National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Forest Health Monitoring at Pictured Rocks National Lakeshore

2017 Field Season

Natural Resource Data Series NPS/GLKN/NRDS—2019/1242

ON THE COVER

Clockwise from top left: Herbaceous quadrat at rich site (NPS); collecting diameter at breast height of a beech tree (NPS); transect line (NPS); collecting herbaceous data in a rich ravine (NPS).

Forest Health Monitoring at Voyageurs National Lakeshore

2017 Field Season

Natural Resource Data Series NPS/GLKN/NRDS—2019/1242

Suzanne Sanders and Jessica Kirschbaum

National Park Service
Great Lakes Inventory and Monitoring Network
2800 Lakeshore Dr. East
Ashland, Wisconsin 54806

November 2019

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available in digital format from the Great Lakes Inventory and Monitoring Network and the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Sanders, S., and J. Kirschbaum. 2019. Forest health monitoring at Pictured Rocks National Lakeshore: 2017 field season. Natural Resource Data Series NPS/GLKN/NRDS—2019/1242. National Park Service, Fort Collins, Colorado.

NPS 625/165452, November 2019

Contents

Contents (continued)

Page

Figures

Figures (continued)

Page

Tables

Page

Executive Summary

We initiated a comprehensive forest monitoring program at Pictured Rocks National Lakeshore in 2009 with the establishment of 59 permanent plots; we resampled these plots in 2017. Sampled and derived metrics included trees (density and basal area of live trees, seedlings, and snags), understory (frequency), browse (bite marks on woody species and presence and height of herbaceous species), species richness, and earthworm impacts. Our 59 permanent plots are divided between two management zones—43 plots are in the core zone where active management is minimal, while 16 are located in the inland buffer zone (IBZ). The IBZ is composed largely of private as well as state-owned land, and active timber harvesting occurs in this zone.

In 2009, we classified sites into one of four broad forest types: Sugar Maple-Beech, Hemlock-Beech-Mixed Hardwood, Balsam Fir-Mixed Conifer, and Pine. Overall tree density in the core zone changed little within each of the forest types between the two sampling periods. However, in Hemlock-Beech-Mixed Hardwood forest in the core, *Fagus grandifolia* (American beech) density increased 32%, to 250 trees/ha between the sampling periods while at Sugar Maple-Beech sites in the core, *F. grandifolia* density increased 67% to 86 trees/ha. Like density, overall basal area changed little between the sampling periods. However, in Hemlock-Beech-Mixed Hardwood forests, basal area of *Fagus grandifolia* dropped 39% from 4.55 ± 0.05 m^2/ha to 2.78 ± 0.06 m^2/ha. In Sugar Maple-Beech forests, this dropped 57% from 2.13 ± 0.89 m^2/ha to 0.91 ± 0.35 m^2/ha.

White-tailed deer browse was generally limited. We recorded bite makes directly visible on woody species within each of 30 browse circles per plot. This occurred in greater than 25% of circles for only three species: *Taxus canadensis* (Canada yew, 50%), *Acer spicatum* (mountain maple, 38%), and *Sambucus racemosa* var. *racemosa* (red elderberry, 28%). Browse on herbaceous species was assessed indirectly, by counting the frequency of presence in 30 quadrats per plot, for 14 preferred browse understory species. Collectively, the summed frequency of presence for all 14 species was similar within forest types between the two sampling periods. We also selected two preferred herbaceous taxa, *Aralia nudicaulis* (sarsaparilla) and *Streptopus* spp. (twistedstalk), on which to collect additional data. For both of these species, frequency of presence declined (17% and 35%, respectively), although maximum quadrat height increased slightly, by 2.15 cm for *A. nudicaulis* and 2.61% for *Streptopus* spp.

The only broad-scale incidence of disease was beech bark disease (BBD), with signs and/or symptoms observed on 66% of *F. grandifolia* individuals. Generally, BBD impacts were not observed on individuals smaller than about 4 cm DBH.

Of the 59 total plots, 11 did not show any evidence of earthworm invasion, while six were heavily invaded. Earthworm-free and minimally invaded plots tended to be located in the Kingston Sand Plain and in the areas immediately near the shore.

Management recommendations focus on the beech resource. Currently, the most significant threat to PIRO forests is the impending impact of BBD. The park is engaged in a joint beech restoration effort with SLBE. While a small fraction (<1%) of naturally-occurring beech trees are resistant to the scale,

the overarching goal of the program is to propagate and cross this material, so to that disease-resistant stock can be outplanted back into the forest. The park should make every effort to ensure continuity of this project, as this will be one of the most effective ways to promote overall forest integrity.

The 59 permanent monitoring plots are scheduled to be resampled in 2026; trend assessments can be made at that time.

Acknowledgments

We wish to thank the vegetation monitoring field crew of E. Blow, L. Theisen, and D. Alsbach. Their unwavering dedication and effort made this possible. We are also grateful to the staff at Pictured Rocks National Lakeshore, including B. Leutscher for assistance with logistics and planning. Finally, R. Key of the Great Lakes Inventory and Monitoring Network provided invaluable assistance with database development and data storage.

Introduction

Routine monitoring of forests provides regular feedback on the status of resources, such as tree density, basal area, and numerous other metrics (Ferretti and Chiarucci 2003, Lewis et al. 2004). Perhaps more importantly, this information can be used to elucidate relationships and understand causal factors of forest health issues (Lindenmayer and Likens 2009). This can be especially valuable in large tracts of land that support high species richness of both plants and animals. Here, the ecological processes that play out are more complex than those in smaller and/or isolated tracts (Lynch and Whigham 1984, Krohne 1997). One such area is Pictured Rocks National Lakeshore (PIRO), located in the Upper Peninsula of Michigan.

Forests at PIRO are experiencing stressors from beech bark disease (BBD) complex, which arises from collective impacts of a non-native scale (*Cryptococcus fagisuga* Lindinger) and two introduced fungal pathogens (*Neonectria ditissitima* and *N. faginata*, Roy and Nolet 2018). Ecosystem drivers include wind (Stueve et al. 2011) as well as fire (Fahey 2014). Other stressors impacting forests here are non-native earthworms (Frelich et al. 2006) and climate change (Groffman et al. 2012). Collectively, these drivers and stressors impart cascading effects on ecosystems (Bohlen et al. 2004, Lovett et al. 2010, Rosemier and Storer 2010), but the effects vary depending on forest components and other drivers and stressors (Mistretta 2002, Latty et al. 2003).

We initiated a long-term forest monitoring program in 2009, establishing 59 permanent monitoring plots. At that time, BBD was largely limited to the east side of the park, but with minimal mortality there. By 2017, BBD has spread westward to include the entire park. Here, we report on changes in forest metrics over the eight-year interval, and discuss observed and potential effects.

Methods

Study Area

Pictured Rocks National Lakeshore is located in the Upper Peninsula of Michigan, extending 61 km along the south shore of Lake Superior between the towns of Munising, to the west, and Grand Marais, on the eastern side (Figure 1). The park extends inland approximately 6 km, although this varies along the length. A key feature of this park, and the driving reason for its designation, are the sandstone cliff faces that extend up to 60 meters over Lake Superior. Leachate from groundwater has colored these cliffs various shades of blue, green, yellow, white, and brown.

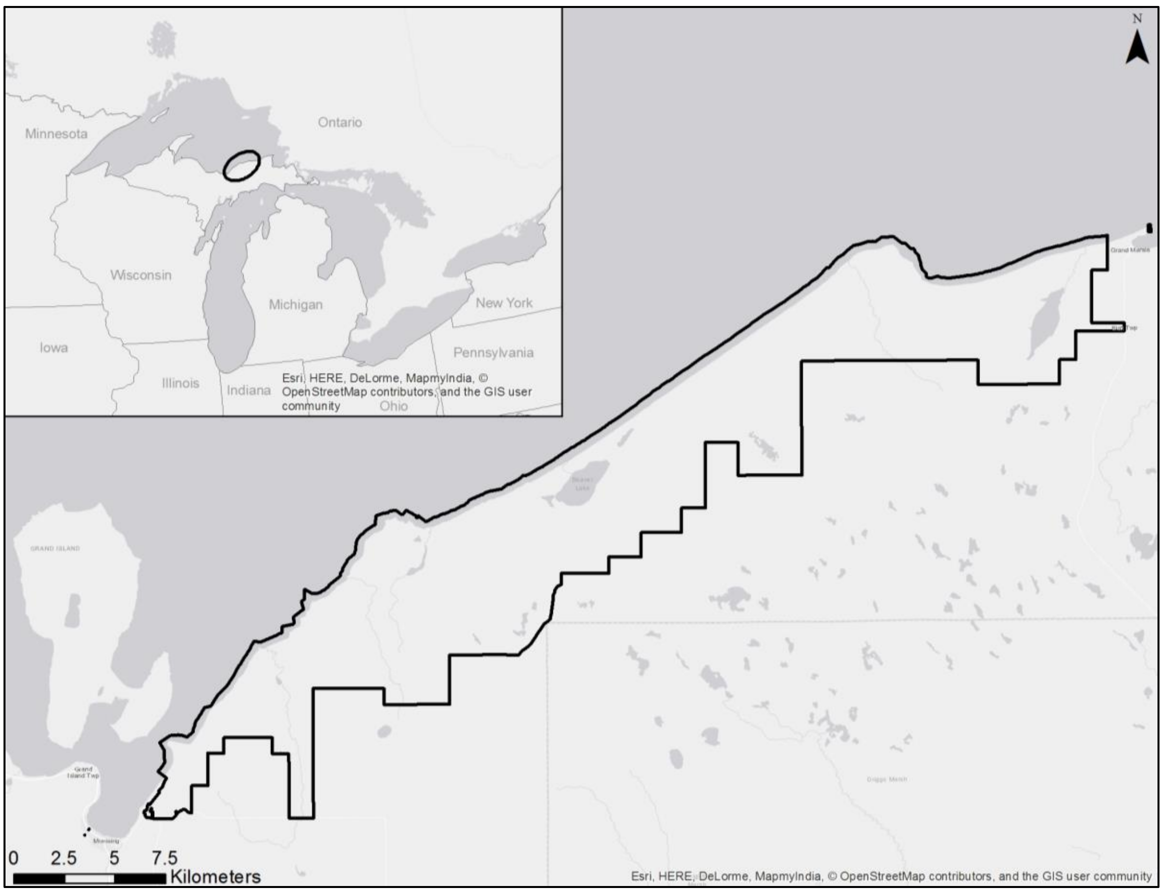

Figure 1. Upper Peninsula of Michigan (*inset*) and Pictured Rocks National Lakeshore (*main map*).

The founding legislation of Pictured Rocks (Public Law 89-668, 1966) designated two distinct zones. The “core” zone, comprising 12,206 ha, abuts Lake Superior and is marked by restricted development and limited anthropogenic impacts. The “inland buffer zone” (IBZ), comprises 15,322 ha, and lies inland of the core. Here, a mix of both public and private ownership and multiple uses dominate, with much of the land under active forest management.

The terrestrial component of the park is dominated by northern hardwood species that cover more than 80% of park land. They include *Acer saccharum* Marsh (sugar maple), *Fagus grandifolia* Ehrh.

(American beech), *Tsuga canadensis* (L.) Carrière (hemlock), *Pinus strobus* L. (white pine), *Betula alleghеniensis* Britton (yellow birch), *Populus tremuloides* Michx. (trembling aspen), *P. grandidentata* Michx. (bigtooth aspen), *Acer rubrum* L. (red maple), and *Quercus rubra* L. (red oak). Fire prone species cover about 5% of the area and mainly include *Pinus resinosa* Aiton (red pine) and *P. banksiana* Lamb. (jack pine). These are largely located within the Kingston Sand Plain, with smaller clusters in the Grand Sable Dunes, along the coast in the Beaver Basin, and in the Sand Point area. Unique resources include vernal pools, trout streams, waterfalls, several state listed plant and animal species, and vast expanses of pit and mound topography.

The key driver in PIRO forests is wind, with fire also playing a role in certain habitats. Currently, the largest stressor is BBD, which reached the park around 2007 (Bruce Leutscher, PIRO Chief of Resource Management, personal communication). Impacted trees were evident in the eastern half of the park by 2009. By 2012, the disease front had reached the park's western edge, while tree death was becoming widespread in the eastern half. By 2017, tree death was occurring throughout the park.

