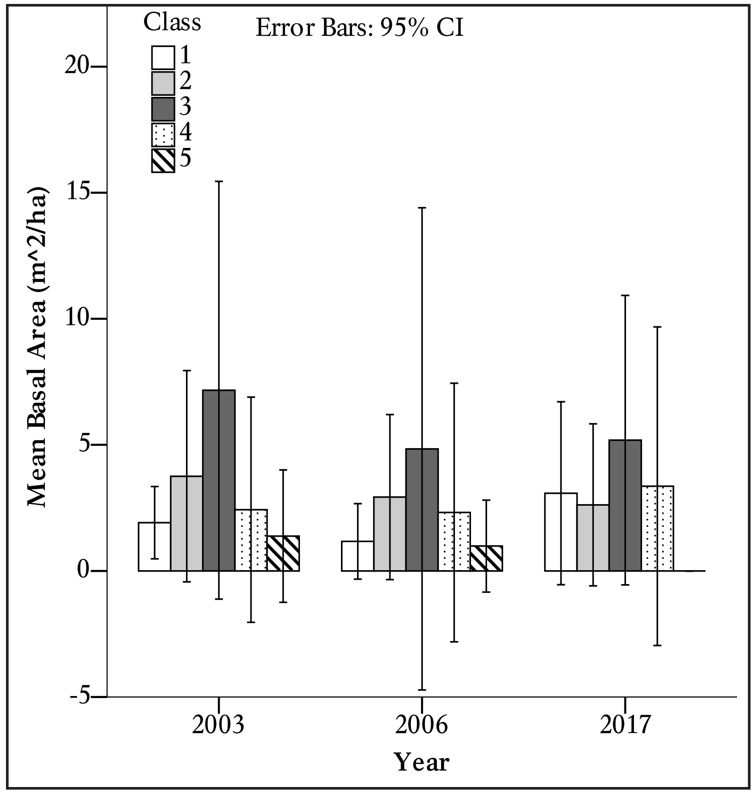

Figure 7. Mean basal area (m^2/ha) of live trees in Manley Woods unit, Wilson's Creek National Battlefield, 2003–2017 (N = 4).

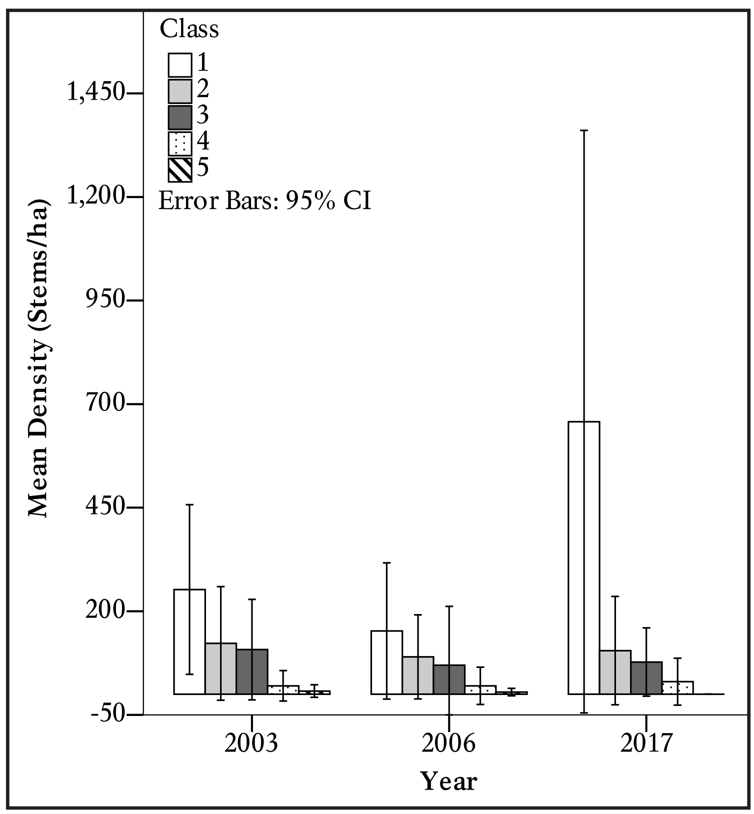

Figure 8. Mean density (stems/ha) of live trees in Manley Woods unit, Wilson's Creek National Battlefield, 2003–2017 (N = 4).

Table 4. Mid- and overstory species mean basal area (m^2/ha, n = 4), 95% confidence intervals (CI), and change between 2003 and 2017 for Manley Woods unit, Wilson's Creek National Battlefield; observations are for all size classes combined. Negative change values indicate less basal area in 2017.

		2003		2006		2017		
Species	**Common name**	**Mean**	**±CI**	**Mean**	**±CI**	**Mean**	**±CI**	**% Change (2003 - 2017)**
Carya spp.	hickory	3.28	4.82	2.32	3.40	2.07	4.03	-36.96
Celtis occidentalis	common hackberry	0.26	0.53	0.11	0.26	0.32	1.01	24.27
Fraxinus spp.	ash	0.06	0.07	0.08	0.08	0.05	0.15	-17.08
Juglans nigra	black walnut	0.86	0.78	0.31	0.99	0.36	1.14	-58.28
Morus alba	white mulberry	0.03	0.11	0	–	0.00	–	-100.00
Morus rubra	red mulberry	0.04	0.13	0.07	0.22	0.12	0.38	187.83
Prunus serotina	black cherry	0.02	0.04	0.01	0.02	0.49	0.81	**2,560.58**[b]
Quercus alba	white oak	**5.86**[a]	13.57	**5.93**[a]	14.61	**3.83**[a]	11.96	-34.68
Quercus muehlenbergii	chinquapin oak	0.15	0.32	0.16	0.34	0.22	0.49	42.95
Quercus rubra	northern red oak	0.86	1.55	0.47	0.77	1.57	4.73	84.12
Quercus stellata	post oak	2.98	6.77	1.84	2.97	3.26	9.79	9.35
Quercus velutina	black oak	1.49	1.82	0.63	2.00	1.49	1.54	0
Sassafras albidum	sassafras	0.00	–	0.00	–	0.09	0.29	–
Ulmus spp.	elm	0.76	2.00	0.32	0.96	0.38	0.74	-50.30

[a] indicates species with the most basal area (also in bold).

[b] indicates species that changed the most through time (also in bold).

Table 5. Mid- and overstory species mean density (stems/ha, n = 4), 95% confidence intervals (CI), and change between 2003 and 2017 for Manley Woods unit, Wilson's Creek National Battlefield; observations are for all size classes combined. Negative values indicate less density in 2017.

		2003		2006		2017		% Change
Species	**Common name**	**Mean**	**±CI**	**Mean**	**±CI**	**Mean**	**±CI**	**(2003 - 2017)**
Carya spp.	hickory	**175**[a]	248.4	**122.5**[a]	206.4	55	82.7	-68.6
Celtis occidentalis	common hackberry	15.0	27.6	17.5	45.7	17.5	55.7	16.7
Fraxinus spp.	ash	12.5	15.2	10.0	13.0	7.5	23.9	-40.0
Juglans nigra	black walnut	20.0	13.0	5.0	15.9	5.0	15.9	-75.0
Morus alba	white mulberry	2.5	8.0	0.0	–	0.0	–	-100.0
Morus rubra	red mulberry	2.5	8.0	5.0	15.9	2.5	8.0	0.0
Prunus serotina	black cherry	5.0	9.2	2.5	8.0	90.0	172.3	**1700.0**[b]
Quercus alba	white oak	85.0	196.4	80.0	203.3	72.5	145.5	-14.7
Quercus muehlenbergii	chinquapin oak	12.5	30.1	12.5	30.1	65.0	196.4	420.0
Quercus rubra	northern red oak	45.0	69.4	25.0	58.8	62.5	119.3	38.9
Quercus stellata	post oak	47.5	90.4	32.5	57.2	75.0	102.7	57.9
Quercus velutina	black oak	20.0	29.0	5.0	15.9	**220.0**[a]	282.8	1000.0
Sassafras albidum	sassafras	0.0	–	0.0	–	25.0	79.6	–
Ulmus spp.	elm	67.5	194.2	20.0	53.6	52.2	109	-22.2

[a] indicates species with the most basal area (also in bold).

[b] indicates species that changed the most through time (also in bold).

Table 6. Mean basal area (m^2/ha) and tree density (stems/ha) were used to determine stocking density in Manley Woods unit, Wilson's Creek National Battlefield, 2003–2017 (N =4). Confidence intervals (CI) = 95%.

