



Forest Health Monitoring at Grand Portage National Monument

2014 Field Season

Natural Resource Report NPS/GLKN/NRR—2015/1072



ON THE COVER

Clockwise from top left: cedar stand; browsed *Clintonia borealis*; view of the Lake Superior trail terminus area and Grand Portage Bay; vegetation monitoring staff hiking along the Grand Portage trail.

All photographs by NPS staff

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Executive Summary

Forest health monitoring programs can provide routine feedback of key indices, such as forest structure and species richness, and provide managers with periodic updates of ecosystem health. This is especially relevant near ecotone boundaries, where climate change impacts are expected to be greatest. Grand Portage National Monument is situated within the southern boreal forest and the suitable habitat for most of its common overstory species is expected to shift northward and out of the park as climate change progresses. A comprehensive forest monitoring program was initiated at Grand Portage National Monument in 2007 with the establishment of 20 permanent plots; in 2014 we resampled the original 20 plots and installed three more. We classified plots into either upland or wet mesic habitat and present here the current status of multiple metrics of forest health. We then assess short-term change, comparing 2007 with 2014 to ask three broad questions about forest health addressing 1) changes in overstory tree density and basal area, 2) impacts of browse on the herbaceous layer, and 3) changes in overall community composition.

Our results for the first question show that, when pooling all overstory tree species together, both density and basal area increased from 2007 to 2014, but were not significantly different between upland and wet-mesic habitats. For individual tree species of interest, density increased for both *Abies balsamea* (balsam fir) and *Populus tremuloides* (trembling aspen) while basal area of *A. balsamea* increased, as well. Neither density nor basal area differed between sampling events or habitats for *Betula papyrifera* (paper birch) or *Fraxinus nigra* (black ash). Our second question addressed the impacts of browse on herbaceous species. We tested whether the frequency of quadrats supporting at least one preferred herbaceous species differed between habitats or changed over time. We found that this frequency did not differ between the two sampling periods, but tended to depend on habitat: 81% of quadrats in upland plots supported at least one preferred browse species, while only 66% of wet mesic sites did so. We also examined height of two understory preferred browse species: height of *Clintonia borealis* (bluebead lily) increased between the sampling events, but did not differ between habitats. Height of *Streptopus* spp. (twisted stalk) did not differ between sampling years or habitats. The effect of sampling year on overall plot species richness differed between the two habitats. In 2007, species richness was greater in upland plots (61.2 vs. 59.5), although in 2014, richness was greater in wet mesic plots (82.2 vs. 71). Pooled across both sampling years, the modified floristic quality index, a collective measure of species' specificity to habitats, was greater in wet mesic plots (5.08 vs. 4.88).

Our work demonstrates the dominance of *A. balsamea*, a species whose suitable habitat is projected to ultimately shift out of the region as climate change continues. This work also shows the limited extent of three species expected to remain in the region: *B. papyrifera*, *Pinus strobus* (white pine), and *Thuja occidentalis* (white cedar). Park managers have implemented a project to promote *P. strobus* within the park, through plantings, advance regeneration release, and seed rain enhancement, while also manually controlling *A. balsamea*. This project will encourage current regeneration of *P. strobus* so that seed sources may be available for future regeneration once *A. balsamea* begins to die out. Managers should continue promoting the growth of species expected to remain in the area,

including *B. papyrifera* and *T. occidentalis*. The 23 permanent monitoring plots will be resampled in 2023 and trend assessments can be made at that time.

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Introduction

Forest health monitoring programs can provide information on the abundance and structure of individual species of interest (Duchesne et al. 2005, Fiedler and McKinney 2014), as well as the composition and integrity of plant communities as a whole (Steinman 2004, Auclair 2005). Provided they are designed appropriately, monitoring programs can elucidate relationships with other biota such as herbivores and insect and fungal pests. These programs can be especially valuable in forests where timber harvest is not occurring, a designation that includes many U.S. and Canadian national parks, and state and provincial parks. Although often designated as “unmanaged,” park personnel are often tasked with promoting healthy forests that would otherwise occur in the absence of ongoing anthropogenic influences. Actions such as reductions in herbivore abundance (Tanentzap et al. 2011), prescribed fire (Mutch and Parsons 1998), thinning as a fire surrogate (Schwilk et al. 2009), seedbed preparation (York et al. 2012), snag creation (Brandeis et al. 2002), and invasive species removal (Flory and Clay 2009) are all examples of active management. Ongoing forest health monitoring programs are often needed by park managers as confirmation of a problem and as documentation before embarking on such projects.