Sampling Design and Field Methods

Sampling Design

Sampling was conducted at PIRO 4 June–28 August 2017. Site selection was made in 2009 prior to the initial sampling event using a generalized random-tessellation stratified design (Stevens and Olsen 2004) This design ensured that our sites were both randomly located and spatially balanced throughout the park. The stratification of our sampling frame was such that we targeted 70% of sites to be located within the core zone and 30% in the IBZ. At the completion of 59 plots—the full complement for the park—43 are in the core and 16 in the IBZ.

Basic Measurements: Trees, Groundlayer, and Coarse Woody Material

We sampled trees, seedlings, coarse woody material, herbs, and deer browse using the Hybrid plot (Johnson et al. 2006, Johnson et al. 2008); Figure 2). Three 50-m parallel transects comprise the plot, with each in an east-west orientation and permanently marked with rebar sunk into the ground. We recorded the species, diameter at breast height (DBH), live/dead status, and damage or disease (see below) for all trees with a DBH ≥2.5 cm and standing within 3 meters of the central transect line (Sanders and Grochowski 2014b). The total area sampled for trees was 300 m^2 for each transect, or 900 m^2 for the entire plot.

We assessed the groundlayer in 1-m^2 quadrats placed every 5 m along each transect (n = 30 per plot). Within each quadrat, we recorded all herbaceous, vine, and shrub species present, allowing a frequency determination for all species-plot combinations. We also counted seedlings, defined as tree species <2.5 cm DBH, but at least 15 cm in height and showing evidence of growth from the previous year (thus, we did not assess the current year's seedlings). Some species we commonly encountered reproduce vegetatively (e.g., *Populus tremuloides*, *Acer rubrum*). Individual sprouts (i.e., both ramets and genets) were deemed "seedlings" if no aboveground connections between them and a parent tree were visible.

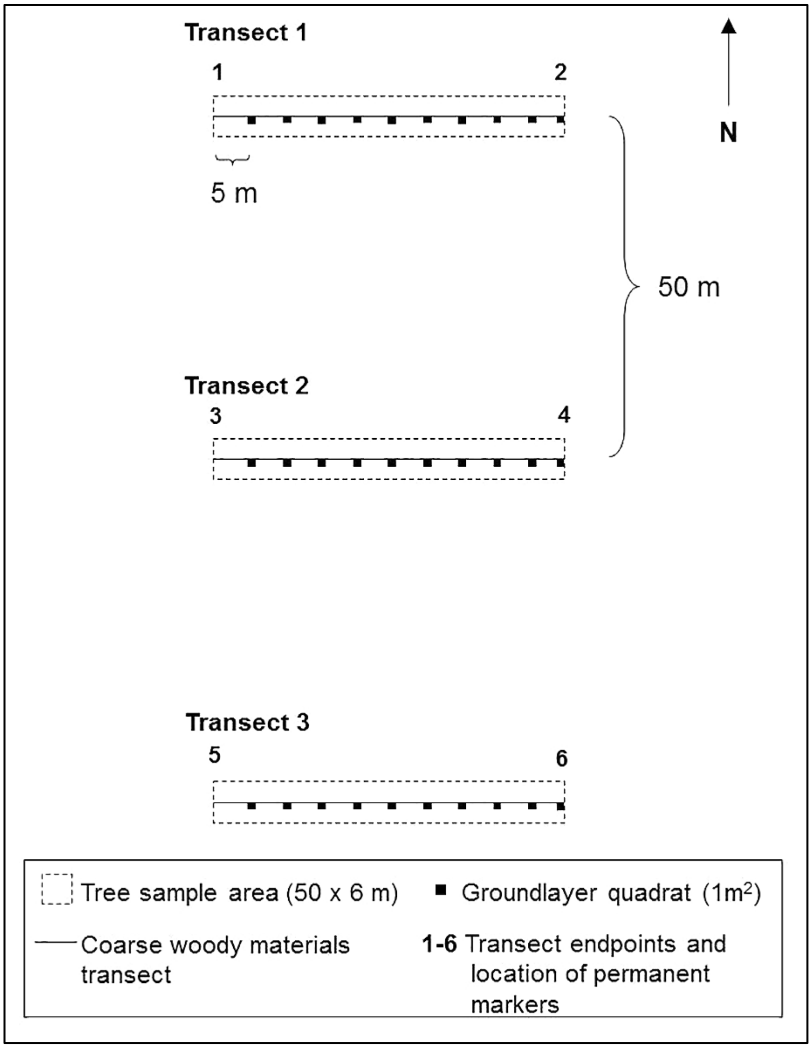

Figure 2. Great Lakes Network Hybrid plot showing three parallel transects (*solid lines*), tree sampling areas (*bounding dashed rectangles*), and quadrat locations (*solid squares*).

We assessed coarse woody material (CWM) using the planar intercept method (Brown 1974, Woodall and Monleon 2007). For all pieces with a diameter at transect intersect ≥7.5 cm and length ≥0.9 m, we measured the large end diameter, small end diameter, length, and decay class (Woodall and Monleon 2007). Our definition of CWM includes pieces with a diameter ≥7.5 cm; therefore, we recorded the length only along where the piece met this criterion.

Browse

We examined browse pressure using two distinct measures. *Direct browse* is an assessment of white-tailed deer (*Odocoileus virginianus* Zimm.) browse visible on *woody species*. This includes bite marks and leaf stripping *directly evident and observable* on individual plants and determined to be from the current year's growth. Our methods did not include an assessment of bark stripping, nor did we include browse attributable to snowshoe hare (*Lepus americanus* Erxleben). *Indirect browse* was used to assess the impacts of herbivory on *herbaceous* species. This assessment measures changes in herbaceous demography, which are often *only indirectly observed over time* (Webster et al. 2001, Kirschbaum and Anacker 2005). These changes are typically manifested as fewer and smaller individuals of preferred herbaceous browse species (Anderson 1994, Webster et al. 2001, Knight et al. 2009).

We assessed direct browse in 3.14-m^2 (1-m radius) circles centered every five meters along each of the three 50-m transects, for a total of 30 direct browse circles per plot, equal to a total sampling area of 94.2 m^2 per plot. Within each direct browse sampling circle, we recorded all woody species present within the browse zone—defined as the space between ground level and 2 m in height—and noted those circles where we observed any evidence of deer browse, and on which species in the circle this occurred. Typically, woody browse surveys are conducted in the spring, prior to the new season's growth, but we are unable to sample at that time. We acknowledge that this limitation introduces bias into our sampling, whereby those sites sampled later in the season would be expected to show more browse than sites sampled earlier. Nonetheless, numerous studies indicate a shift in food preference from woody to herbaceous in the spring (Crawford 1982, McCullough 1985), suggesting that the bias in our summer woody browse sampling may be minimized. Despite this preference, however, a consistent use of woody material throughout the year has also been shown (Kohn and Mooty 1971, Cypher et al. 1988). We feel that our assessments of woody browse in the field are valuable in that they provide insight on general levels of pressure and on species preferences, but should be interpreted with these qualifiers in mind.

We used direct browse data to calculate the *Proportion of Browse* (Frerker and Waller 2013) for each species and by forest type. At the species level ($PB_{species}$), for each plot, we divided the total number of circles in which we observed browse on $Species_A$ by the total number of circles in which $Species_A$ was present. We then calculated the parkwide mean for each species, across all plots. To determine proportion browse by forest type ($PB_{forest\ type}$), we first calculated proportion browse at the plot level; the numerator is sum of the number of circles in which browse was observed for all species while the denominator is the sum of the number of circles present for all species. We then calculated the mean for all plots in each forest type.

The direct browse methods employed in 2017 differed from those of 2009 when we assessed browse in both 2-m^2 circles (0.8-m radius) and 4-m^2 circles (1.1-m radius). Because of the differences in methods, no comparisons are made here between the two time periods.

We assessed the *indirect impacts* (typically evidenced by *fewer and smaller plants*) of summer browse on herbs by two means. We used our personal knowledge to identify *preferred* browse species as those that are both relatively common in the region and favored by white-tailed deer (Table 1). We then used the groundlayer data to assess abundance as the *Summed Frequency of Presence* of these preferred species. We did not count the number of individuals of these species in the groundlayer quadrats, but used frequencies of presence (from among the 30 quadrats per plot) as a measure of abundance. For this indicator, we then summed the frequencies of the 14 preferred species within each plot, then calculated the mean for all plots within each habitat. We also assessed indirect impacts of white-tailed deer browse by measuring the tallest of each of three *target* taxa—*Aralia borealis* L. (wild sarsaparilla), *Streptopus lanceolatus* var. *roseus* (Michx.) Reveal (rosy twistedstalk), and *Clintonia borealis* (Aiton) Raf. (bluebead lily)—within each quadrat where they were present. For each species, we calculated a *Maximum Height* for each plot as the mean of the tallest individuals of each of the three species in each quadrat. We elected to replace one of our 2009 target taxa (*Arisaema triphyllum* (L.) Schott (Jack-in-the-pulpit) with a different species in 2017 (*C. borealis*), leaving only two taxa in common between the two sampling periods for comparison.

Table 1. Preferred browse species at PIRO for calculating Summed Frequency of Presence.

Species	Common name
Actaea pachypoda Elliott	white baneberry
Actaea rubra (Aiton) Willd.	red baneberry
Aralia nudicaulis L.	wild sarsaparilla
Arisaema triphyllum (L.) Schott	Jack-in-the-pulpit
Clintonia borealis (Aiton) Raf.*	bluebead lily
Erythronium americanum Ker. Gawl.	yellow trout lily
Maianthemum canadense Desf.	Canada mayflower
Maianthemum racemosum (L.) Link	false Solomon’s seal
Maianthemum stellatum (L.) Link	Starry false lily of the valley
Polygonatum pubescens (Willd.) Pursh	hairy Solomon's seal
Sanguinaria canadensis L.	Bloodroot
Streptopus lanceolatus var. *roseus* (Michx.) Reveal*	rosy twistedstalk
Trillium cernuum L.*	nodding trillium
Trillium grandiflorum (Michx.) Salisb.	great white trillium

*Target taxa for assessing height.

Tree Health

To assess tree health, we used an evidence-based approach whereby we examined each tree for the presence of broad classes of disease, damage, or injury (U.S. Department of Agriculture 2010). These classes included dieback, epicormic sprouting, wilted foliage, defoliation, discolored foliage, insect sign, and human induced stress. If a tree exhibited symptoms of one of these primary classes, a further classification of the damage or disease was made, based on predefined characteristics within each of the primary classes. For example, if a tree was classified as having discolored foliage, we would note whether this damage was in the form of (among other choices) marginal browning of the leaves, interveinal browning of the leaves, the leaves possessing a white coating, or a general yellowing of the leaves. At PIRO, beech bark disease has been a widespread problem since shortly prior to our 2009 sampling. We noted this in the class “insect presence” by “scale”. This symptom-based assessment of damage and disease allows us to easily classify tree health issues, from which a diagnosis of the root cause can possibly be assigned upon further investigation. We feel that this symptom-based approach is more accurate than directly assigning a root cause to problems observed when at the field site. For some symptoms, there are dozens of possible causes and a pathologist or entomologist with specialization in the region would be needed to accurately assess the problem. Large-scale or persistent symptoms noted with this method can alert the park staff to potential disease or insect outbreaks, which would require further investigation by the park to identify the exact disease or pest.

Earthworm Impacts

Earthworm assessments were conducted at vegetation monitoring plots to determine the extent of invasive earthworm presence at PIRO. Earthworm presence was determined using a simple visual evaluation of the forest floor combined with a soil core assessment that followed methods developed for the Invasive Earthworm Rapid Assessment Tool (IERAT) (Loss et al. 2013). For the forest floor evaluation, we determined whether the forest floor was intact and layered, partially intact, or only present as the previous year's leaves. We noted and quantified the presence of earthworm casts, or excretions, as well as that of middens, or piles, of cast material created by the nightcrawler (*Lumbricus terrestris* L.) (Hale and Host 2005). We assessed organic layer depth using a core. At all plots, we performed four assessments at four locations in the plot, judged representative. From these evaluations, we ranked plots as earthworm-free, minimally invaded, moderately invaded, substantially invaded, or heavily invaded. For example, an earthworm-free sample has fresh litter, duff, and organic matter present; no evidence of earthworm casts or middens; and the presence of an E soil horizon. A moderately invaded sample has both fresh and decayed litter, but no organic matter present; earthworm casts are present but not abundant; and earthworm middens may be present or absent. A heavily invaded sample would have fresh litter but no decayed litter and no organic matter, and earthworm casts and middens would be abundant (Loss et al. 2013). No earthworm assessments were carried out in 2009, so comparisons in earthworm impacts between the two time periods were not made.