Year	Mean basal area (m^2/ha)	±CI	Mean Density (stems/ha)	± CI	Stocking (%)	± CI
2003	16.6	15.7	510	39.3	42.3	39.5
2006	12.2	18.3	337.5	38.1	31.2	46.6
2017	14.2	11.3	870	23.1	35.4	29.8

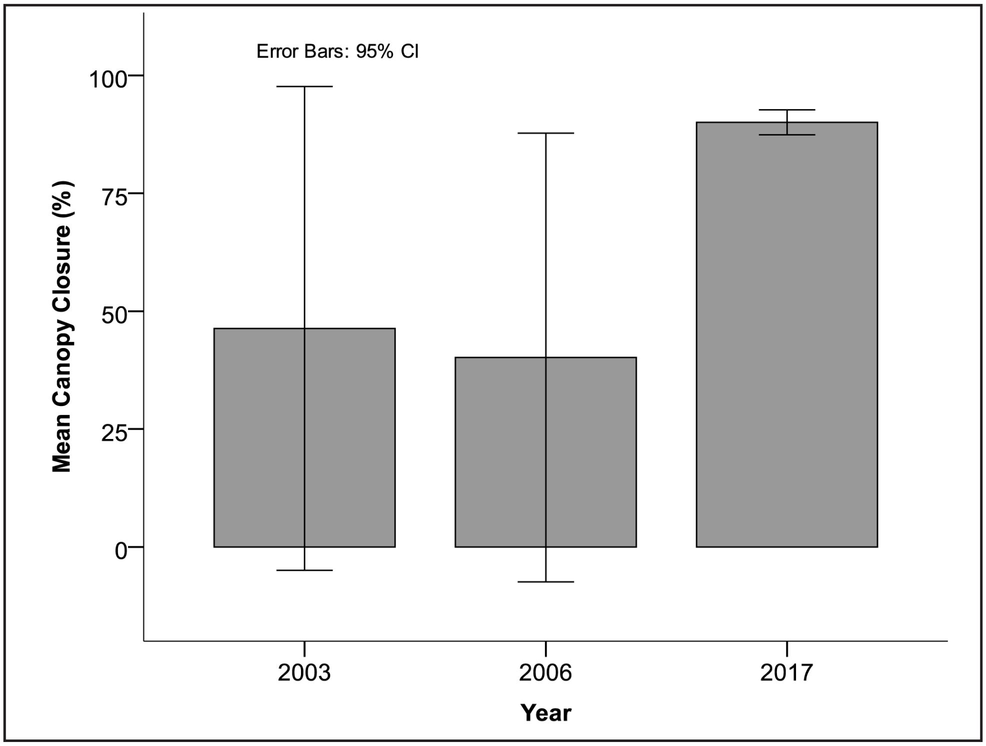

Figure 9. Canopy closure in Manley Woods unit, Wilson's Creek National Battlefield, 2003–2017 (N = 4).

Canopy closure, similar to stocking rate, can define target woodland structure (e.g., the Manley Woods target is open canopy). Mean canopy closure was relatively open and highly variable across the four monitoring sites for 2003 and 2006 (Figure 9). By contrast, the canopy was more closed and homogenous (90.1% ± 1.7 SD) in 2017. The increase in canopy closure coincided with the increase in stem density of midstory trees (class 1). Because stocking density and canopy closure define the woodland as both open and closed, we suggest that the current stand structure is at a critical tipping point.

Understory

Regeneration is a key concern for managers at Wilson's Creek NB. This includes the class 1 midstory trees described above and the understory regeneration layer. We found seedling density to be lower since 2003, but variable across the woodland (Figure 10a). The number of small saplings has fluctuated through time, but peaked in 2017. Large saplings continue to be of the lowest density, but in 2017 were nearly 11 times greater than in 2007 (Figure 10b).

The increase in large saplings in 2017 was driven by oak and hickory (Table 7). However, several early successional species like hackberry (*Celtis* sp.), black cherry, mulberry (*Morus* spp.), sassafras, and elm (*Ulmus* spp.) had increases in seedlings and small saplings. We were interested in the density of eastern redcedar (*Juniperus virginiana*) in the woodland because eastern redcedar can become invasive in the absence of fire. We found that the number of seedlings decreased, but more small saplings have established.

The park had a particular goal for oak regeneration (maintain regeneration within 10% of the 2003 level). Mean oak regeneration (seedling and saplings) was within range of the goal except for in 2006 when the goal was exceeded. However, oak regeneration was consistently less after the tornado than prior to it (Figure 11).

The proportion of regeneration (seedlings and saplings) that was oak was least in 2003, 2004, and 2017. Although oak regeneration has varied since 2003, it is currently at the lowest levels measured in Manley Woods (Figure 11).

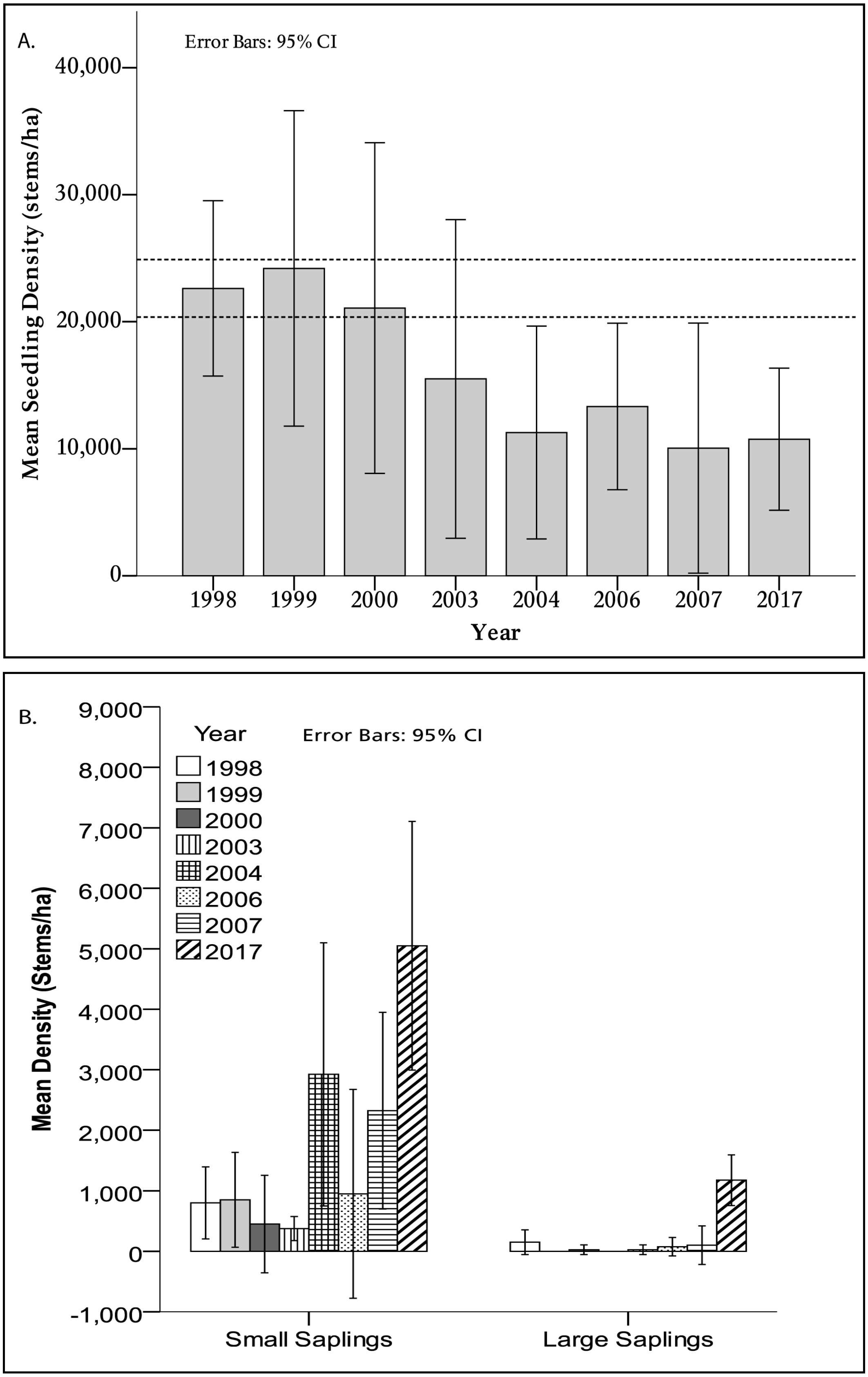

Figure 10. Regeneration in Manley Woods unit, Wilson's Creek National Battlefield, 1998–2017 (N = 4). A. Mean seedling density; dotted lines are 95% confidence interval. B. Mean small and large sapling density.