Grand Portage National Monument (GPNM) is a 287 ha tract in northeastern Minnesota, near the boundary of northern mixed temperate forests and southern boreal forests. This park was established largely to commemorate the cultural legacy of the fur trade era and the native peoples of the region. It includes a 13.7 km foot path connecting Lake Superior with the Pigeon River (Figure 1) and which serves as a portage trail, bypassing several major waterfalls on the lower reaches of the river. The park is surrounded by the Grand Portage Band of Lake Superior Chippewa reservation, a mosaic of forest and wetlands with large areas managed for timber.

Cultural resources at GPNM are tightly linked to natural resources, as both the fur traders and native peoples relied heavily on the forest. Grand Portage park managers wish to promote species of cultural interest that are more resilient to impending climate-induced changes, thereby promoting both cultural and biologic integrity. These species include *Acer saccharum* Marsh. (sugar maple), *Larix laricina* (Du Roi) K. Koch (tamarack), *Pinus resinosa* Aiton (red pine), *Pinus strobus* L. (white pine), *Betula papyrifera* Marshall (paper birch) and both *Populus tremuloides* Michx. (trembling aspen) and *Populus grandidentata* Michx. (bigtooth aspen). These actions will aid in visitor interpretation of the fur trade, help maintain traditional uses of plants by the Ojibwa people, and bring the species composition of the forests more in line with that historically maintained via natural disturbance processes (National Park Service 2003). Early settlement (prior to 1870) forest vegetation of GPNM varied along the length of the trail. On the lower trail, nearer to Lake Superior, a matrix of *P. tremuloides*, *B. papyrifera*, *Betula alleghaniensis* Britton (yellow birch), and mixed conifers were dominant, while further inland, *P. strobus* and *P. resinosa* were most common on the landscape (Marschner 1974). Park managers wish to promote the pine component, especially *P. strobus*, in GPNM forests. The current structure and composition are largely a result of human-induced fires during and after the settlement period (ca. 1870-1910) followed by decades of fire suppression (White and Host 2003). Two early successional species, *B. papyrifera* and *P. tremuloides*, are now prominent as scattered mature individuals amid large numbers of standing dead

trees and downed boles. Gaps are largely filled with young *Abies balsamea* (L.) Mill (balsam fir), along with dense *Acer spicatum* Lam. (mountain maple) and *Corylus cornuta* Marshall (beaked hazel).

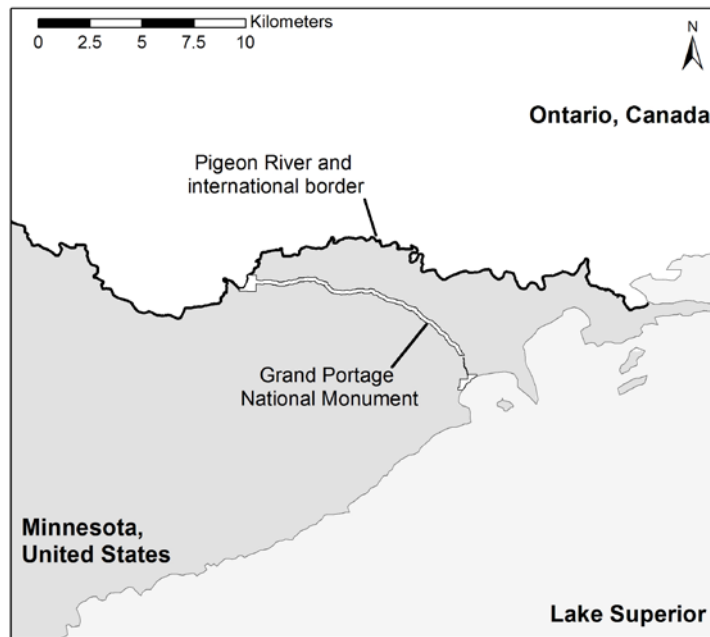


Figure 1. The location of Grand Portage National Monument showing proximity to Lake Superior, the Pigeon River, and Ontario, Canada.