Plant Identification

We attempted to identify all plants to the species level while in the field. When this was not possible, we typically collected specimens for later identification. In some instances, it was not possible to distinguish between multiple species present in a park, unless they were flowering or fruiting, which often was not the case. In these instances, we identified only to the genus or family level. Examples include *Carex* sp. L. (sedge) and Asteraceae (daisy family). For *Amelanchier* sp. Medik. (serviceberry), another genus that presented identification challenges, we assigned individual plants to one of three groups of species complexes, with Group 1 containing *A. bartramiana* (Tausch) M. Roem.; Group 2 containing *A. arborea* (F. Michx.) Fernald, *A. laevis* Wiegand, and *A. interior* E.L. Nielsen; and Group 3 containing an uncertain number of species (Smith 2008). Finally, if a grass was not in flower or fruit, it was typically only possible to identify to the family (Poaceae) level. All nomenclature follows that of the Integrated Taxonomic Information System (Integrated Taxonomic Information System (ITIS) (2019).

Classifications and Summaries

Forest Type Classification

We classified all plots in the field using both the Kotar classification system (Burger and Kotar 2003) and the National Vegetation Classification System (NVCS) (Hop et al. 2010). Each system resulted in our plots falling into a large number of types with only a small number of plots in each type. We wanted to explore and summarize data in an efficient and practical manner, so after the field season, we grouped plots into similar broad forest types using cluster analysis (McCune and Grace 2002); thus, we identified groups that supported similar plots but had significant differences from other groups. To do this, we constructed a multivariate matrix based on abundance indices of both tree and groundlayer species within each plot. For trees, we calculated the importance value, determined by the mean of the relative density and relative basal area, for each species-plot combination (Dyer 2006, Elliott and Swank 2008). We calculated understory (herb and shrub) abundance for each species-plot combination as the proportion of quadrats in which each species was located within that plot. We limited inclusion in the cluster analysis to those taxa that were present in at least 8% (5 of 59) of the plots. For this classification, we used PC-ORD software version 5.33 (McCune and Grace 2002) and selected a Sørenson distance measure and a flexible beta linkage (ß = −0.25). We assigned habitat type names based on the dominant trees in these groups. We used non-metric multidimensional scaling (NMS) to verify the legitimacy of these groups, again using PC-ORD.

Functional Groups

All taxa were assigned to classes within each of four larger groups. Within the *life history group*, taxa were assigned to either the annual, biennial, or perennial class. For taxa that are known to exhibit a range of life history strategies, we assigned the shortest strategy. For example, if a taxon is known to be either biennial or perennial, we assigned it to the biennial class. Within the *growth form group*, taxa were considered to be either woody (trees, shrubs, woody vines), graminoid (grasses, sedges, and rushes), or forbs (herbaceous vines and broadleaved herbs). For this report, the latter class included ferns and fern allies. For the *pollination group*, taxa were considered to be abiotically pollinated if the flowers are non-existent (conifers) or not showy, and not known to produce any sensory attractants (e.g., grasses and sedges). These are typically wind-pollinated. Otherwise, flowering taxa were considered to be biotically pollinated. Ferns and fern allies were assigned to the "not pollinated" class within this functional group. Within the *nativity group*, taxa were assigned to native, non-native, or native/non-native. Naturalized taxa (e.g., *Trifolium pretense* L. (red clover)) were considered non-native. In some instances taxa were identified only to the genus level and could not be assigned to a nativity group, as species within these genera are both native and non-native. Examples include *Hieracium* sp. L. (hawkweed) and *Salix* sp. L. (willow); such taxa were noted as "native/non-native."

For each plot, we calculated the abundance of species in each group of each trait. We then calculated the means for all plots within each forest type.

Coefficients of Conservatism and the Modified Floristic Quality Index

We identified the coefficient of conservatism (CoC) values for all species located during the sampling at PIRO (Herman et al. 2001). These values quantify the habitat faithfulness of species

(Swink and Wilhelm 1994) and range from 0 (either non-native species or generalists with no faithfulness to any particular habitat) to 10 (conservative species found only in high-quality, non-degraded habitats). We then used CoC values to calculate the modified floristic quality index (mFQI) (Rooney and Rogers 2002, Sanders and Grochowski 2014a) where mFQI is simply the mean of the CoC values for all species present within that plot. We then summarized mFQI by year and forest type.

2017 Status and Short-term Change of Indices

We present the current (2017) tree densities by diameter class and species to elucidate successional status. We also present the current status of select indices where data are not available or comparable between the two sampling periods. These include proportion browse and earthworm impacts.

For most indices, we calculated means and standard errors and show short-term change between the sampling periods via graphs and tables. In some instances, we are not only interested in how these change between years, but also how they vary within forest types. These metrics include those for assessing trees (density, basal area, etc.). For other metrics (e.g., browse metrics) we are simply interested in the differences between years. Data are summarized and presented separately for the 43 plots within the core zone and the 16 plots within the IBZ, unless noted.

Results

All 59 plots originally sampled in 2009 were resampled in 2017 (Table 2, Figure 3); the plots were classified into four distinct forest types. The taxa sampled included 32 tree, 44 shrub and woody vine, 113 forb, 59 graminoid, and 29 fern species (Appendix A).

Table 2. Four habitat types and the plots classified in each. All plots were initially sampled in 2009, then again in 2017. Those plots in bold are located in the core zone.

Forest type	Plots
Sugar Maple-Beech	**6001***, **6005***, **6006***, **6007***, **6008***, **6009***, 6010, 6013, **6016***, **6017***, **6021***, **6026***, **6030***, **6033***, **6035***, **6036***, **6040***, **6042***, 6045, 6049, **6051***, 6055, **6056***, **6064***, **6069***
Hemlock-Beech-Mixed Hardwood	**6012***, **6018***, **6022***, **6024***, 6025, **6032***, 6037, 6039, **6041***, **6054***, **6059***, **6062***, **6068***, 6070
Balsam Fir-Mixed Conifer	**6002***, 6023, 6029, **6031***, **6044***, 6047, **6048***, **6053***, **6058***, **6063***, **6065***
Pine	**6004***, **6014***, 6015, 6020, 2027, **6028***, **6034***, 6043, **6067***

* Plots located in the core zone (also in bold font).

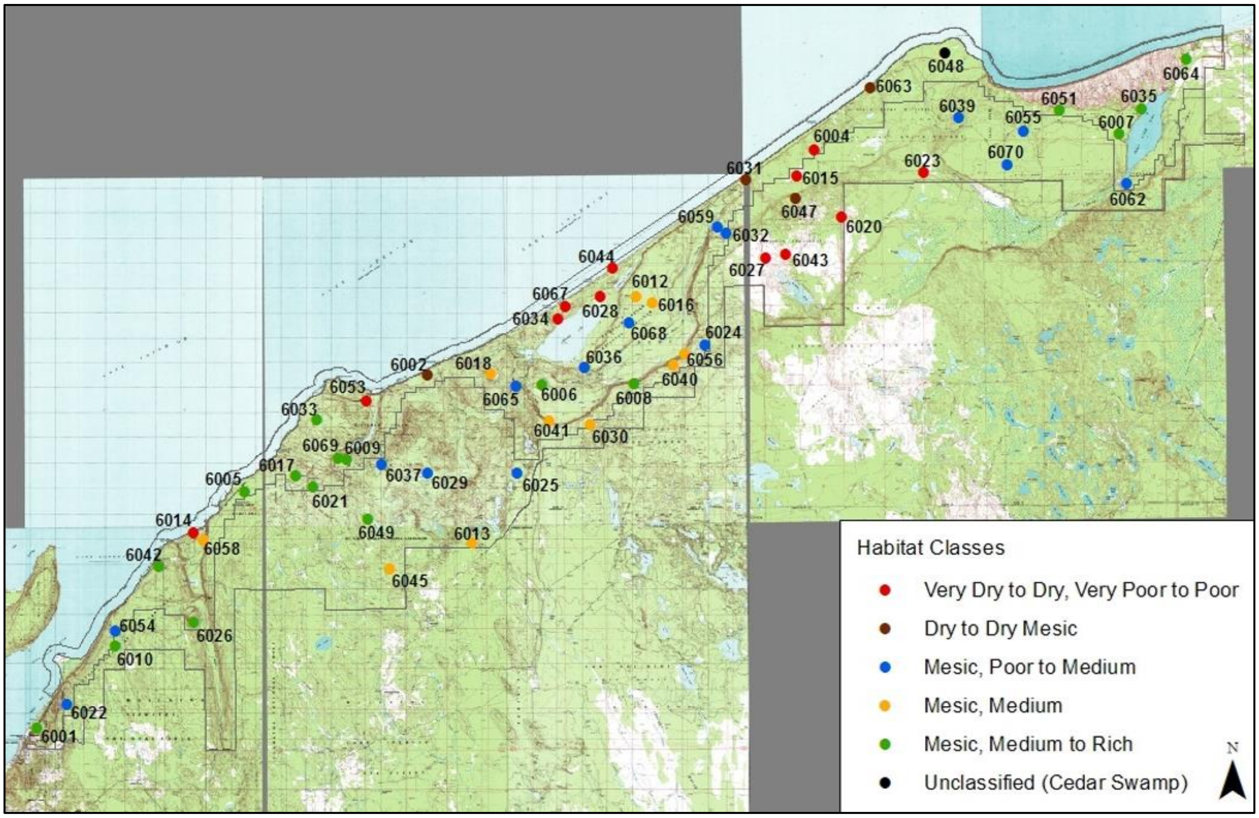

Figure 3. Locations of 59 permanent monitoring plots. Dot color indicates the plot's habitat class.

Trees: 2017 Density by Diameter Classes

Acer saccharum dominated the hardwood component in all size classes of Sugar Maple-Beech and Hemlock-Beech-Mixed Hardwood forests (Figure 4, left column); these two forest types comprised 39 of the 59 total plots. *Fagus grandifolia* was also common in both of these forest types and was present in 29 of the 59 total plots and in 23 of those 43 plots within the core. The conifer component (Figure 4, right column) was limited in both of these types; in Sugar Maple-Beech, this was almost exclusively *Abies balsamea*, while *Tsuga canadensis* was present in all size classes of Hemlock-Beech-Mixed Hardwood forests.

In Balsam Fir-Mixed Conifer forests, *Abies balsamea* was abundant across all size classes, with *Pinus strobus* comprising approximately 10% of individuals (Figure 4, right). Here, *Acer rubrum* was the dominant hardwood species. Pine forests were dominated by *Pinus strobus* in the smaller size classes and *P. banksiana* and *P. resinosa* in the larger classes.