Table 7. Regeneration density by species (mean stems/ha) in Manley Woods unit, Wilson's Creek National Battlefield. Percent change indicates the difference in stems between 1998 and 2017. Negative values indicate fewer stems in 2017. Note: *Aesculus glabra* was observed in other monitoring years and is not shown here.

	Mean Seedlings			Mean small saplings			Mean large saplings			% change 1998–2017		
Species	**1998**	**2003**	**2017**	**1998**	**2003**	**2017**	**1998**	**2003**	**2017**	**seedlings**	**small saplings**	**large saplings**
Acer negundo	0	0	100	0	0	0	0	0	0	–	–	–
Aesculus glabra	0	0	0	0	0	0	0	0	0	–	–	–
Carya spp.	2500	1200	1150	100	50	725	0	0	150	-54	625	
Celtis sp.	1150	1550	1600	0	25	**1225**[a]	25	0	0	39	–	-100
Cercis canadensis	625	200	50	25	25	50	0	0	125	-92	100	–
Cornus florida	0	0	25	0	0	0	0	0	0	–	–	–
Corylus americana	0	25	0	0	0	0	0	0	0	–	–	–
Diospyros virginiana	525	150	50	25	25	125	0	0	0	-90	400	–
Fraxinus spp.	675	400	275	100	50	350	25	0	0	-59	250	-100
Gleditsia triacanthos	50	25	0	0	0	0	0	0	0	-100	–	–
Juglans nigra	75	0	25	0	0	0	0	0	0	-67	–	–
Juniperus virginiana	1550	3700	450	0	0	175	25	0	25	-71	–	0
Maclura pomifera	0	25	0	0	0	50	0	0	0	–	–	–
Morus alba	0	250	0	0	25	0	0	0	0	–	–	–
Morus rubra	200	25	450	25	0	50	0	0	25	**125**[b]	100	–
Nyssa sylvatica	0	0	25	0	0	0	0	0	0	–	–	–
Prunus spp.	0	325	0	0	50	0	0	0	0	–	–	–
Prunus serotina	2075	200	250	**250**[a]	25	400	0	0	125	-88	60	
Red oak group	5050	1800	425	200	**75**[a]	500	25	0	**175**[a]	-92	150	**600**[b]
White oak group	3575	1350	950	75	25	575	25	0	100	-73	**667**[b]	300
Sassafras albidum	550	150	50	0	0	175	0	0	125	-91	–	–
Ulmus spp.	**5725**[a]	**4625**[a]	**4525**[a]	0	0	375	25	0	25	-21	–	0

[a] indicates species with the most basal area (also in bold).

[b] indicates species that changed the most through time (also in bold).

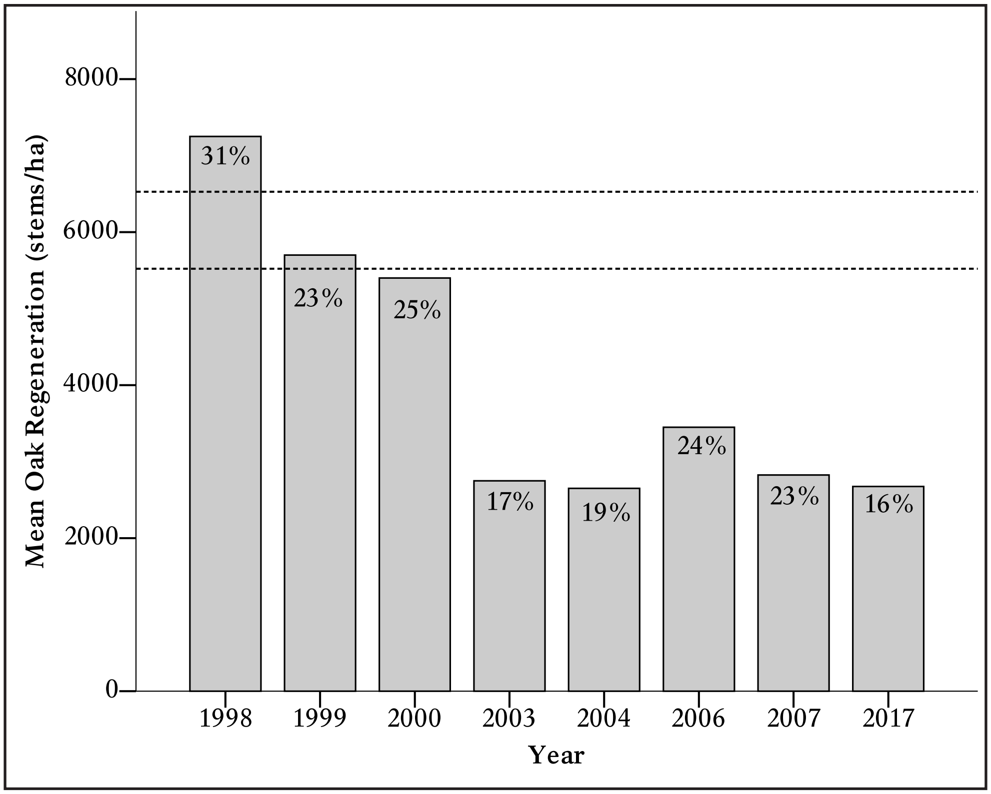

Figure 11. Oak regeneration through the monitoring period (mean number of stems/ha) in Manley Woods unit, Wilson's Creek National Battlefield. Dotted lines represent the 90% confidence interval for the pre-tornado years (1998–2000). Proportion of regeneration stems that were oaks for each year is printed at the top of each bar.

Community diversity indices for the ground flora demonstrated sensitivity to the tornado event and 2006 prescribed fire (Table 8). Alpha diversity averaged 57 species per site over the dataset and mean gamma diversity was 99 species for the four sites. Beta diversity was relatively low and varied little through time. This indicates similarity between site understory communities.

Table 8. Community diversity indices for Manley Woods unit, Wilson's Creek National Battlefield,1998–2017.

Year	Alpha	Gamma	Beta
1998	62	108	0.74
1999	60.5	102	0.69
2000	58.2	98	0.68
2003	50.2	93	0.85
2004	57	102	0.79
2006	49.8	82	0.65
2007	57.8	97	0.68
2017	66.2	110	0.66

Mean native species richness varied by 16 species through time (Figure 12). There were notable declines in 2003 and 2006 that coincided with intense disturbance events in the woods. The confidence intervals constructed for the dataset provide a sense for change in species richness through time with respect to the pre-tornado levels. Interestingly, 2017 native richness levels slightly exceed the confidence intervals for species richness.

In 2017, we recorded sedges (*Carex* spp.) and rosette grass (*Dichanthelium* spp.) species to the species level when previously they were only identified to the genus level. Although we continued to lump them for analyses, a list of the 14 species we observed are in Appendix A.

Exotic species were uncommon through the monitoring record (Figure 13). The greatest number of exotic species in a monitoring site was 10 in 2007 (site 5). The species with the greatest mean cover was common mullein (*Verbascum thapsus*; 1.05% in 2007). Prickly lettuce (*Lactuca serriola*) occurred in

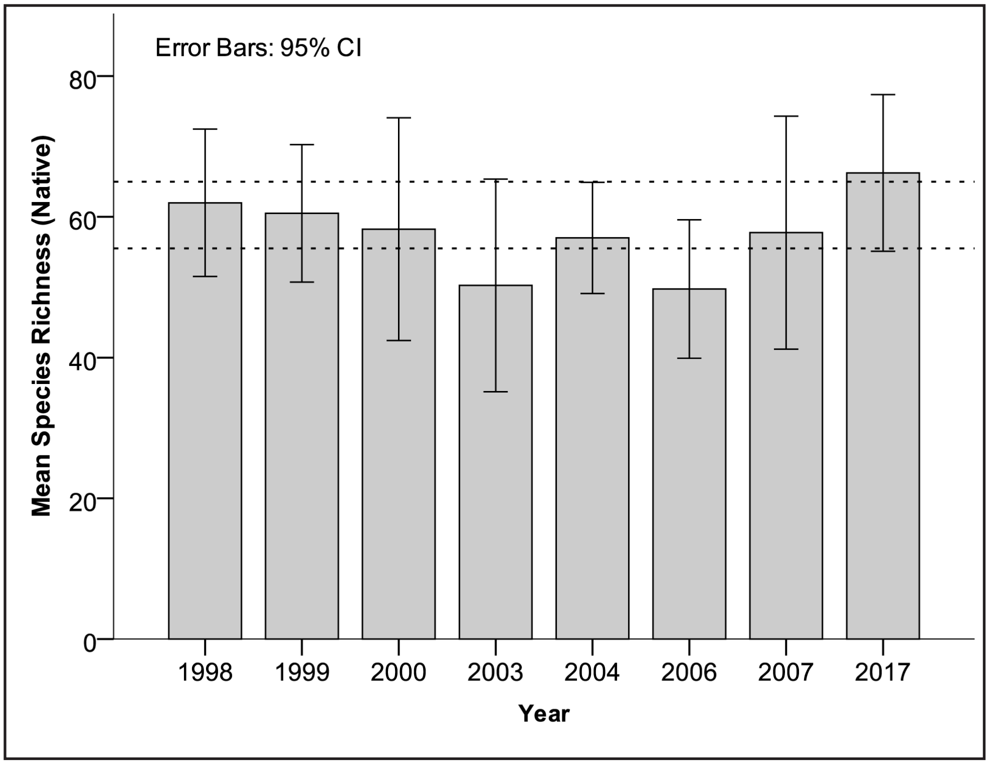

Figure 12. Mean site native species richness for Manley Woods unit, Wilson's Creek National Battlefield, 1998–2017. Dashed lines indicate a 95% confidence interval calculated from pre-tornado data.