At the inception of a long-term monitoring program in 2007, the National Park Service (NPS) Great Lakes Inventory and Monitoring Network established and sampled 20 permanent forest monitoring plots at GPNM. These plots were resampled in 2014 and an additional three plots were established for a total of 23. Here we summarize the status of GPNM forests in 2014 and provide comparisons with the first sampling in 2007. Metrics reported on include tree basal area and diameter, seedling, shrub, and herb abundance, coarse woody material size and abundance, and browse and disease occurrence. We assess forest change from 2007-2014 using data from both sampling events to answer the following broad questions:

- 1) Have density or basal area (the cross sectional area of tree boles) of trees changed during the sampling interval, and if so, how is this manifested? We posed this question first by including all species sampled, then by looking only at key species of interest: *A. balsamea*, *P. tremuloides*, *B. papyrifera*, *P. strobus*, and *Fraxinus nigra* Marsh. (black ash).
- 2) How has browse impacted GPNM forests? We tested for evidence of indirect impacts of browse on the herbaceous layer. This evidence is generally manifested as fewer and smaller herbaceous species. We looked at the abundance of preferred browse species, collectively, then assessed height for two of these targeted preferred browse taxa on which additional data were collected.

3) How has the plant community changed? We tested for differences in species richness and the modified floristic quality index between habitats and sampling events. We also used non-metric multidimensional scaling to see how plot locations shifted, relative to one another, in ordination space during the seven-year sampling interval.

Methods

Study Area and Sampling Design

Grand Portage National Monument is composed of a 13.7 km long foot trail connecting Lake Superior with the Pigeon River; the park boundary provides a forested buffer of about 100 meters on both sides of the trail for most of its length. At the Lake Superior terminus, a 28 ha tract of culturally maintained vegetation (mowed, garden, etc.) and historic buildings occupy the site. The Pigeon River trail terminus includes an expanded area of 44 ha, which is forested, with small openings for two primitive campsites. Our sampling frame included all park lands except the Lake Superior tract, and the nearest 1.0 km of trail to the Lake, since the park boundary here was only slightly wider than the trail itself.

The Monument is located within the Northern Superior Upland section (212L) of the Laurentian Mixed forest province (Ecoregion 212) (Cleland et al. 1997). The mean July temperature high and low in Grand Portage for the time period of 1992-2014 were 23.3 °C and 11.4 °C, respectively. For January during that same time period, the mean high and low were -6.2 °C and -16.8 °C, respectively. Mean annual precipitation from 1992-2014 was 75.4 cm with 44% falling from May through August (www.climateanalyzer.org).

The Grand Portage Trail generally traverses high ground although several small streams cross it; moist pockets and forested wetlands are not uncommon within the buffer area on either side of the trail. A 2.1 ha beaver pond is located along the trail, 9.4 km from the Lake Superior terminus.

Sampling was conducted at GPNM from 8 June–29 July, 2007 and 22 June–19 August 2014. Sites were selected prior to the 2007 sampling season using a generalized random-tessellation stratified design (Stevens and Olsen 2004), ensuring that sites were both randomly located and spatially balanced throughout the park. In accordance with the monitoring protocol, all sites were required to have a minimum of 10% cover of tree species, thus eliminating areas largely or exclusively covered with *Alnus* sp. Mill. (alder).

Field Methods

Basic Measurements

Sites were sampled using the Hybrid plot (Figure 2) developed specifically to meet the needs of the Great Lakes Network's long-term monitoring program (Johnson et al. 2006, Johnson et al. 2008). The plot is composed of three 50-m parallel transects oriented east–west; the end of each transect is permanently demarcated with rebar sunk flush into the ground. Tree data were collected in a 6-m-wide band along the length of each transect. Tree data collected included species, diameter at breast height (DBH), whether the tree was alive or dead, and select characteristics indicating damage and/or disease. Trees were defined as having a DBH ≥ 2.5 cm.