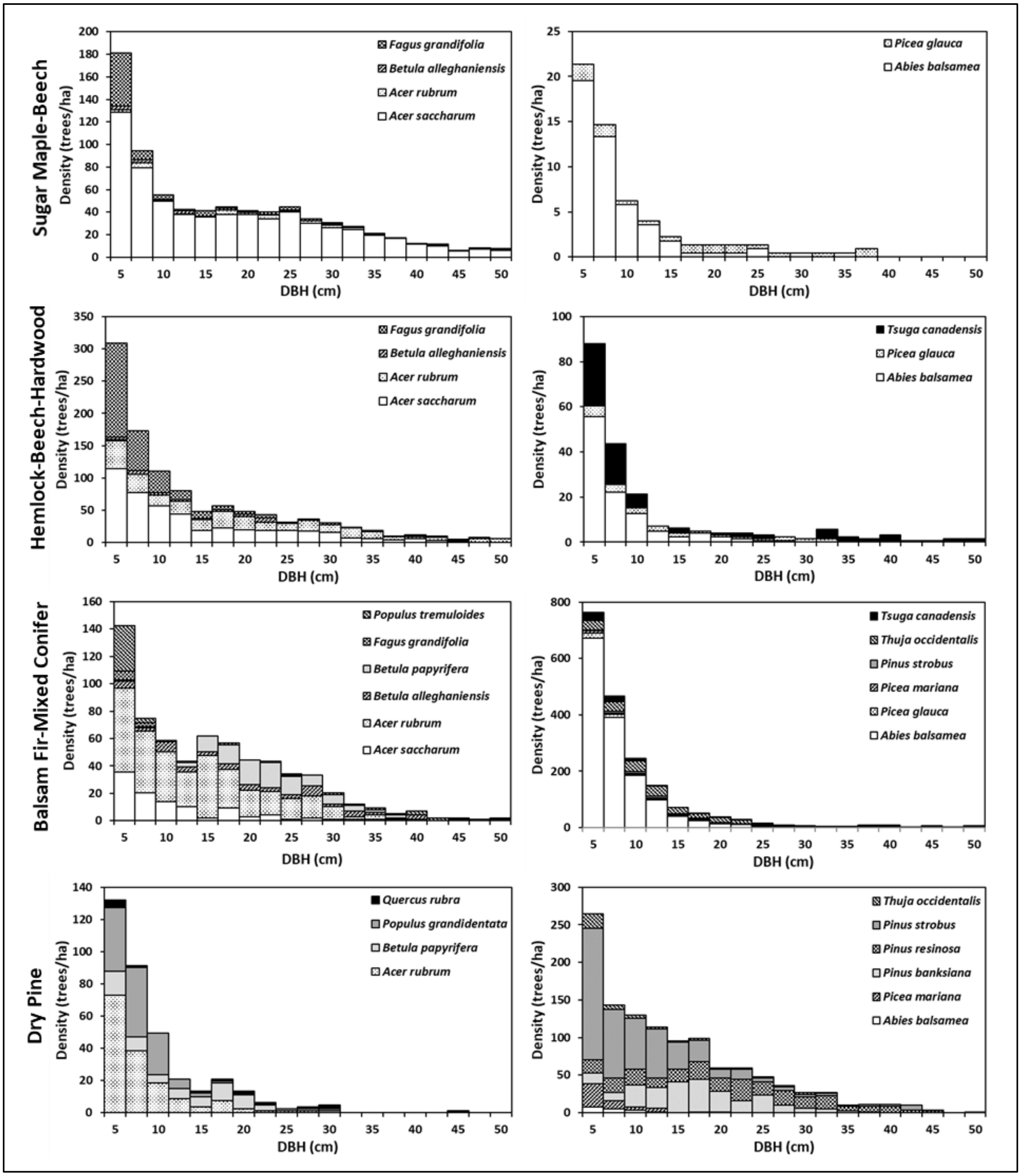

Figure 4. Density by diameter size classes for plots, by forest type, 2017. Hardwoods are shown in the left column and conifers on the right. These graphs incorporate plots in both the core and IBZ. Note the scales of the y-axes vary.

Trees: Short-Term Change

In both management classes and within all four forest types, live tree density changed little between the sampling periods (Figure 5a). In the core, tree density in the Balsam Fir-Mixed Conifer plots was highest (3,381 ± 638 trees/ha) and was more than twice that of the other three types.

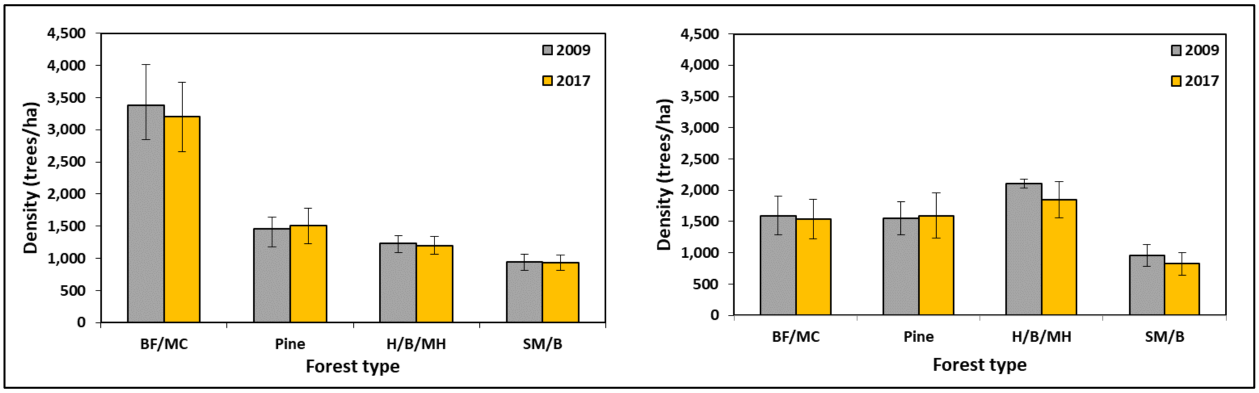

Figure 5a. Density of live trees by forest type in the core (*left*) and IBZ (*right*). Forest type abbreviations are: BF/MC: Balsam Fir-Mixed Conifer; H/B/MH: Hemlock-Beech-Mixed Hardwood; SM/B: Sugar Maple-Beech.

Fagus grandifolia was largely limited to Hemlock-Beech-Mixed Hardwood forest types (Figure 5b). Here, in the core, density of living beech increased 32%, to 250 trees/ha between the sampling periods.

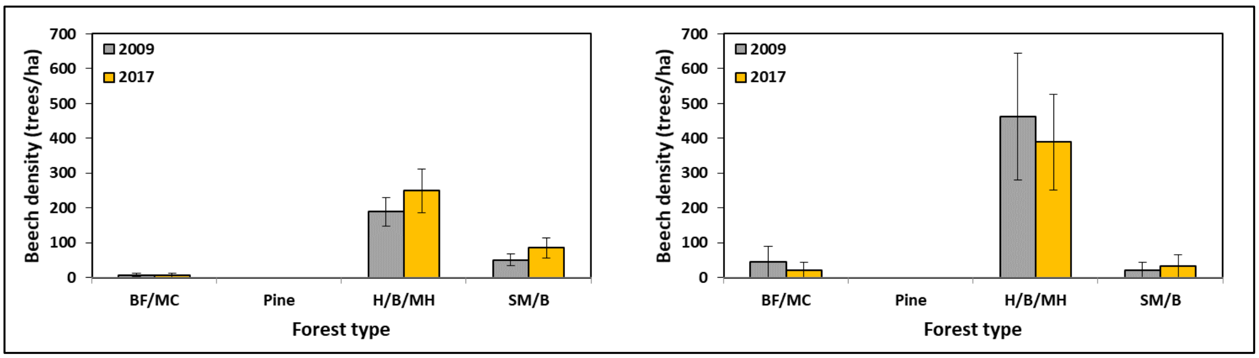

Figure 5b. Density of living *Fagus grandifolia* density by forest type in core plots (*left*) and IBZ (*right*). See Figure 5a for forest type abbreviations.

Live tree basal area was generally comparable between the two sampling events, across all forest types. Only Balsam Fir-Mixed Conifer had basal area >40 m^2/ha (40.4 m^2/ha in the core 2017), while Pine was the only forest type with basal area <30 m^2/ha (28.4 m^2/ha in the core 2017) (Figure 6a).

In Hemlock-Beech-Mixed Hardwood forests in the core, basal area of *Fagus grandifolia* dropped 39% from 4.55 ± 0.05 m^2/ha to 2.78 ± 0.06 m^2/ha (Figure 6b). In Sugar Maple-Beech forests, this dropped 57% from 2.13 ± 0.89 m^2/ha to 0.91 ± 0.35 m^2/ha.

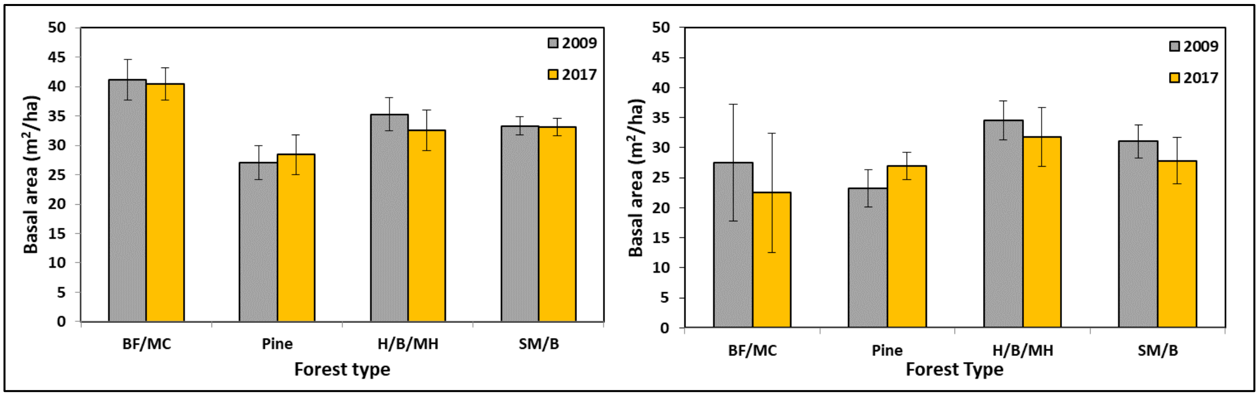

Figure 6a. Basal area of live trees by forest type in core plots (*left*) and IBZ (*right*). See Figure 5a for forest type names.

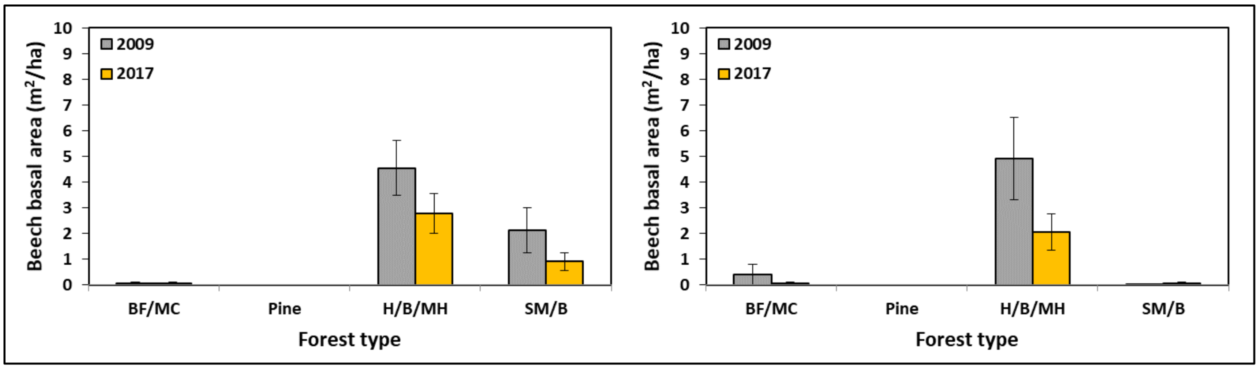

Figure 6b. Basal area of living *Fagus grandifolia* by forest type in core plots (*left*) and IBZ (*right*). See Figure 5a for forest type names.

Across all forest types and both management zones, basal area of standing, dead *Fagus grandifolia* increased from 1.3 to 2.3 m^2/ha between the sampling periods (Figure 7). Basal area of living *F. grandifolia* was 1.9 m^2/ha in 2017.

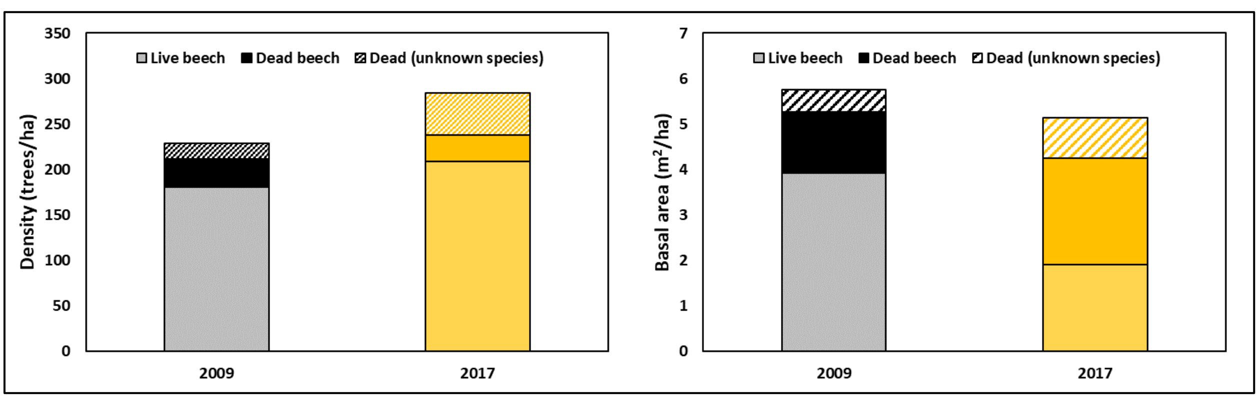

Figure 7. Density (*left*) and basal area (*right*) of living beech, standing dead beech, and standing dead trees of unknown species. Data are pooled over all forest types and both management zones.