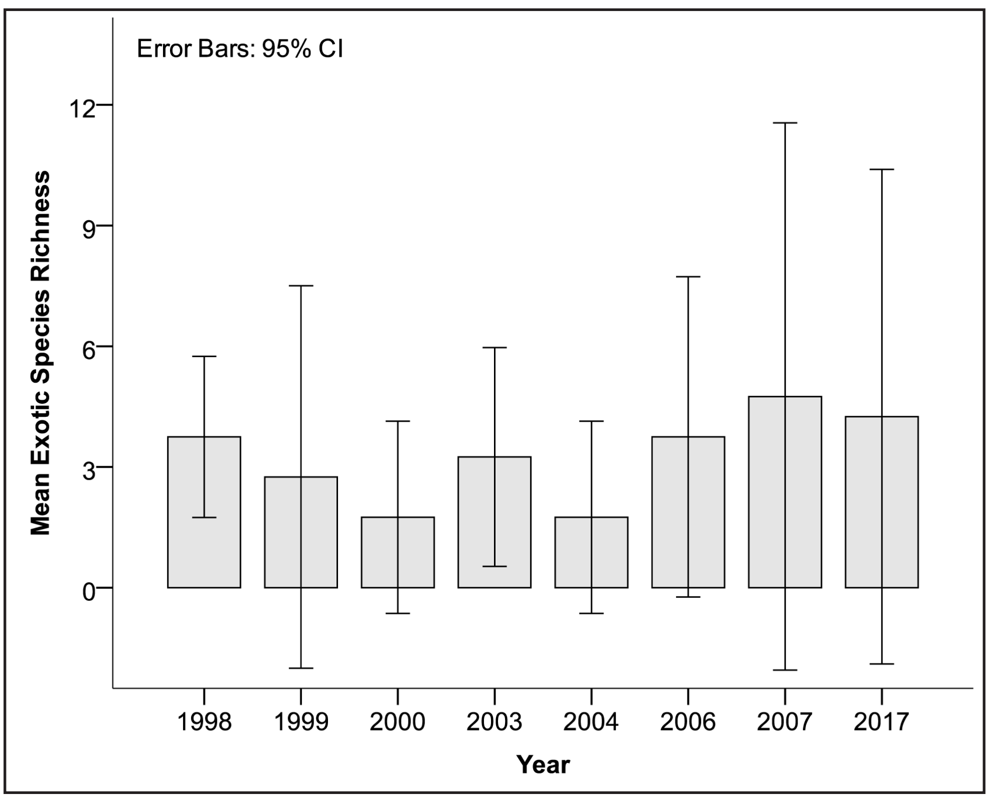

Figure 13. Mean site exotic species richness for Manley Woods unit, Wilson's Creek National Battlefield, 1998–2017.

the most years (6) of any of the exotic species, but mean cover was less than 1%. See Appendix A for 2017 abundance data.

Species diversity indices reveal that native species were quite stable in the woods through time (Figure 14). This is consistent with the community level beta diversity index patterns as well (Table 7). Shannon diversity (H′) described moderately diverse monitoring sites through time. As evenness (J′) approaches 1, species are evenly distributed.

The distribution of native plants in Manley Woods among guilds was variable through time (Figure 15). Forbs and woody plants dominated the woodland floor. Grasses were lowest in the middle of the monitoring record while grass-like plants like sedges and rushes had a sustained reduction from 2003 to the present. Woody plants were variable within and among years. Vines were only recently detected in Manley Woods.

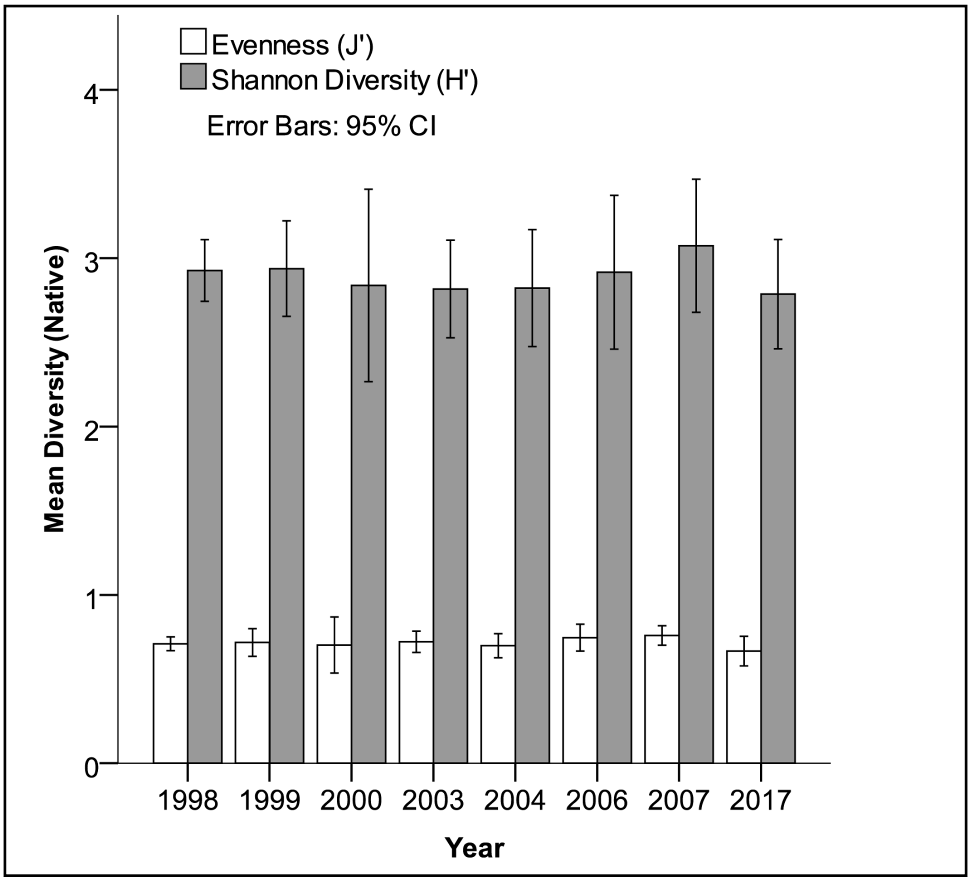

Figure 14. Species diversity indices for Manley Woods unit, Wilson's Creek National Battlefield, 1998–2017.