Groundlayer vegetation data were collected in 1 m² quadrats placed every 5 m along each transect (n = 30 per plot). Within each quadrat, we recorded the presence of all herbaceous, vine, and shrub species present, and counted and recorded tree seedlings. Seedlings were defined as tree species <2.5

cm DBH, but at least 15 cm in height and showing evidence of growth from the previous year. Some species we commonly encountered reproduce vegetatively (e.g., *P. tremuloides*). Individual sprouts (i.e., both ramets and genets) were deemed “seedlings” if no aboveground connections between them and a parent tree were visible. We measured coarse woody materials (CWM) along each of the three transects using the planar intercept method (Brown 1974, Woodall and Williams 2007). For all pieces ≥ 7.5 cm in diameter at the point of transect intercept, we recorded the diameter at intercept; the small and large end diameters; the length; the decay class (Woodall and Williams 2007); and, if possible, the species. Because we defined CWM as having a diameter ≥ 7.5 cm, the length of a piece was measured only along the section where the diameter met or exceeded this amount. These methods differed from those of 2007 where we only recorded the piece length and the diameter at the transect intercept. Finally, we performed a half-hour time-delimited search of the entire 50 m $\times$ 100 m plot area to locate any additional species not recorded in any other the sampling.

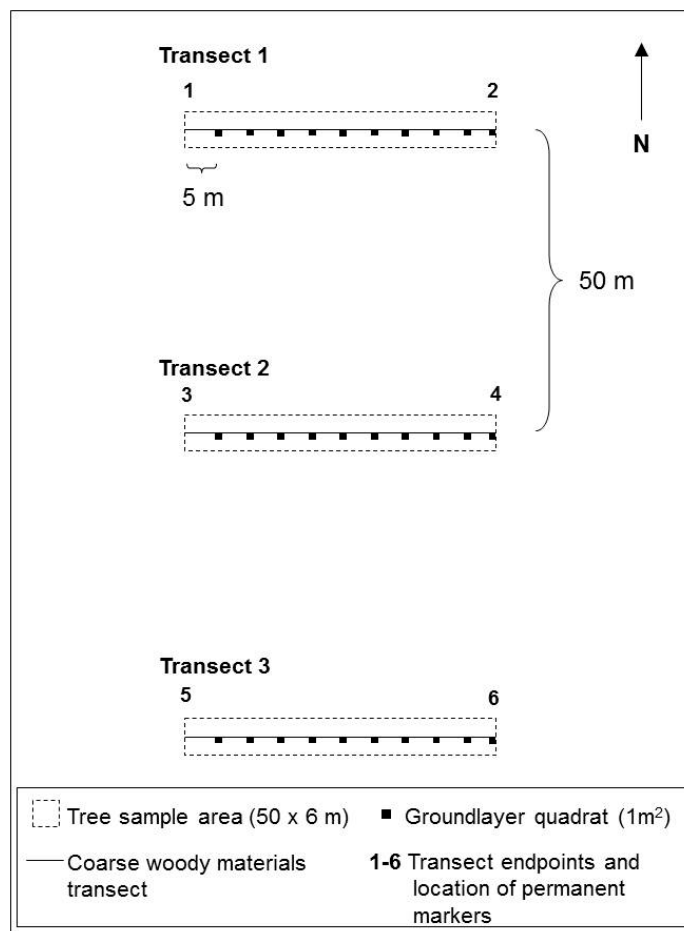


Figure 2. The Hybrid plot layout, showing three parallel transects, each 50 m long and oriented east-to-west.

Browse Assessments

We examined browse pressure using two distinct measures. *Direct browse* is an assessment of white-tailed deer (*Odocoileus virginianus* Zimm.) and moose (*Alces alces* L.) browse visible on woody

species. This includes bite marks and leaf stripping, *directly evident and observable* on individual plants. Our methods did not include an assessment of bark stripping, nor did we include browse attributable to snowshoe hare (*Lepus americanus* Erxleben). *Indirect browse* is 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).

Direct browse was assessed in 3.14 m² (1 m radius) circles centered every five meters along each of the three 50-m transects, and along four additional transects flanking the east and west sides of the plot (Figure 3). This resulted in 68 direct browse circles per plot, equal to a total sampling area of 213 m² 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 3.0 m in height – and noted those circles (and species) with evidence of deer or moose browse. Typically, winter browse surveys are conducted in the spring, prior to the new season's growth. Because we were not able to sample in the spring, we only considered a plant browsed when it was apparent that the browse occurred during the current season's growth. This was evidenced by the bite marks on green and/or non-woody tissue. This was often accompanied with new growth arising from the bud immediately below the point of browse.