Seedling density increased between the two time periods in all forest types and both management zones (Figure 8). In the core, seedling density in Hemlock-Beech-Mixed Hardwood plots increased 148% to 38,233 seedlings/ha in 2017; in Sugar Maple-Beech plots, this more than tripled to 46,317 seedlings/ha.

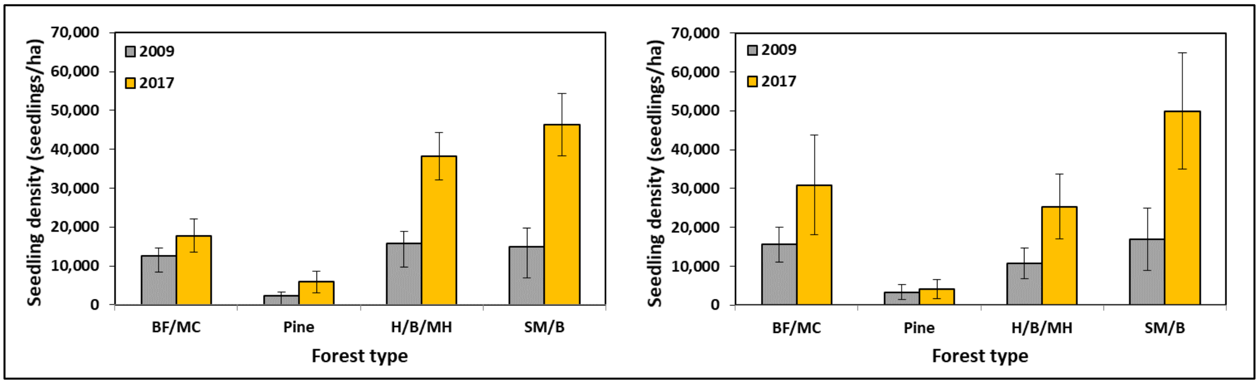

Figure 8. Seedling density by forest type in core plots (*left*) and IBZ (*right*). The value of Balsam Fir-Mixed Conifer in the IBZ does not reflect data from plot 6010 in 2017 which has 298,667 seedlings/ha in 2017. See Figure 5a for forest type names.

Coarse Woody Material and Standing Dead Trees

There was generally less coarse woody material in 2017 than in 2009; biomass in the core was 7.9% less (Table 3) and density of pieces in the core 2.4% less. Volume was similar for the two sampling periods.

Table 3. Volume, biomass, and density of coarse woody material for both time periods.

	Volume (m^3/ha)		Biomass (kg/ha)		Density (pieces/ha)	
Year	***Core***	***IBZ***	***Core***	***IBZ***	***Core***	***IBZ***
2009	48.33 ± 7.87	29.23 ± 6.51	13,910 + 2,462	9,126 ± 2,102	462.2 ± 48.64	458.8 ± 86.8
2017	48.89 ± 7.58	25.05 ± 5.96	12,810 ± 1,892	7,529 ± 2,015	451.0 ± 41.70	400.1 ± 72.0

Parkwide, the amount of large, advanced-decay, down, woody material (≥2 m length, ≥30 cm diameter, decay class 3 or 4) was generally lower in 2017 (Figure 9). In the core, this decreased 2.7 pieces/ha to 5.40 ± 2.34 pieces/ha in 2017.

Density of standing dead trees (snags) ≥30 cm DBH varied highly between forest types and, in core plots, between years (Figure 10). Large snag density increased 150% to 22.2 snags/ha in Hemlock-Beech-Mixed Hardwood forest; this increased 33% to 15.6 snags/ha in Sugar Maple-Beech forest.

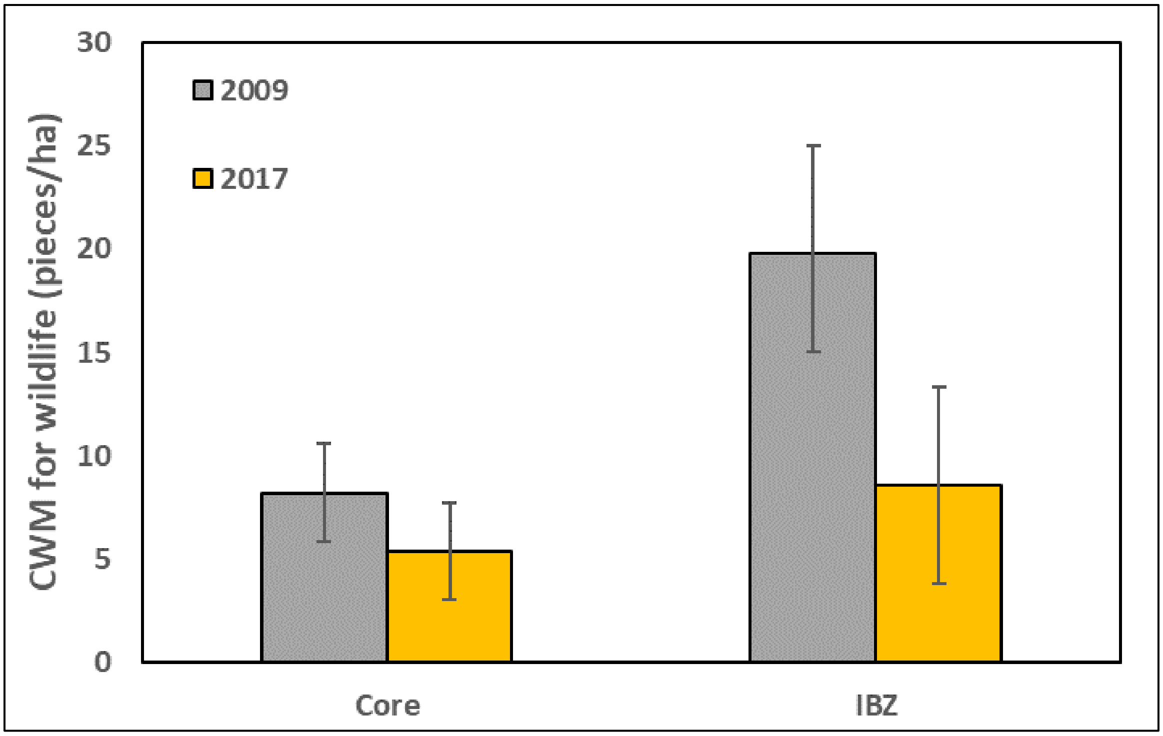

Figure 9. Density of large, advanced decay, coarse, woody material pieces for wildlife (≥30 cm DBH, ≥2 m length, decay class 3 or 4).

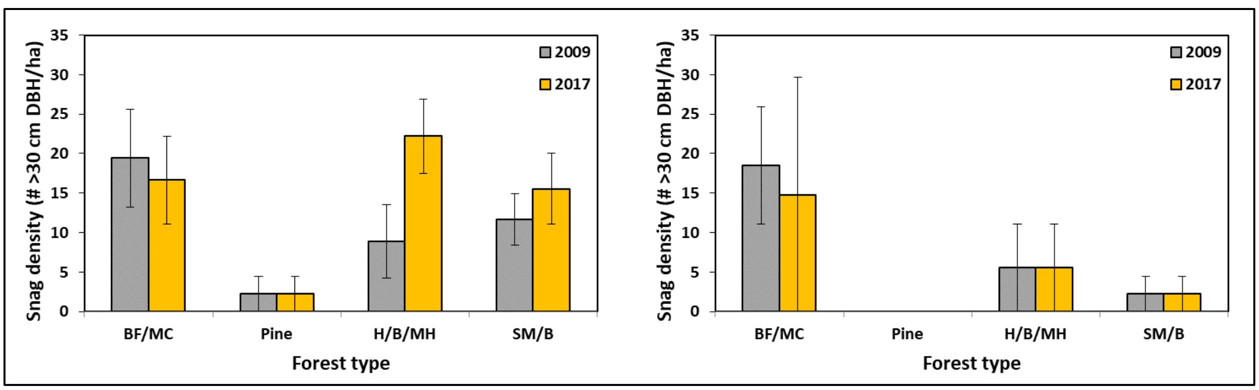

Figure 10. Density of standing dead trees ≥30 cm DBH in core plots (*left*) and IBZ plots (*right*). See Figure 5a for forest type names.

Browse and Disease

Browse on woody species varied greatly. At the species level, parkwide (all forest types and both management zones), $PB_{Species}$ (Proportion Browse on species) was >20% for *Taxus canadensis* Marsh (Canada yew), *Acer spicatum* Lam. (striped maple), and *Sambucus racemosa* var. *racemosa* L. (red elderberry) (Table 4). Six other taxa had bite marks in >10% of the circles in which they were present (Table 4). No browse was recorded on eight species.

Table 4. Proportion browse by species, for all woody species present in at least five plots. These values reflect all plots (i.e., those in both the core and IBZ).

Species	Common name	Proportion browse
Taxus canadensis	Canada yew	0.5000
Acer spicatum	mountain maple	0.3824
Sambucus racemosa var. *racemosa*	red elderberry	0.2883
Betula papyrifera	paper birch	0.1765
Betula allegheniensis	yellow birch	0.1429
Acer rubrum	red maple	0.1345
Fraxinus nigra	black ash	0.1333
Lonicera canadensis	fly honeysuckle	0.1220
Rubus sachalinensis var. *sachalinensis*	red raspberry	0.1020
Amelanchier sp. Group 2	serviceberry	0.0947
Acer pensylvanicum	striped maple	0.0833
Acer saccharum	sugar maple	0.0694
Pinus strobus	white pine	0.0533
Prunus serotina	black cherry	0.0530
Ostrya virginiana	hophornbeam	0.0323
Thuja occidentalis	eastern white cedar	0.0290
Tsuga canadensis	eastern hemlock	0.0159
Fagus grandifolia	American beech	0.0144
Vaccinium myrtilloides	velvetleaf blueberry	0.0130
Vaccinium angustifolium	lowbush blueberry	0.0068

*Species for which no browse was recorded were: *Abies balsamea, Gaylussacia baccata, Picea glauca, P. mariana, Pinus resinosa, Populus grandidentata, Ribes triste, and Rubus pubescens*.

Proportion browse by forest type ($PB_{forest\ type}$) was consistent across forest types; the proportion browsed ranged from 0.600 in Hemlock-Beech-Mixed Hardwood forests to 0.084 in Pine forests (Figure 11). Different methods were used to assess this in 2009, so comparisons between years are not possible.

For the 14 preferred browse species (see Table 1) with which we measure indirect browse, *Summed Frequency of Presence* was generally comparable between the two management zones and both sampling periods, although this varied between forest types. Generally, the summed frequency of presence of preferred browse species was lowest in Pine forests and highest in those with beech (Figure 12).

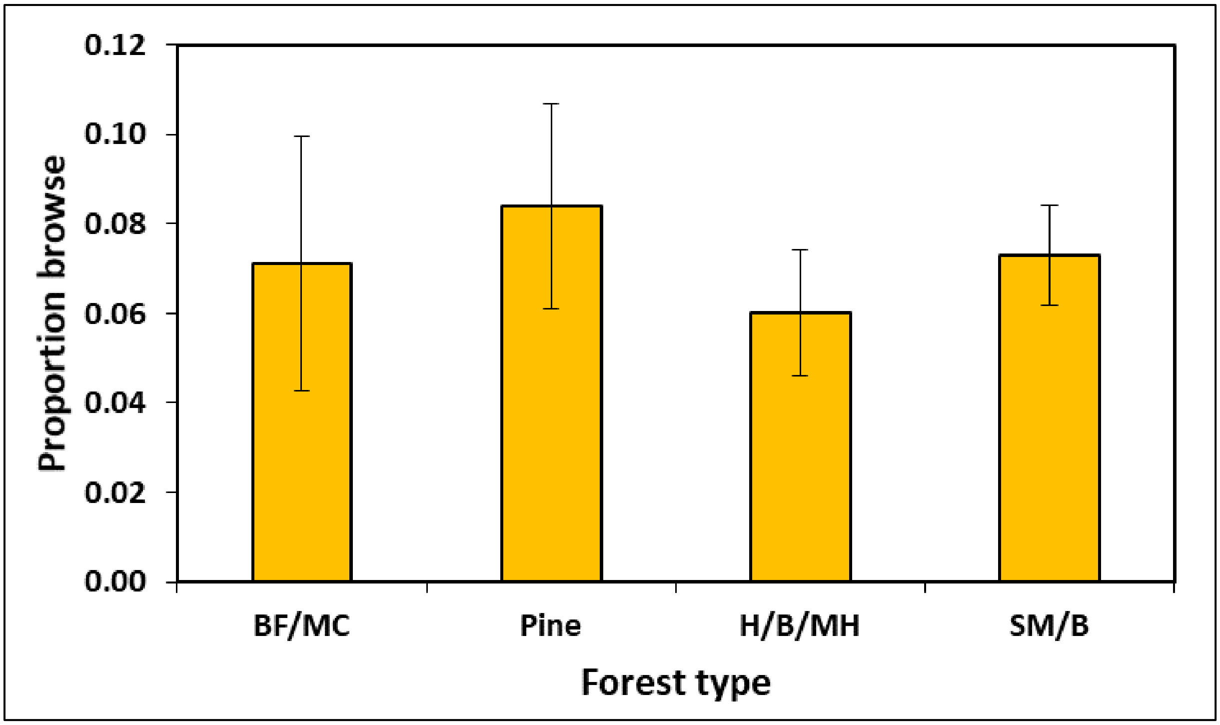

Figure 11. Proportion browse by forest type in the four forest types, in 2017. This reflects all plots, i.e., those in both the core and IBZ. Error bars represent ± one standard error. See Figure 5a for forest type names.