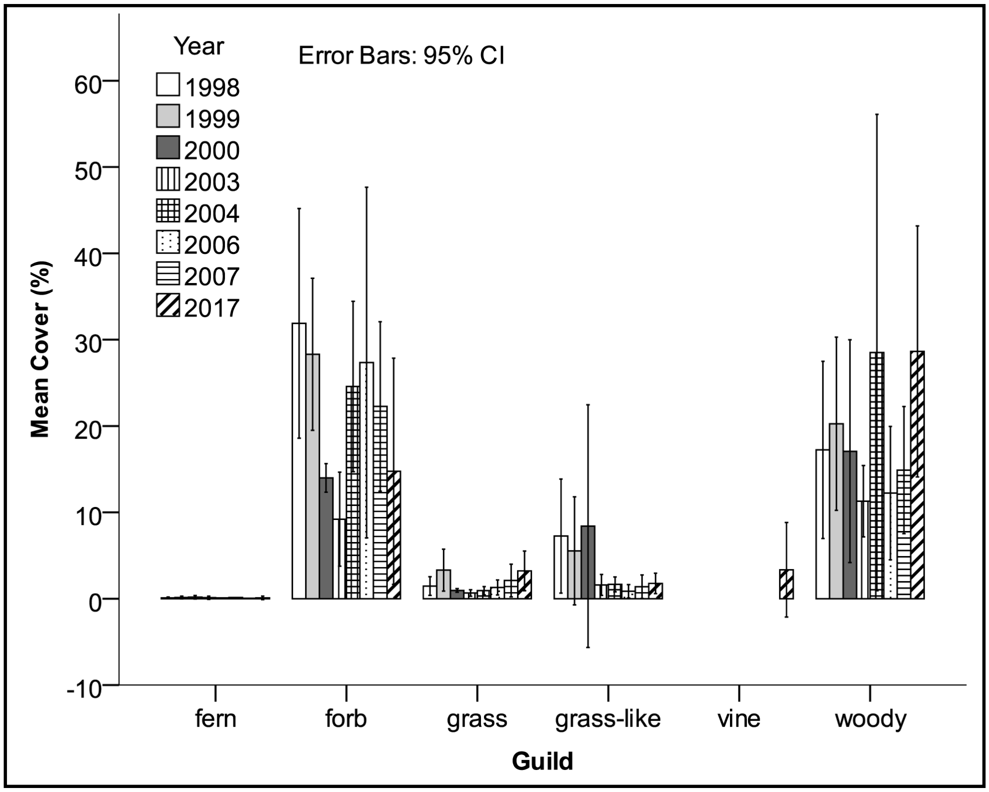

Figure 15. Distribution of native plant guilds through time at Manley Woods unit, Wilson's Creek National Battlefield, 1998–2017.

Discussion

The Manley Woods unit of Wilson's Creek NB has been subject to intense disturbance events such as a tornado, a severe fuel reduction burn, an ice storm, and periodic drought (Appendix B, Figure 5). The Heartland Inventory and Monitoring Network was fortunate to begin monitoring prior to the tornado event, allowing for pre- and post-tornado plant community investigation. Management objectives include maintaining an open woodland and characteristic composition (overstory, recruitment, and species richness).

Fuel loading remains an important concern in the woods. Fuel loads were reduced after prescribed fires, but continue to accumulate above typical levels (Stambaugh et al. 2007). However, Stambaugh et al. (2007) did not include duff measurements, which averaged 9% of total site fuel loads (ranging from 1–30%). The drought occurring in 2006 (Figure 5), which was simultaneous with the first post-tornado burn, may have contributed to the severity of the fire. Mean fuel loading in Manley Woods was 21 tons/acre in 2017 (Figure 4), as compared to a regional study where the Springfield Plain subsection of the Ozark Highlands mean fuel load averaged 4.4 tons/acre (ranging from 0.1–36.8 tons/acre) (Stambaugh et al. 2007). From 2003 to 2006, heavy fuels (1000-hr) comprised the majority of the loading (84% mean; Leis and James 2008; and this dataset). Heavy fuel loads are of particular concern during periods of drought especially at higher elevations because it presents elevated fire risk (Stambaugh et al. 2007). Although Manley Woods rises above the Wilson's Creek valley below, the peak of the hill is at an average elevation for the surrounding area.

The vegetation communities assigned to Manley Woods through time have ranged from shrubland to woodland to forest, revealing the spatial variability of the disturbances that occurred there. Historically, Gremaud (1986) estimated the woods to be savanna and glade, but at the time of his survey, the unit was a mature upland forest with glades. The 2013 vegetation map described more heterogeneity including a shrubland type (John Milner Associates 2004; Diamond et al. 2012). Specifically, the area classified as successional shrubland and woodland experienced the greatest impact from the 2003 tornado, while the area classified as upland deciduous forest was least impacted. Our results demonstrate that a great deal of overstory heterogeneity continues across the four monitoring sites with broad confidence intervals for many metrics. Canopy cover of all woody stems greater than 5 cm dbh, however, has increased in closure and become more uniform across sites. The increase in canopy closure is likely a result of the increase in midstory (class 1) trees. The expansion of this cohort of trees can reduce sunlight to the forest floor even if the larger class trees are not as dense. Midstory trees are critical for maintaining or transitioning woodland communities to desirable or undesirable conditions.

To characterize the community type for Manley Woods, we looked at stand structure metrics including canopy closure, overstory basal area, density, and stocking. The 2017 canopy cover values are nearly equal to the maximum canopy closure for closed woodland communities (87% maximum; Hanberry et al. 2014). The basal area and density data provided conflicting assignments for community type. The current basal area was relatively low and indicative of an open woodland, but tree density, especially of class 1 trees, increased to a level indicative of a closed community structure. Percent stocking best characterized Manley Woods as an open woodland because the metric integrates density with basal area. We acknowledge that the measurement of subplots for three of the four sites in 2017 could have affected the overstory metrics. Because large trees are rare in the woods, we may have missed those trees in our sample. However, many of the important trends are still valid.

Oak species are of particular interest in this community type. Blackjack oak (*Quercus marilandica*) and black oak (*Quercus velutina*) were dominant in the area in pre-settlement times (Gremaud 1986). For oaks, development and recruitment are ideal when stocking is below 60% (1/3 full light; Johnson et al. 2009; Blizzard et al. 2013; Dey et al. 2017), and stocking was well within this range in our study (35.4% stocking in 2017). However, the high canopy closure could be a limiting factor in the establishment of new oak regeneration (Figure 9). Furthermore, with tree stocking at relatively low rates, we can expect midstory and overstory density and/or basal area will continue to increase as trees take advantage of the growing space still available.

Management staff designed a recent fire-free interval to address recruitment concerns and it appears to have been successful (Arthur et al. 2012). The distribution of overstory trees among size classes has changed; there were more class 1 trees observed in 2017 than in prior monitoring events. Increased sapling recruitment in 2017 paralleled the increase in class 1 midstory trees. The recruitment of small overstory trees was also likely encouraged by the canopy gaps created by the tornado. Between 2003 and 2017, the greatest increase in overstory tree density occurred in species characterized as shade intolerant, namely black cherry and most oak species, except white oak (Marquis 1990; Johnson et al. 2009). Unfortunately, this trend in recruitment may have exceeded the amount needed to maintain an open woodland.

Seedling recruitment goals yielded variable results (Gale et al. 2004). The park's goal of recruiting 125 tree seedlings/400 m^2 was not met (2017: 55 seedlings/400 m^2, total recruitment of 109 stems/400 m^2). Managers also hoped to reduce eastern redcedar recruitment from 150 seedlings/400 m^2 in 2003 to 50 seedlings/400 m^2 in 2008. Values in 2017 indicate that this goal was met with only 26 total stems of eastern redcedar regeneration per 400 m^2. Despite not meeting general seedling recruitment goals, we found the midstory trees to be on the increase. Perhaps fewer regeneration stems are needed to sustain a woodland than predicted. The conditions that allow for recruitment to the class 1 stage may be a more important concern.

We observed seedlings of early successional species such as black cherry, sassafras, and elm increasing in Manley Woods. These species generally remain in the understory unless a gap is created allowing for rapid growth and progression to the midstory. These species can also be top-killed by fire (Uchytil 1991). Dey and Hartman (2005) found that 90% of sassafras stems survived fire, however. The tornado clearly created the needed canopy gaps for establishment and the fire-free interval contributed to recruitment into later phases. Although our monitoring does not allow us to directly test for the effects of the ecological disturbances, Arthur et al. (2012) indicate that fire affects regeneration phases differently.

Despite the severe disturbances in Manley Woods, ground flora species diversity metrics indicate stable communities with few exotic plants. Managers aimed to increase native species richness from 105 species in 2003 to 115 species in 2008 (Gale et al. 2004). Although we calculated native gamma richness in the woods as 93 species in 2003, not 105 species, richness increased to 110 species in 2017. The goal prescribed an increase of 10 species and we measured an increase of 17 species, exceeding expectations. We also observed 10 sedge and four grass species not previously captured during monitoring (Appendix A).

Conclusion

Natural resource staff at Wilson's Creek NB manage the woodlands to sustain natural plant communities and to provide a sense for the historic scene at the time of the Civil War battle. The Manley Woods unit of Wilson's Creek NB has undergone substantial change through the monitoring period (1997–2017). Manley Woods continues to have characteristic oak open woodland structure, but it is at a tipping point towards a forest community type rather than the more open target structure (i.e., savanna; Gremaud 1986). A recent long fire return interval supported recruitment of saplings and class 1 trees (5–14.9 cm DBH), but fuels and canopy closure are elevated. The woodland is heterogeneous because of topography and disturbance history. Understory species richness increased in the last monitoring period. Remarkably, we observed few exotic species in the woodland.