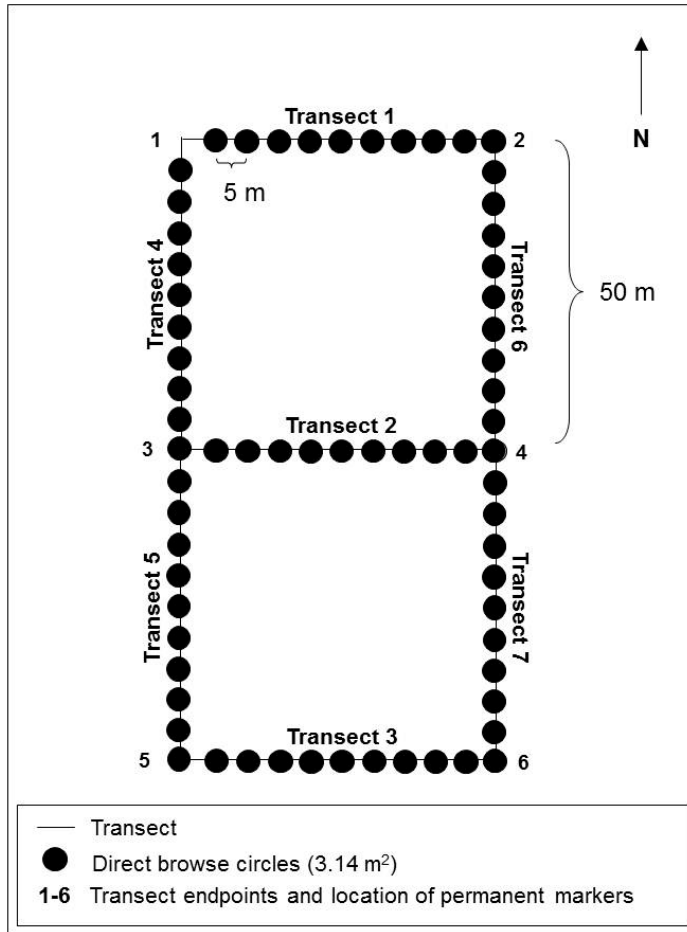


Figure 3. Location of the direct browse sampling circles in a plot.

Direct browse data were used to calculate the *Proportion of Browse* for each plot and habitat; this was calculated by first dividing the number of species browsed by the number of species present in direct browse circles. The proportion of browse values range from 0 to 1, where 0 represents a browse circle where no species present were browsed, and 1 represents a browse circle where all species present were browsed (Frerker and Waller 2013). We then calculated the mean value for all browse circles within each plot, as well as each habitat. The proportion of browse calculation can also be used to determine which species are being browsed more frequently relative to others.

The direct browse methods employed in 2014 differed considerably from those of 2007 when we simply noted the closest woody plants to each of the thirty herbaceous quadrats and recorded whether browse was present. Because of the differences in methods, no comparisons are made here between the two time periods.

The data collected for the direct browse assessments were also used to calculate *Frequency of Occurrence* of shrub and woody vine species present in each plot. This was calculated as the ratio of the number of browse circles in which a shrub or woody vine species was present to the total number

of browse circles in the plot. Because of the difference in methodology between sampling events, no comparisons could be made between 2007 and 2014.