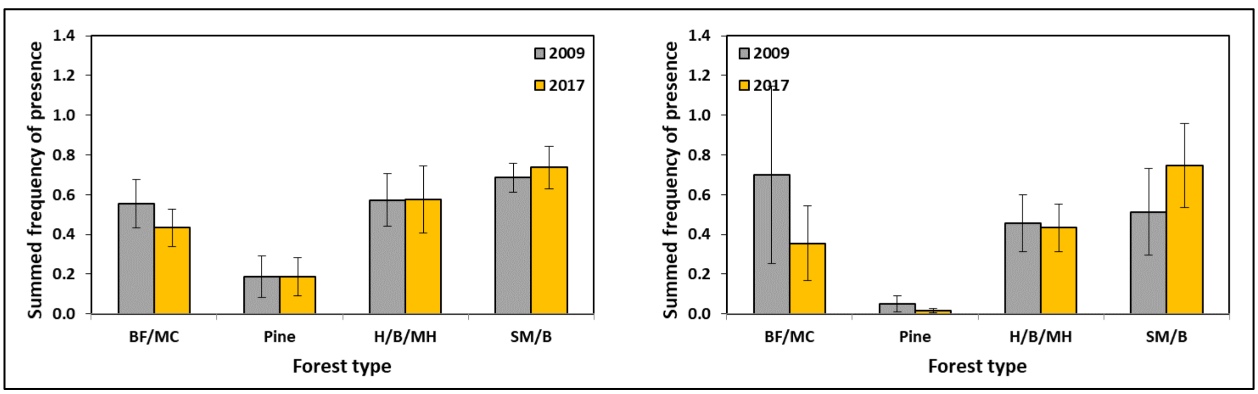

Figure 12. The summed frequency of presence for the 14 preferred browse species. Core plots on the left and IBZ plots on the right. Error bars represent ± one standard error. See Figure 5a for forest type names.

Differences in the frequency of quadrats supporting target indirect browse taxa were notable with 17% and 35% fewer quadrats in core plots supporting *Aralia nudicaulis* and *Streptopus* sp., respectively, during the second sampling period (Figure 13, left). These percentages also dropped in plots within the IBZ (Figure 13, right).

In the plots where these target species were present, mean maximum quadrat height increased between the sampling periods 2.15 cm for *A. nudicaulis* and 2.61 cm for *Streptopus* sp. (Figure 14).

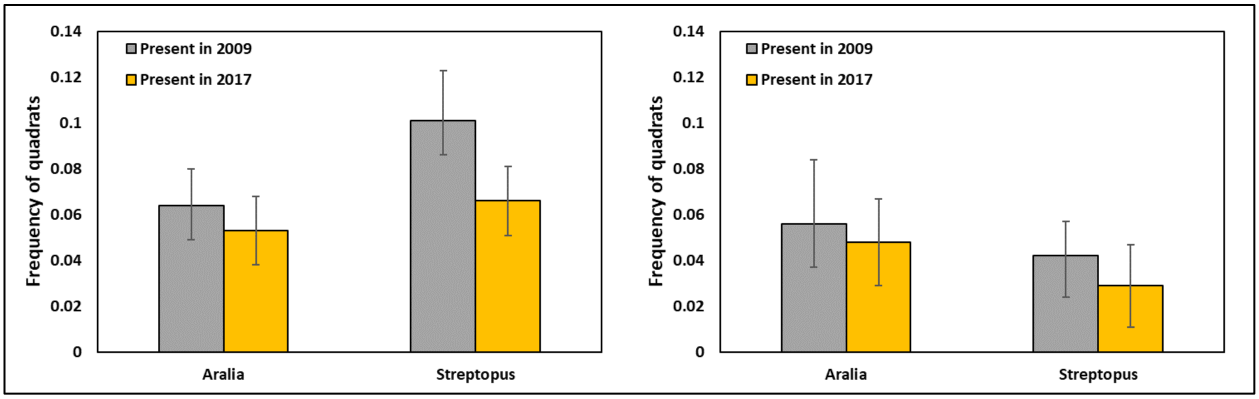

Figure 13. The frequency of presence for the two target species. Core plots on the left and IBZ plots on the right. Error bars represent ± one standard error.

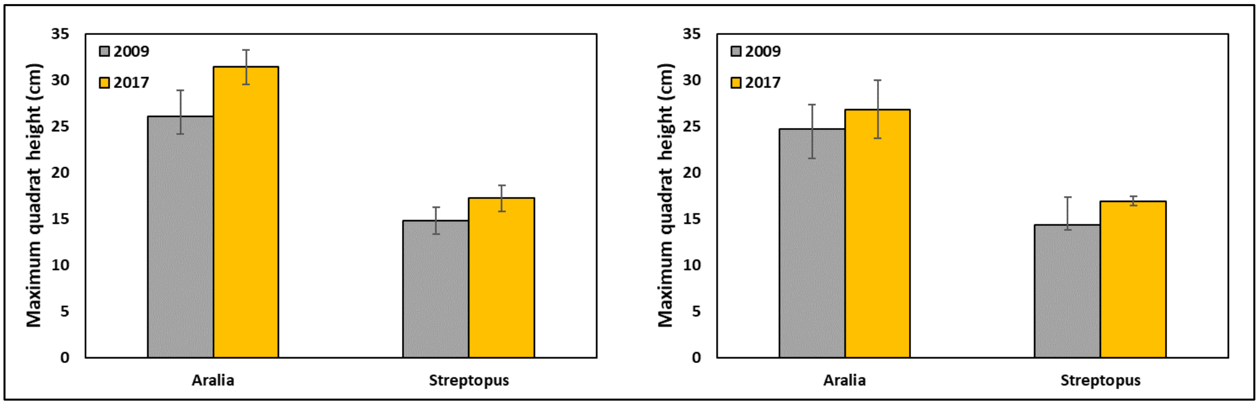

Figure 14. The maximum height of target species in plots in the core (*left*) and IBZ (*right*). Error bars represent ± one standard error.

Tree Health

The only broad-scale tree health concern was beech bark disease. *Fagus grandifolia* individuals were located in all forest types except Pine, with the majority of these having beech scale present (Table 5).

Table 5. Number of *Fagus grandifolia* trees in each forest type (where present) and number of those showing beech scale. Note: these numbers include all size classes, down to 2.5 cm DBH.

Number of trees	Sugar maple-beech	Hemlock-beech-mixed hardwood	Balsam fir-mixed conifer
Present	169	365	11
With scale	76	279	7

Community Indices

Species richness in core plots did not change greatly between the two years (Figure 15) and was similar between the two management zones. In the core, this was higher in Balsam Fir-Mixed Conifer forests (42.9 ± 5.6 species/plot in 2017) and lowest in Pine forests (29.2 ± 5.4 species/plot in 2017).

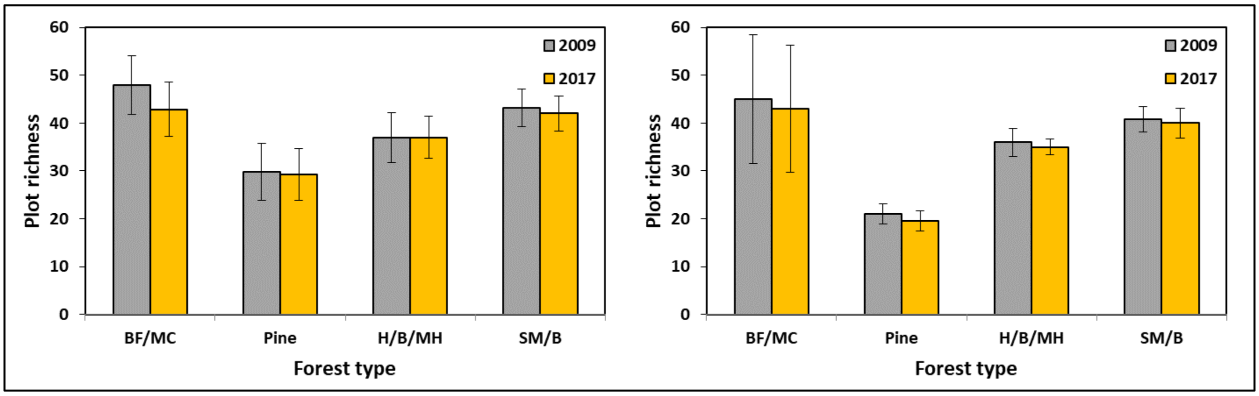

Figure 15. Species richness was generally comparable between the core (*left*) and IBZ (*right*), but varied between forest types. Generally, this was highest in Balsam Fir-Mixed Conifer forests and lower in Pine forests. See Figure 5a for forest type names.

In core plots in 2017, the plot coefficient of conservatism ranged from 4.0 to 4.6; this varied little between years, management zones, and forest types (Figure 16).

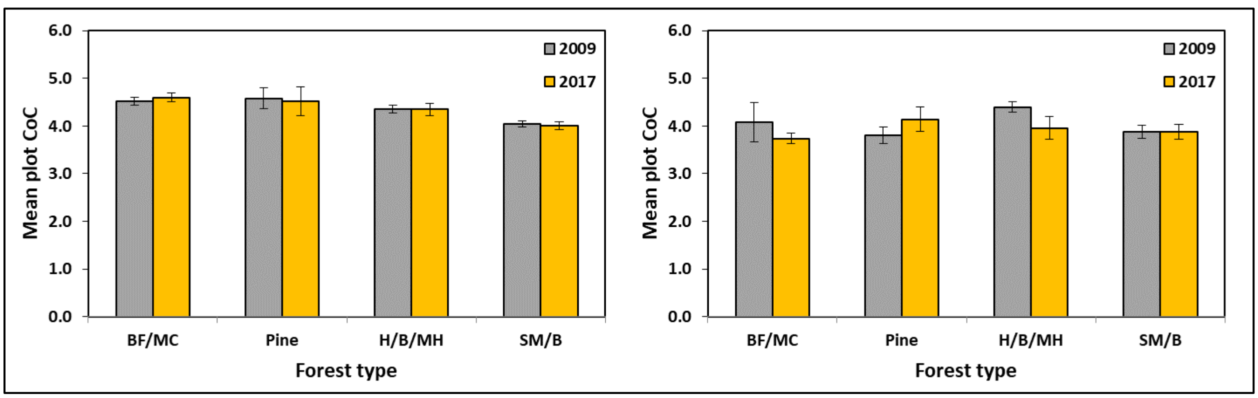

Figure 16. Coefficient of conservatism varied little between the sampling periods, forest types, and management zones. See Figure 5a for forest type names.

Earthworm Impacts

The impacts of earthworms on soils varied. Thirteen of the 59 plots assessed did not show any evidence of earthworm invasion (Figure 17, Table 6), while 17 plots were heavily invaded. Earthworm-free and minimally invaded plots tended to be located in the Kingston Sand Plain and in the areas immediately near the shore.