Continued dominance of the woodland by oak species will require fire and a more open canopy. Because the midstory trees are contributing to canopy closure, we recommend prescribed fire. Fire can be used to thin this class of trees and favor fire-tolerant oaks. Regular subsequent fires may be helpful for achieving the desired character of the woodland and preventing mesophytic species from becoming dominant.

Heartland I&M staff traversing Manley Woods at Wilson's Creek National Battlefield in July 2017. Photograph by Jacob Johnson/Heartland I&M Network, NPS.

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Appendix A. Species Occurrence

Ground Flora

Table A1. Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Acalypha monococca	Ozarkian short-stalk copperleaf	forb	N	0	–	0
Acalypha virginica	Virginia threeseed mercury	forb	N	0.138	0.04	100
Ageratina altissima	white snakeroot	forb	N	0.15	0.05	75
Agrimonia	agrimony	forb	N	0	–	0
Agrimonia pubescens	soft agrimony	forb	N	0.05	0.02	75
Agrimonia rostellata	beaked agrimony	forb	N	0.562	0.45	100
Allium canadense	meadow garlic	forb	N	0	–	0
Ambrosia artemisiifolia	annual ragweed	forb	N	0.038	0.02	50
Ambrosia trifida	great ragweed	forb	N	0	–	0
Amorpha canescens	leadplant	forb	N	0	–	0
Amphiachyris dracunculoides	prairie broomweed	forb	N	0	–	0
Amphicarpaea bracteata	American hogpeanut	forb	N	2.862	1.36	100
Andropogon gerardii	big bluestem	grass	N	0.013	0.01	25
Andropogon virginicus	broomsedge bluestem	grass	N	0.1	0.08	50
Anemone virginiana	tall thimbleweed	forb	N	0.05	0.02	75
Antennaria plantaginifolia	woman's tobacco	forb	N	0	–	0
Arabis canadensis	sicklepod	forb	N	0	–	0
Arenaria serpyllifolia	thymeleaf sandwort	forb	E	0.013	0.01	25
Aristolochia serpentaria	Virginia snakeroot	forb	N	0.063	0.02	75
Asclepias sp.	milkweed	forb	N	0	–	0
Asclepias syriaca	common milkweed	forb	N	0	–	0
Asplenium platyneuron	ebony spleenwort	fern	N	0.05	0.05	25

Table A1 (continued). Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Aster sp.	aster	forb	N	0	–	0
Bidens bipinnata	Spanish needles	forb	N	0	–	0
Boehmeria cylindrica	smallspike false nettle	forb	N	0	–	0
Botrychium virginianum	rattlesnake fern	fern	N	0.025	0.01	50
Bromus sp.	brome	grass	E	0	–	0
Bromus pubescens	hairy woodland brome	grass	N	0.6	0.36	100
Bromus racemosus	bald brome	grass	E	0	–	0
Bromus sterilis	poverty brome	grass	E	0.1	0.08	50
Campanulastrum americanum	American bellflower	forb	N	0	–	0
Cardamine concatenata	cutleaf toothwort	forb	N	0	–	0
Carduus nutans	nodding plumeless thistle	forb	E	0	–	0
Carex sp.	sedge	grass-like	N	1.763	0.37	100
Ceanothus americanus	New Jersey tea	woody	N	0	–	0
Celastrus scandens	American bittersweet	woody	N	0.1	0.04	75
Cerastium nutans	nodding chickweed	forb	N	0.013	0.01	25
Cerastium pumilum	European chickweed	forb	E	0	–	0
Chamaecrista fasciculata	partridge pea	forb	N	0.013	0.01	25
Circaea lutetiana ssp. *canadensis*	broadleaf enchanter's nightshade	forb	N	0.025	0.03	25
Cirsium sp.	thistle	forb	E	0	–	0
Cirsium altissimum	tall thistle	forb	N	0.075	0.04	50
Cirsium vulgare	bull thistle	forb	E	0	–	0
Claytonia virginica	Virginia springbeauty	forb	N	0	–	0
Convolvulus arvensis	field bindweed	forb	E	0	–	0
Conyza canadensis	Canadian horseweed	forb	N	0.038	0.02	50
Crataegus sp.	hawthorn	woody	N	0	–	0
Croton glandulosus	vente conmigo	forb	N	0	–	0

Table A1 (continued). Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Cyperus sp.	flatsedge	grass-like	N	0	–	0
Danthonia spicata	poverty oatgrass	grass	N	0.075	0.04	75
Daucus carota	Queen Anne's lace	forb	E	0	–	0
Desmodium sp.	ticktrefoil	forb	N	0.013	0.01	25
Desmodium cuspidatum	largebract ticktrefoil	forb	N	0.1	0.08	50
Desmodium glabellum	Dillenius' ticktrefoil	forb	N	1.275	0.99	100
Desmodium glutinosum	pointedleaf ticktrefoil	forb	N	3.525	2.81	100
Desmodium nudiflorum	nakedflower ticktrefoil	forb	N	0	–	0
Desmodium nuttallii	Nuttall's ticktrefoil	forb	N	0	–	0
Desmodium obtusum	stiff ticktrefoil	forb	N	0	–	0
Desmodium paniculatum	panicledleaf ticktrefoil	forb	N	0.325	0.09	100
Desmodium pauciflorum	fewflower ticktrefoil	forb	N	0	–	0
Desmodium perplexum	perplexed ticktrefoil	forb	N	1.425	1.07	75
Desmodium rotundifolium	prostrate ticktrefoil	forb	N	0.238	0.13	75
Dianthus armeria	Deptford pink	forb	E	0	–	0
Dichanthelium sp.	rosette grass	grass	N	0.3	0.14	75
Dioscorea quaternata	fourleaf yam	forb	N	0.013	0.01	25
Dioscorea villosa	wild yam	forb	N	0	–	0
Diospyros virginiana	common persimmon	woody	N	0	–	0
Elephantopus carolinianus	Carolina elephantsfoot	forb	N	0.1	0.04	75
Elymus macgregorii	wildrye	grass	N	0.575	0.35	100
Elymus villosus	hairy wildrye	grass	N	0	–	0
Elymus virginicus	Virginia wildrye	grass	N	0.2	0.17	75
Enemion biternatum	False rue anemone	forb	N	0	–	0
Erechtites hieraciifolia	American burnweed	forb	N	0.013	0.01	25
Erigeron sp.	fleabane	forb	N	0	–	0

Table A1 (continued). Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Erigeron strigosus	prairie fleabane	forb	N	0	–	0
Euonymus alatus	burning bush	woody	E	0.013	0.01	25
Euonymus fortunei	winter creeper	woody	E	0.05	0.04	50
Euphorbia corollata	flowering spurge	forb	N	0.013	0.01	25
Euphorbia dentata	toothed spurge	forb	N	0.025	0.01	50
Festuca paradoxa	clustered fescue	grass	N	0.075	0.08	25
Festuca subverticillata	nodding fescue	grass	N	0.425	0.15	100
Fleischmannia incarnata	pink thoroughwort	forb	N	0.1	0.07	50
Fragaria virginiana	Virginia strawberry	forb	N	0	–	0
Galactia volubilis	downy milkpea	forb	N	0	–	0
Galium aparine	stickywilly	forb	N	0.025	0.01	50
Galium arkansanum	Arkansas bedstraw	forb	N	0	–	0
Galium circaezans	licorice bedstraw	forb	N	0.138	0.06	100
Galium concinnum	shining bedstraw	forb	N	0.025	0.01	50
Galium obtusum	bluntleaf bedstraw	forb	N	0	–	0
Galium pilosum	hairy bedstraw	forb	N	0	–	0
Galium trifidum	threepetal bedstraw	forb	N	0.087	0.09	25
Galium triflorum	fragrant bedstraw	forb	N	0	–	0
Gamochaeta purpurea	spoonleaf purple everlasting	forb	N	0	–	0
Geranium carolinianum	Carolina geranium	forb	N	0	–	0
Geranium maculatum	spotted geranium	forb	N	0	–	0
Geum canadense	white avens	forb	N	0.113	0.02	100
Geum vernum	spring avens	forb	N	0.025	0.03	25
Hackelia virginiana	beggarslice	forb	N	0.038	0.01	75
Helianthus hirsutus	hairy sunflower	forb	N	0.225	0.16	100
Heuchera americana	American alumroot	forb	N	0	–	0

Table A1 (continued). Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Heuchera richardsonii	Richardson's alumroot	forb	N	0	–	0
Hieracium gronovii	queendevil	forb	N	0.013	0.01	25
Houstonia purpurea	Venus' pride	forb	N	0.025	0.03	25
Hypericum sp.	St. Johnswort	forb	N	0	–	0
Juncus sp.	rush	grass-like	N	0	–	0
Juncus tenuis	poverty rush	grass-like	N	0.013	0.01	25
Krigia biflora	twoflower dwarfdandelion	forb	N	0	–	0
Kummerowia stipulacea	Korean clover	forb	E	0	–	0
Lactuca sp.	lettuce	forb	N	0	–	0
Lactuca canadensis	Canada lettuce	forb	N	0.075	0.05	50
Lactuca floridana	woodland lettuce	forb	N	0.162	0.03	100
Lactuca serriola	prickly lettuce	forb	E	0.013	0.01	25
Lamium purpureum	purple deadnettle	forb	E	0	–	0
Leersia virginica	whitegrass	grass	N	0.088	0.07	50
Lespedeza procumbens	trailing lespedeza	forb	N	0.188	0.08	75
Lespedeza repens	creeping lespedeza	forb	N	0	–	0
Lespedeza violacea	violet lespedeza	forb	N	0.025	0.03	25
Lespedeza virginica	slender lespedeza	forb	N	0.013	0.01	25
Leucanthemum vulgare	oxeye daisy	forb	E	0	–	0
Lindera benzoin	northern spicebush	woody	N	0.038	0.04	25
Lobelia inflata	Indian-tobacco	forb	N	0.013	0.01	25
Lonicera japonica	Japanese honeysuckle	woody	E	0.088	0.04	75
Lonicera maackii	Amur honeysuckle	woody	E	0.013	0.01	25
Menispermum canadense	common moonseed	woody	N	0	–	0
Monarda russeliana	redpurple beebalm	forb	N	0	–	0
Muhlenbergia	muhly	grass	N	0	–	0

Table A1 (continued). Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Muhlenbergia schreberi	nimblewill	grass	N	0.487	0.36	75
Oxalis sp.	woodsorrel	forb	N	0.013	0.01	25
Oxalis dillenii	slender yellow woodsorrel	forb	N	0.05	0.03	50
Oxalis violacea	violet woodsorrel	forb	N	0	–	0
Parietaria pensylvanica	Pennsylvania pellitory	forb	N	0	–	0
Parthenocissus quinquefolia	Virginia creeper	woody	N	2.037	0.65	100
Passiflora lutea	yellow passionflower	forb	N	0.025	0.01	50
Perilla frutescens	beefsteakplant	forb	E	0	–	0
Phryma leptostachya	American lopseed	forb	N	0.087	0.06	75
Physalis angulata	cutleaf groundcherry	forb	N	0.013	0.01	25
Physalis heterophylla	clammy groundcherry	forb	N	0	–	0
Physalis virginiana	Virginia groundcherry	forb	N	0.05	0.02	75
Phytolacca americana	American pokeweed	forb	N	0	–	0
Pilea pumila	Canadian clearweed	forb	N	0.038	0.04	25
Poa compressa	Canada bluegrass	grass	E	0.025	0.01	50
Poa pratensis	Kentucky bluegrass	grass	E	0	–	0
Poa sylvestris	woodland bluegrass	grass	N	0.088	0.07	50
Poa wolfii	Wolf's bluegrass	grass	N	0	–	0
Podophyllum peltatum	mayapple	forb	N	0.1	0.10	25
Polygonatum biflorum	smooth Solomon's seal	forb	N	0.013	0.01	25
Polygonum	knotweed	forb	N	0	–	0
Polygonum scandens	climbing false buckwheat	forb	N	0	–	0
Polygonum virginianum	jumpseed	forb	N	0	–	0
Potentilla simplex	common cinquefoil	forb	N	0	–	0
Prenanthes altissima	tall rattlesnakeroot	forb	N	0	–	0
Prenanthes aspera	rough rattlesnakeroot	forb	N	0	–	0

Table A1 (continued). Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Prunus americana	American plum	woody	N	0.025	0.01	50
Prunus virginiana	chokecherry	woody	N	0	–	0
Pseudognaphalium obtusifolium ssp. *obtusifolium*	Fragrant cudweed	forb	N	0.025	0.01	50
Ranunculus abortivus	littleleaf buttercup	forb	N	0	–	0
Ranunculus hispidus	bristly buttercup	forb	N	0.013	0.01	25
Ranunculus micranthus	rock buttercup	forb	N	0	–	0
Ranunculus recurvatus	blisterwort	forb	N	0.013	0.01	25
Rhamnus lanceolata	lanceleaf buckthorn	woody	N	0.013	0.01	25
Rhus aromatica	fragrant sumac	woody	N	4.938	0.99	100
Rhus copallinum	winged sumac	woody	N	5.312	3.55	75
Rhus glabra	smooth sumac	woody	N	0.5	0.34	100
Ribes missouriense	Missouri gooseberry	woody	N	1.4	1.04	100
Rosa carolina	Carolina rose	woody	N	0.05	0.02	75
Rosa multiflora	multiflora rose	woody	E	0.075	0.08	25
Rosa setigera	climbing rose	woody	N	0.013	0.01	25
Rubus sp.	blackberry	woody	N	0.113	0.07	75
Rubus occidentalis	black raspberry	woody	N	3	1.77	100
Rubus pensilvanicus	Pennsylvania blackberry	woody	N	0	–	0
Rudbeckia triloba	browneyed Susan	forb	N	0.112	0.05	75
Ruellia humilis	fringeleaf wild petunia	forb	N	0	–	0
Ruellia strepens	limestone wild petunia	forb	N	0.063	0.03	75
Sanicula sp.	sanicle	forb	N	0	–	0
Sanicula canadensis	Canadian blacksnakeroot	forb	N	0.1	0.03	100
Sanicula odorata	clustered blacksnakeroot	forb	N	0.05	0.04	50
Scrophularia marilandica	carpenter's square	forb	N	0	–	0

Table A1 (continued). Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Scutellaria parvula	small skullcap	forb	N	0	–	0
Setaria faberi	Japanese bristlegrass	grass	E	0	–	0
Setaria viridis	green bristlegrass	grass	E	0	–	0
Sherardia arvensis	blue fieldmadder	forb	E	0	–	0
Sideroxylon lanuginosum ssp. *albicans*	gum bully	woody	N	0.612	0.34	100
Sisyrinchium angustifolium	narrowleaf blue-eyed grass	forb	N	0.025	0.03	25
Smilax sp.	greenbrier	woody	N	0.013	0.01	25
Smilax tamnoides	bristly greenbrier	woody	N	0.213	0.10	100
Solanum carolinense	Carolina horsenettle	forb	N	0.038	0.02	50
Solidago sp.	goldenrod	forb	N	0	–	0
Solidago altissima	Canada goldenrod	forb	N	0.013	0.01	25
Solidago buckleyi	Buckley's goldenrod	forb	N	0	–	0
Solidago caesia	wreath goldenrod	forb	N	0	–	0
Solidago hispida var. hispida	hairy goldenrod	forb	N	0	–	0
Solidago petiolaris	downy ragged goldenrod	forb	N	0.025	0.03	25
Solidago ulmifolia	elmleaf goldenrod	forb	N	0.575	0.34	75
Sphenopholis obtusata	prairie wedgescale	grass	N	0.013	0.01	25
Stellaria media	common chickweed	forb	E	0	–	0
Stenaria nigricans var. *nigricans*	Madder	forb	N	0	–	0
Symphoricarpos orbiculatus	coralberry	woody	N	9.238	1.63	100
Symphyotrichum patens var. *patens*	Clasping wild aster	forb	N	0.013	0.01	25
Symphyotrichum turbinellum	Prairie wild aster	forb	N	0.013	0.01	25
Taenidia integerrima	yellow pimpernel	forb	N	0	–	0
Taraxacum officinale	common dandelion	forb	E	0	–	0
Teucrium canadense	Canada germander	forb	N	0	–	0
Thalictrum dasycarpum	purple meadow-rue	forb	N	0	–	0