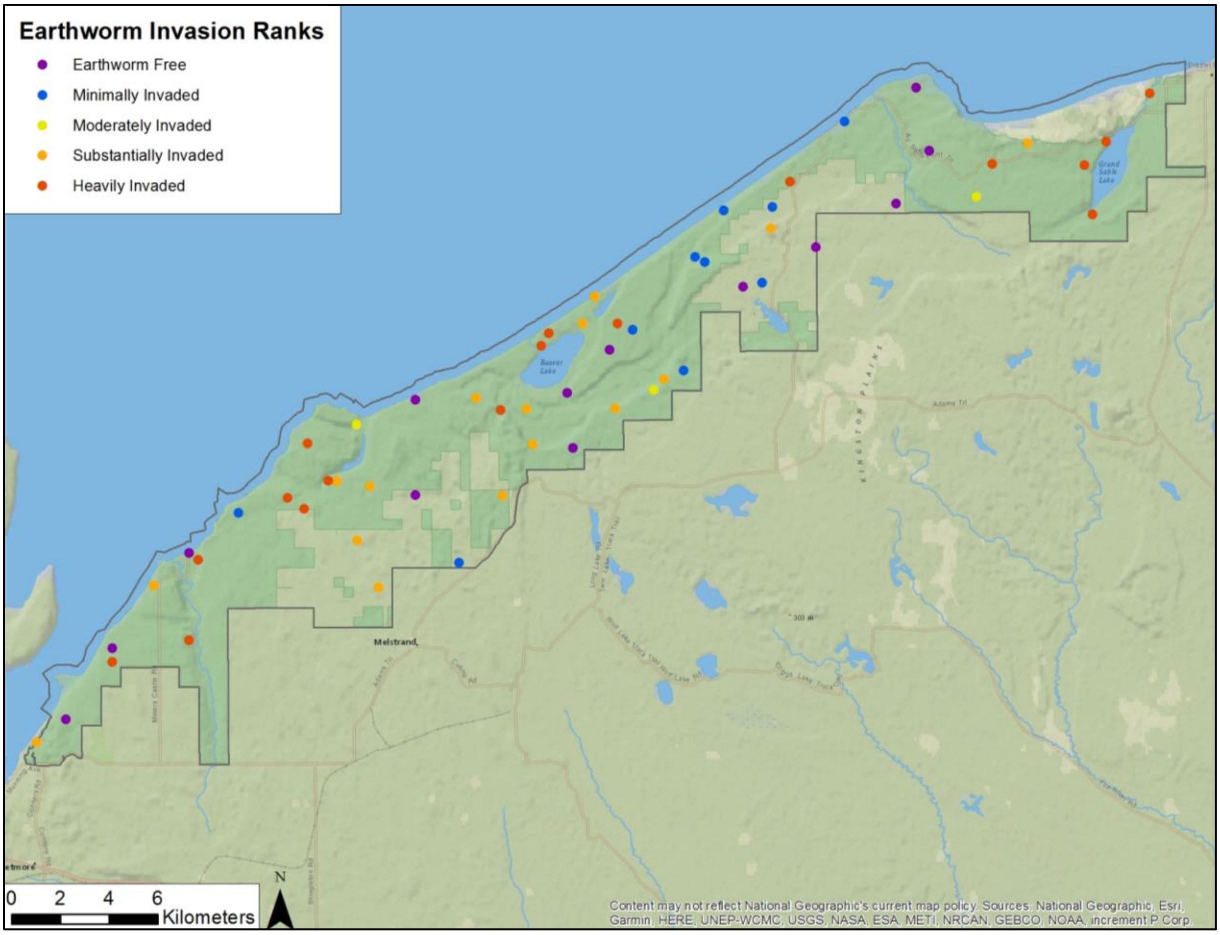

Figure 17. Earthworm invasion ranks at each plot. These designations show the highest level of impairment of the four assessments completed at each plot.

Table 6. Classification of plots into categories denoting severity of earthworm invasion. For severity, we used the most severe (i.e., "worst") classification of the four samples collected at each plot.

	Severity of Invasion				
Habitat	***Earthworm-free***	***Minimally invaded***	***Moderately invaded***	***Substantially invaded***	***Heavily invaded***
Balsam Fir-Mixed Conifer	4	2	1	2	2
Pine	3	2	0	1	3
Hemlock-Beech-Mixed Hardwood	4	3	1	4	2
Sugar Maple-Beech	2	3	1	9	10

Discussion

Picture Rocks National Lakeshore forests are now fully experiencing the impacts of BBD. Most notable at this point is the death of larger diameter trees, resulting in decreased basal area. One hallmark of BBD-invaded forests is an understory thicket of beech suckers, resulting in marked increases in density (Hane 2003, Duchesne et al. 2005). Our data do not show increased density in both Hemlock-Beech-Mixed Hardwood and Sugar Maple-Beech sites, but to look at them in the field, PIRO forests have not progressed to the stage of invasion where small beech suckers dominate the groundlayer.

Density-diameter graphs suggest that successionally, Sugar Maple-Beech forests may transition to largely *Acer saccharum* with small components of *Betula allegheniensis*. Hemlock-Beech-Mixed Hardwood forests will likely be dominated by *Acer rubrum*, with *Tsuga canadensis* and *Abies balsamea* being lesser components. In Pine forests, typically found within the Kingston Sand Plain, fire-dependent species (*Pinus banksiana*, *P. rubra*, and *Picea mariana*) are being replaced with more mesic species including *Acer rubra* and *Pinus strobus*. In the continued absence of fire, these forests will likely fully transition to a more mesic state.

Management Recommendations

Pictured Rocks National Lakeshore is jointly involved with Sleeping Bear Dunes in a beech restoration project. As part of this project, disease-resistant individuals are being developed by grafting shoots of known resistant trees onto rootstock, cross-pollinating flowers on resistant shoots, and planting the resulting beechnuts. Unfortunately, this program is in its infancy and resistant stock for outplanting will likely not be available for six to eight years. Care should be taken to include genetic source material (beechnuts and stems for grafting) from PIRO.

The park may also wish to pursue prescribed burning in the Kingston Sand Plain to ensure persistence of fire-dependent species and ecosystem.

PIRO is currently at a pivotal point with regard to ecosystem health. The current state of park forests are reasonably healthy and functioning. However, the full impacts of BBD, when coupled with the eventual spread of earthworms and the loss of fire as a disturbance mechanism, will likely be enough to irreversibly alter forest composition and function. As this occurs, other problems arise, typified by the ingress of invasive plant species. Managers must act now if they wish to prevent this from happening.

Literature Cited

Anderson, R. C. 1994. Height of white-flowered trillium (*Trillium grandiflorum*) as an index of deer browsing intensity. Ecological Applications 4:104–109.

Bohlen, P. J., S. Scheu, C. M. Hale, M. A. McLean, S. Migge, P. M. Groffman, and D. Parkinson. 2004. Non-native invasive earthworms as agents of change in northern temperate forests. Frontiers in Ecology and the Environment 2:427–435.

Brown, J. K. 1974. Handbook for Inventorying Downed Woody Material. USDA Forest Service General Technical Report INT-16. Intermountain Forest & Range Experiment Station, Ogden, Utah.

Burger, T. L., and J. Kotar. 2003. A Guide to Forest Communities and Habitat Types of Michigan. The Department of Forest Ecology and Management, University of Wisconsin-Madison, Madison, Wisconsin.

Crawford, H. S. 1982. Seasonal food selection and digestibility by tame white-tailed deer in central Maine. Journal of Wildlife Management 46:974–982.

Cypher, B. L., R. H. Yahner, and E. A. Cypher. 1988. Seasonal food use by white-tailed deer at Valley Forge National Historical Park, Pennsylvania, USA. Environmental Management 12:237–242.

Duchesne, L., R. Ouimet, J.-D. Moore, and R. Paquin. 2005. Changes in structure and composition of maple-beech stands following sugar maple decline in Québec, Canada. Forest Ecology and Management 208:223–236.

Dyer, J. M. 2006. Revisiting the deciduous forests of eastern North America. Bioscience 56:341–352.

Elliott, K. J., and W. T. Swank. 2008. Long-term changes in forest composition and diversity following early logging (1919–1923) and the decline of American chestnut (*Castanea dentata*). Plant Ecology 197:155–172.

Fahey, T. J. 2014. Composition, structure, and trajectories of Great Lakes coastal pine forests in relation to historical baselines and disturbance history. The American Midland Naturalist 172:285–302.

Ferretti, M., and A. Chiarucci. 2003. Design concepts adopted in long-term forest monitoring programs in Europe—Problems for the future? The Science of the Total Environment 310:171–178.

Frelich, L. E., C. M. Hale, S. Scheu, A. R. Holdsworth, L. Heneghan, P. J. Bohlen, and P. B. Reich. 2006. Earthworm invasion into previously earthworm-free temperate and boreal forests. Biological Invasions 8:1235–1245.

Frerker, K., and D. W. Waller. 2013. Comparing and evaluating methods used to assess the impacts of ungulate browsing in the Great Lakes Network national parks. Natural Resource Technical Report NPS/GLKN/NRTR—2013/680. National Park Service, Fort Collins, Colorado.

Groffman, P. M., L. E. Rustad, P. H. Templer, J. L. Campbell, L. M. Christenson, N. K. Lany, A. M. Socci, M. A. Vadevoncoeur, P. G. Schaberg, G. F. Wilson, C. T. Driscoll, T. J. Fahey, M. C. Fisk, C. L. Goodale, M. B. Green, S. P. Hamburg, C. E. Johnson, M. J. Mitchell, J. L. Morse, L. H. Pardo, and N. L. Rodenhouse. 2012. Long-term integrated studies show complex and surprising effects of climate change in the northern hardwood forest. Bioscience 62:1056–1066.

Hale, C. M., and G. E. Host. 2005. Assessing the impacts of European earthworm invasions in beech-maple hardwood and aspen-fir boreal forests of the western Great Lakes region. Great Lakes Network Report GLKN/2005/11. National Park Service, Ashland, Wisconsin.

Hane, E. 2003. Indirect effects of beech bark disease on sugar maple seedling survival. Canadian Journal of Forest Research 33:807–813.

Herman, K. D., L. A. Masters, M. R. Penskar, A. A. Reznicek, G. S. Wilhelm, W. W. Brodovich, and K. P. Gardiner. 2001. Floristic Quality Assessment with Wetland Categories and Examples of Computer Applications for the State of Michigan, 2nd edition. Michigan Department of Natural Resources, Lansing, Michigan.

Hop, K., S. Menard, J. Drake, S. Lubinski, and J. Dieck. 2010. National Park Service Vegetation Inventory Program: Apostle Islands National Lakeshore, Wisconsin. Natural Resources Resource Report NPS/GLKN/NRR—2010/199. National Park Service, Fort Collins, Colorado.

Integrated Taxonomic Information System (ITIS). 2019. ITIS online database. Available at: www.itis.gov (accessed 2 February 2019).

Johnson, S. E., E. L. Mudrak, E. A. Beever, S. Sanders, and D. M. Waller. 2008. Comparing power among three sampling methods for monitoring forest vegetation. Canadian Journal of Forest Research 38:143–156.

Johnson, S. E., E. L. Mudrak, and D. M. Waller. 2006. A comparison of sampling methodologies for long-term monitoring of forest vegetation in the Great Lakes Network national parks. Great Lakes Network Report GLKN/2006/03. National Park Service, Ashland, Wisconsin.

Kirschbaum, C. D., and B. L. Anacker. 2005. The utility of *Trillium* and *Maianthemum* as phyto-indicators of deer impact in northwestern Pennsylvania, USA. Forest Ecology and Management 217:54–66.

Knight, T. M., J. L. Dunn, L. A. Smith, J. Davis, and S. Kalisz. 2009. Deer facilitate invasive plant success in a Pennsylvania forest understory. Natural Areas Journal 29:110–116.

Kohn, B. E., and J. J. Mooty. 1971. Summer habitat of white-tailed deer in north-central Minnesota. The Journal of Wildlife Management 35:476–487.

Krohne, D. T. 1997. Dynamics of metapopulations of small mammals. Journal of Mammalogy 78:1014–1026.

Latty, E. F., C. D. Canham, and P. L. Marks. 2003. Beech bark disease in northern hardwood forests: The importance of nitrogen dynamics and forest history for disease severity. Canadian Journal of Forest Research 33:257–268.

Lewis, S. L., O. L. Phillips, T. R. Baker, J. Lloyd, Y. Malhi, S. Almeida, N. Higuchi, W. F. Laurance, D. A. Neill, J. N. M. Silva, J. Terborgh, A. T. Lezama, R. Vásquez Martínez, S. Brown, J. Chave, C. Keuebler, P. N. Vargas, and B. Vinceti. 2004. Concerted changes in tropical forest structure and dynamics: Evidence from 50 South American long-term plots. Philosophical Transactions of the Royal Society of London, B 359:421–436.