Table A1 (continued). Ground flora species (excluding regeneration) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Species with 0 values were observed during monitoring events other than 2017. SE = standard error. Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean Cover 2017 (%)	SE 2017	Occurrence 2017 (%)
Thalictrum thalictroides	rue anemone	forb	N	0.038	0.01	75
Thaspium barbinode	hairyjoint meadowparsnip	forb	N	0	–	0
Torilis japonica	erect hedgeparsley	forb	E	0.1	0.06	50
Toxicodendron radicans	eastern poison ivy	woody	N	0	–	0
Tradescantia bracteata	longbract spiderwort	forb	N	0	–	0
Tradescantia ohiensis	bluejacket	forb	N	0	–	0
Tradescantia tharpii	Tharp's spiderwort	forb	N	0	–	0
Tragia betonicifolia	betonyleaf noseburn	forb	N	0	–	0
Tridens flavus	purpletop tridens	grass	N	0.063	0.02	75
Trifolium campestre	field clover	forb	E	0	–	0
Trillium sessile	toadshade	forb	N	0	–	0
Triodanis perfoliata	clasping Venus' looking-glass	forb	N	0	–	0
Triosteum perfoliatum	feverwort	forb	N	0	–	0
Valerianella radiata	beaked cornsalad	forb	N	0	–	0
Verbascum thapsus	common mullein	forb	E	0	–	0
Verbena urticifolia	white vervain	forb	N	0	–	0
Verbesina alternifolia	wingstem	forb	N	0.238	0.08	75
Vernonia baldwinii	Baldwin's ironweed	forb	N	0.25	0.12	100
Veronica arvensis	corn speedwell	forb	E	0.013	0.01	25
Viburnum prunifolium	blackhaw	woody	N	0	–	0
Viburnum rufidulum	rusty blackhaw	woody	N	0.237	0.15	100
Viola sp.	violet	forb	N	0.038	0.02	50
Viola triloba	three-lobed violet	forb	N	0.075	0.03	75
Vitis aestivalis	summer grape	woody	N	0.1	0.07	75
Vitis vulpina	frost grape	vine	N	3.35	1.72	100
Woodsia obtusa	bluntlobe cliff fern	fern	N	0	–	0

Table A2. Additional species of ground flora (14) observed in 2017 that were lumped into genera for analysis for Manley Woods unit, Wilson's Creek National Battlefield.

Species	Common Name	Guild	Occurrence 2017 (%)
Carex albicans	whitetinge sedge	grass-like	75
Carex blanda	eastern woodland sedge	grass-like	50
Carex cephalophora	oval-leaf sedge	grass-like	50
Carex festucacea	fescue sedge	grass-like	25
Carex hirsutella	fuzzy wuzzy sedge	grass-like	25
Carex jamesii	James' sedge	grass-like	25
Carex muehlenbergii	Muhlenberg's sedge	grass-like	100
Carex oligocarpa	richwoods sedge	grass-like	50
Carex retroflexa	reflexed sedge	grass-like	100
Carex umbellata	parasol sedge	grass-like	75
Dichanthelium acuminatum	western panicgrass	grass-like	75
Dichanthelium laxiflorum	openflower rosette grass	grass	50
Dichanthelium linearifolium	slimleaf panicgrass	grass	25
Dichanthelium malacophyllum	softleaf rosette grass	grass	75

Overstory Trees

Table A3. Overstory tree species (regeneration not included) for Manley Woods unit, Wilson's Creek National Battlefield. Species abundance and occurrence data from most recent monitoring event (2017). Origin codes: N = native, E = exotic.

Species	Common Name	Guild	Origin	Mean BA (2017)	CI (95%)	2017 Occurrence (%)
Carya sp.	hickory	woody	N	0.00	–	0
Carya alba	mockernut hickory	woody	N	0.00	–	0
Carya cordiformis	bitternut hickory	woody	N	0.61	1.16	50
Carya texana	black hickory	woody	N	0.33	0.81	50
Carya tomentosa	mockernut hickory	woody	N	1.13	3.43	50
Celtis occidentalis	common hackberry	woody	N	0.32	1.01	25
Fraxinus americana	white ash	woody	N	0.00	–	0
Fraxinus pennsylvanica	green ash	woody	N	0.05	0.15	25
Juglans nigra	black walnut	woody	N	0.36	1.14	25
Morus alba	white mulberry	woody	E	0.00	–	0
Morus rubra	red mulberry	woody	N	0.12	0.38	25
Prunus serotina	black cherry	woody	N	0.31	0.11	100
Quercus alba	white oak	woody	N	3.83	11.96	50
Quercus muehlenbergii	chinquapin oak	woody	N	0.22	0.49	50
Quercus rubra	northern red oak	woody	N	1.57	4.73	50
Quercus stellata	post oak	woody	N	3.26	9.79	75
Quercus velutina	black oak	woody	N	1.49	1.54	100
Sassafras albidum	sassafras	woody	N	0.09	0.29	25
Ulmus americana	American elm	woody	N	0.25	0.79	25
Ulmus rubra	slippery elm	woody	N	0.13	0.36	50

Appendix B. Management and Sampling History

Table B1. Sampling and management history for the Manley Woods unit, Wilson's Creek National Battlefield. Years not listed had no activity. X = sampling occurred.

		Year																							
Element	**Site**	**1992**	**1993**	**1995**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Understory	4	–	–	–	–	–	–	–	–	–	X	X	–	X	X	–	–	–	–	–	–	–	–	–	X
Regeneration	4	–	–	–	–	–	–	–	–	–		X	–	X	X	–	–	–	–	–	–	–	–	–	X
Overstory	4	–	–	–	–	–	–	–	–	–	X	–	–	X	–	–	–	–	–	–	–	–	–	–	X
fuels-pre	4	–	–	–	–	–	–	–	–	–	X	X	X	–	–	–	X	–	–	X	–	–	–	–	X
Fuels-post	4	–	–	–	–	–	–	–	–	–	–	–	–	X	–	–	X	–	–	–	–	–	–	–	–
fire history	4	–	–	–	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
understory	5	–	–	–	–	–	–	–	–	–	X	X	–	X	X	–	–	–	–	–	–	–	–	–	X
Regeneration	5	–	–	–	–	–	–	–	–	–	–	X	–	X	X	–	–	–	–	–	–	–	–	–	X
Overstory	5	–	–	–	–	–	–	–	–	–	X	–	–	X	–	–	–	–	–	–	–	–	–	–	X
fuels-pre	5	–	–	–	–	–	–	–	–	–	X	X	X	–	–	–	–	–	–	–	–	–	–	–	X
fuels-post	5	–	–	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–
fire history	5	–	–	–	X	X	X	X	X	X	X	X	X	X	X	X	–	X	X	X	X	X	X	X	X
Understory	6	–	–	–	X	X	X	X	–	–	X	X	–	X	X	–	–	–	–	–	–	–	–	–	X
Regeneration	6	–	–	–	–	–	–	–	–	–	X	X	–	X	X	–	–	–	–	–	–	–	–	–	X
Overstory	6	–	–	–	–	–	–	–	–	–	X	–	–	X	–	–	–	–	–	–	–	–	–	–	X
fuels-pre	6	–	–	–	–	–	–	–	–	–	X	X	X	–	–	–	X	–	–	X	–	–	–	–	X
fuels-post	6	–	–	–	–	–	–	–	–	–	–	–	–	X	–	–	X	–	–	–	–	–	–	–	–
fire history	6	–	–	–	–	–	–	–	–	–	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Understory	7	–	–	–	–	–	–	–	–	–	X	X	–	X	X	–	–	–	–	X	–	–	–	–	X
Regeneration	7	–	–	–	–	–	–	–	–	–	X	X	–	X	X	–	–	–	–	X	–	–	–	–	X
Overstory	7	–	–	–	–	–	–	–	–	–	X	–	–	X	–	–	–	–	–	X	–	–	–	–	X
fuels-pre	7	–	–	–	–	–	–	–	–	–	X	X	X	–	–	–	X	–	–	X	–	–	–	–	X
fuels-post	7	–	–	–	–	–	–	–	–	–	–	–	–	X	–	–	X	–	–	–	–	–	–	–	–
fire history	7	–	–	–	X	X	X	X	X	X	X	X	X	X	X	X	partial	X	X	X	X	X	X	X	X

Table B2. Manley Woods fire and disturbance history (1992-2017). X = fire occurred, T = tornado, L = logging, I = ice storm, D = drought. Years not listed had no activity.

		Year																							
Element	**Site**	**1992**	**1993**	**1995**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Fire Occurrence	4	–	–	X	–	X	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	–	–	–
Other Disturbance	4	–	–	–	–	–	–	–	–	–	T	–	L	–	I	–	–	–	–	D	D	D	–	–	D
Fire Occurrence	5	X	X	X	–	X	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	–	–	–
Other Disturbance	5	–	–	–	–	–	–	–	–	–	T	–	L	–	I	–	–	–	–	D	D	D	–	–	D
Fire Occurrence	6	X	X	X	–	X	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	–	–	–
Other Disturbance	6	–	–	–	–	–	–	–	–	–	T	–	–	–	I	–	–	–	–	D	D	D	–	–	D
Fire Occurrence	7	X	X	X	–	X	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–	–	–	–
Other Disturbance	7	–	–	–	–	–	–	–	–	–	–	–	–	–	I	–	–	–	–	D	D	D	–	–	D

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