Lindenmayer, D. B., and G. E. Likens. 2009. Adaptive monitoring: A new paradigm for long-term research and monitoring. Trends in Ecology and Evolution 24:482–486.

Loss, S. R., R. M. Hueffmeier, C. M. Hale, G. Host, G. Sjerven, and L. E. Frelich. 2013. Earthworm invasions in northern hardwood forests: A rapid assessment method. Natural Areas Journal 33:21–30.

Lovett, G. M., M. A. Arthur, K. C. Weathers, and J. M. Griffin. 2010. Long-term changes in forest carbon and nitrogen cycling caused by an introduced pest/pathogen complex. Ecosystems 13:1188–1200.

Lynch, J. F., and D. F. Whigham. 1984. Effects of forest fragmentation on breeding bird communities in Maryland, USA. Biological Conservation 28:287–324.

McCullough, D. R. 1985. Variables influencing food habits of white-tailed deer on the George Reserve. Journal of Mammology 66:682–692.

McCune, B., and J. B. Grace. 2002. Analysis of Ecological Communities. MjM software, P.O. Box 129, Gleneden Beach, Oregon 97388 USA.

Mistretta, P. A. 2002. Managing for forest health. Journal of Forestry 100:24–27.

Rooney, T. P., and D. A. Rogers. 2002. The modified floristic quality index. Natural Areas Journal 22:340–344.

Rosemier, J. N., and A. J. Storer. 2010. Assessing the responses of native small mammals to an incipient invation of beech bark disease through changes in seed production of American beech (*Fagus grandifolia*). American Midland Naturalist 164:238–259.

Sanders, S., and J. Grochowski. 2014a. Alternative metrics for evaluating forest integrity and assessing change at four northern-tier U.S. national parks. American Midland Naturalist 171:185–203.

Sanders, S., and J. Grochowski. 2014b. Forest vegetation monitoring protocol version 2.0: Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR—2014/799. National Park Service, Fort Collins, Colorado.

Smith, W. R. 2008. Trees and Shrubs of Minnesota. University of Minnesota Press, Minneapolis, Minnesota.

Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99:262–278.

Stueve, K. M., C. H. Perry, M. D. Nelson, S. P. Healey, A. D. Hill, G. G. Moisen, W. B. Cohen, D. D. Gormanson, and C. Huang. 2011. Ecological importance of intermediate windstorms rivals large, infrequent disturbances in the northern Great Lakes. Ecosphere 2(1): Article 2. DOI: https://doi.org/10.1890/ES10-00062.1.

Swink, F., and G. Wilhelm. 1994. Plants of the Chicago Region, 4th edition. The Indiana Academy of Science, Lisle, Illinois.

U.S. Department of Agriculture. 2010. IPED Field Guide Pest Evaluation and Detection. Northeastern Areas State and Private Forestry. Newtown Square, Pennsylvania.

Webster, C. R., M. A. Jenkins, and G. R. Parker. 2001. A field test of herbaceous plant indicators of deer browsing intensity in mesic hardwood forests of Indiana, USA. Natural Areas Journal 21:149–158.

Woodall, C. W., and V. J. Monleon. 2007. Sampling protocol, estimation, and analysis procedures for the down woody materials indicator of the FIA program. U.S. Forest Service, Newtown Square, Pennsylvania.

Appendix A. List of all species sampled

Designates invasive species

Herbaceous - Fern / Fern Allies

Dennstaedtiaceae
Pteridium aquilinum

Dryopteridaceae
Dryopteris carthusiana
Dryopteris cristata
Dryopteris goldiana
Dryopteris intermedia
Polystichum braunii
Polystichum lonchitis

Equisetaceae
Equisetum arvense
Equisetum palustre
Equisetum pratense
Equisetum scirpoides
Equisetum sylvaticum

Lycopodiaceae
Huperzia lucidula
Lycopodium annotinum
Lycopodium clavatum
Lycopodium dendroideum
Lycopodium digitatum
Lycopodium obscurum

Onocleaceae
Matteuccia struthiopteris
Onoclea sensibilis

Ophioglossaceae
Botrychium virginianum

Osmundaceae
Osmunda claytoniana
Osmunda regalis
Osmundastrum cinnamomeum

Pteridaceae
Adiantum pedatum

Thelypteridaceae
Phegopteris connectilis
Thelypteris palustris

Woodsiaceae
Athyrium filix-femina
Gymnocarpium dryopteris

Herbaceous - Forb

Amaryllidaceae
Allium tricoccum

Apiaceae
Osmorhiza claytonii
Osmorhiza sp.
Sanicula marilandica

Apocynaceae
Apocynum androsaemifolium

Araceae
Arisaema triphyllum

Araliaceae
Aralia nudicaulis

Araliaceae
Aralia racemosa

Asparagaceae
Maianthemum canadense
Maianthemum racemosum ssp. *racemosum*
Maianthemum stellatum
Maianthemum trifolium
Polygonatum pubescens

Asteraceae
Achillea millefolium
Antennaria sp.
Arctium minus *
Cirsium palustre *
Cirsium sp.
Eurybia macrophylla
Eutrochium maculatum
Hieracium aurantiacum *

Hieracium sp.
Lactuca canadensis
Lactuca sp.
Lapsana communis
Solidago sp.
Symphyotrichum lanceolatum
Symphyotrichum lateriflorum
Symphyotrichum puniceum
Symphyotrichum sp.
Taraxacum officinale

<u>Balsaminaceae</u>
Impatiens capensis

<u>Berberidaceae</u>
Caulophyllum thalictroides

<u>Boraginaceae</u>
Myosotis sp.

<u>Brassicaceae</u>
Cardamine concatenata
Cardamine diphylla

<u>Caryophyllaceae</u>
Silene latifolia

<u>Cornaceae</u>
Cornus canadensis

<u>Ericaceae</u>
Chimaphila umbellata
Gaultheria hispidula
Gaultheria procumbens
Hypopitys monotropa
Monotropa uniflora
Orthilia secunda
Pyrola asarifolia
Pyrola sp.

<u>Geraniaceae</u>
Geranium robertianum

<u>Hypericaceae</u>
Hypericum perforatum *

Iridaceae
Iris versicolor

Lamiaceae
Clinopodium vulgare

Lamiaceae
Galeopsis tetrahit
Lycopus uniflorus
Mentha arvensis
Prunella vulgaris
Scutellaria lateriflora

Liliaceae
Clintonia borealis
Erythronium americanum
Streptopus amplexifolius
Streptopus lanceolatus var. *roseus*

Linnaeaceae
Linnaea borealis

Melanthiaceae
Trillium cernuum

Montiaceae
Claytonia caroliniana

Onagraceae
Chamerion angustifolium
Circaea alpina
Circaea canadensis ssp. *canadensis*
Circaea sp.
Epilobium ciliatum
Epilobium coloratum
Epilobium sp.

Orchidaceae
Cypripedium acaule
Cypripedium sp.
Epipactis helleborine *
Goodyera oblongifolia
Goodyera pubescens
Neottia convallarioides
Platanthera hyperborea

Orobanchaceae
Epifagus virginiana
Melampyrum lineare

Oxalidaceae
Oxalis montana

Papaveraceae
Dicentra canadensis
Sanguinaria canadensis

Plantaginaceae
Plantago major
Veronica chamaedrys
Veronica officinalis

Polygalaceae
Polygala paucifolia

Polygonaceae
Rumex acetosella *
Rumex britannica
Rumex crispus *
Rumex obtusifolius

Primulaceae
Lysimachia thyrsiflora
Trientalis borealis

Ranunculaceae
Actaea pachypoda
Actaea rubra
Actaea sp.
Anemone acutiloba
Anemone americana
Anemone quinquefolia
Caltha palustris
Clematis virginiana
Coptis trifolia
Ranunculus abortivus
Ranunculus acris
Ranunculus pensylvanicus
Ranunculus recurvatus
Ranunculus sp.
Thalictrum dioicum

Rosaceae
Agrimonia gryposepala
Agrimonia striata
Fragaria vesca
Fragaria virginiana
Geum aleppicum
Geum macrophyllum
Geum sp.

Rubiaceae
Galium triflorum
Mitchella repens

Sarraceniaceae
Sarracenia purpurea

Saxifragaceae
Mitella nuda

Urticaceae
Urtica dioica ssp. *gracilis*

Violaceae
Viola cucullata
Viola pubescens
Viola sp.

Herbaceous - Forb (vine)

Ericaceae
Epigaea repens

Polygonaceae
Fallopia cilinodis

Herbaceous - Graminoid

Cyperaceae
Carex arctata
Carex bebbii
Carex brunnescens
Carex communis
Carex crinita
Carex deweyana
Carex disperma
Carex gracillima
Carex gynandra

Carex hystericina
Carex intumescens
Carex laxiflora
Carex leptalea
Carex leptonervia
Carex oligosperma
Carex peckii
Carex pedunculata
Carex pensylvanica
Carex plantaginea
Carex projecta
Carex pseudocyperus
Carex radiata
Carex retrorsa
Carex rosea
Carex scabrata
Carex sp.
Carex stipata
Carex trisperma
Eriophorum sp.
Scirpus cyperinus
Scirpus sp.

<u>Juncaceae</u>
Juncus sp.

<u>Poaceae</u>
Avenella flexuosa
Brachyelytrum erectum
Calamagrostis canadensis
Cinna latifolia
Danthonia spicata
Dichanthelium sp.
Elymus hystrix var. *hystrix*
Glyceria canadensis
Glyceria sp.
Glyceria striata
Melica smithii
Milium effusum
Oryzopsis asperifolia
Phalaris arundinacea *
Poa compressa *
Poa sp.

Shr.ub

Adoxaceae
Sambucus racemosa var. *racemosa*
Viburnum lentago

Aquifoliaceae
Ilex mucronata
Ilex verticillata

Araliaceae
Aralia hispida

Betulaceae
Alnus incana ssp. *rugosa*
Corylus cornuta

Caprifoliaceae
Lonicera canadensis
Lonicera hirsuta

Cornaceae
Cornus alternifolia
Cornus sericea ssp. *sericea*

Cupressaceae
Juniperus communis

Diervillaceae
Diervilla lonicera

Ericaceae
Andromeda polifolia var. *latifolia*
Chamaedaphne calyculata
Gaylussacia baccata
Kalmia polifolia
Rhododendron groenlandicum
Vaccinium angustifolium
Vaccinium macrocarpon
Vaccinium membranaceum
Vaccinium myrtilloides
Vaccinium ovalifolium
Vaccinium oxycoccos

Grossulariaceae
Ribes cynosbati

Ribes glandulosum
Ribes hirtellum
Ribes lacustre
Ribes triste

Myricaceae
Myrica gale

Rhamnaceae
Rhamnus alnifolia

Rosaceae
Amelanchier sp. Group 2
Amelanchier sp. Group 3
Rosa blanda
Rubus allegheniensis
Rubus canadensis
Rubus hispidus
Rubus parviflorus
Rubus pubescens
Rubus sachalinensis var. *sachalinensis*

Taxaceae
Taxus canadensis

Shrub - Woody Vine

Anacardiaceae
Toxicodendron rydbergii

Caprifoliaceae
Lonicera dioica

Solanaceae
Solanum dulcamara *

Tree

Betulaceae
Betula alleghaniensis
Betula papyrifera
Carpinus caroliniana
Ostrya virginiana

Cupressaceae
Thuja occidentalis

Fagaceae
Fagus grandifolia
Quercus rubra

Malvaceae
Tilia americana

Oleaceae
Fraxinus nigra
Fraxinus pennsylvanica

Pinaceae
Abies balsamea
Larix laricina
Picea glauca
Picea mariana
Pinus banksiana
Pinus resinosa
Pinus strobus
Tsuga canadensis

Rosaceae
Prunus pensylvanica
Prunus serotina
Prunus virginiana
Sorbus decora

Salicaceae
Populus balsamifera
Populus grandidentata
Populus tremuloides

Sapindaceae
Acer pensylvanicum
Acer rubrum
Acer saccharum
Acer spicatum

Ulmaceae
Ulmus americana

Tree / Shrub

Rosaceae
Amelanchier sp.
Malus sp.

Salicaceae
Salix sp.

NPS 625/165452, November 2019

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525