We assessed the indirect impacts 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. While we are primarily interested in deer impacts, browse from other species is possible. Because moose browse on herbaceous plants is generally limited to aquatic species, and moose browse on terrestrial species typically occurs on woody shrubs and small tree branches, we assumed that browse impacts on terrestrial herbs due to moose were minimal. In addition, moose densities have remained low for the decade preceding this work (DelGiudice 2015). Snowshoe hare (*Lepus americanus* Erxleben), however, do browse many of the same herbaceous species as deer (Belovsky 1984; Rouleau et al. 2002; Frerker et al. 2013); attributing browse impacts to either mammal is only possible using supporting, ancillary data. The preferred browse species identified were *Actaea pachypoda* Elliott (white baneberry), *A. rubra* (Aiton) Willd. (red baneberry), *Aralia nudicaulis* L. (wild sarsaparilla), *Clintonia borealis* (Aiton) Raf. (bluebead lily), *Maianthemum racemosum* (L.) Link (false Solomon's seal), *Streptopus amplexifolius* (L.) DC. (clasping twistedstalk), *S. lanceolatus* var. *roseus* (Michx.) Reveal (rosy twistedstalk), and *Trillium cernuum* L. (whip-poor-will flower). We then used the groundlayer data to look at *Frequency of Presence*. For the current work, we pooled species and determined the frequency of quadrats within plots where at least one of these species was present. We also assessed indirect impacts of white-tailed deer browse by measuring the tallest of each of three target taxa (*C. borealis*, *Streptopus* spp., and *T. cernuum*), within each quadrat where they were present. For each taxon, we then calculated *Maximum Height*, as the mean value of the tallest individuals in the plot. We elected to replace one of our 2007 target taxa (*Maianthemum canadense* Desf. [Canada mayflower]) with a different species in 2014 (*T. cernuum*), leaving only two taxa in common between the two sampling periods.

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. 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. In 2007, we attempted to assign actual

diseases or causal agents to diseased or injured trees, rather than focus on identification of the symptoms. Because of the differences in methods, no comparisons were made here between the two time periods.

Visual Assessment/Photo Points

We took six photographs at each plot. The six photo points were located at each of the transect endpoints, with the photo taken facing into the plot (i.e., due east at points 1, 3, and 5, and due west at points 2, 4, and 6; see Figure 1).

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), *Pyrola* sp. Raf. (shinleaf), and Asteraceae (daisy family). For *Amelanchier* sp. (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) 2014).

Analysis and Classification Methods

Habitat Identification and Characterization

We grouped plots into similar habitat types using cluster analysis. 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). Understory (herb and shrub) abundance for each species-plot combination was determined by 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% (3 of 23) of the plots. For this classification, we used PC-ORD software (McCune and Grace 2002) and selected a Sørensen distance measure and a flexible beta linkage ($\beta = -0.25$). Habitat type names were assigned 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.

We used indicator species analysis (Dufrêne and Legendre 1997) to identify characteristic understory species in each habitat type; this returns an indicator value for each species in each habitat type, quantifying the abundance within, and faithfulness to, that type. This analysis was based on the frequency of occurrence of herbaceous and shrub species within quadrats in each plot. We limited inclusion to those species present in at least three plots. Higher importance values indicate greater abundance and habitat type faithfulness than lower indicator values. In addition to an indicator value

for each species-group combination, for each species, this analysis also provides a probability (p) of an indicator value equal to or greater than the highest reported value from among all groups. We identified characteristic species for both types as those species for which $p \leq 0.01$. We used PC-ORD software (McCune and Grace 2002) for this analysis.

Functional Groups

All taxa were assigned to classes within each of four functional 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.”

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 GPNM. 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). Because CoC values have not been assigned for terrestrial species in Minnesota, we used the values defined for the province of Ontario (Oldham et al. 1995) for species present in 2014 sampling. For two species, however, (*Salix planifolia* Pursh (diamondleaf willow) and *Viburnum edule* (Michx.) Raf. (squashberry)), these were not listed in the Ontario publication; for these two species, we used CoC values assigned for wetland species in the state of Minnesota (Milburn et al. 2007). We then used CoC values to calculate the modified floristic quality index (mFQI) (Rooney and Rogers 2002, Sanders and Grochowski 2014) where mFQI is simply the mean of the CoC values for all species present within that plot.

Forest Change Analyses

To address our first question about forest change, we used two-way repeated measures ANOVA and tested whether tree density and basal area differed between sampling periods, and also between habitat types. We performed this analysis pooling all tree species together, then also for each key species of interest, individually. For all two-way repeated measures ANOVA tests, three effects, *habitat*, *year*, and their interaction term, were considered fixed; the *plot(habitat)* term, and its interaction with *year*, were considered random effects. We also tested whether total tree seedling

density differed between sampling periods or habitat, using the same model. All ANOVA tests were conducted using JMP (v 7; SAS Institute Inc., Cary, NC, US). Lastly, we compared the diameter-distribution of trees in 2007 with that in 2014, by carrying out the Kolmogorov-Smirnov test using the R statistical software package (R Core Team 2012).

Our second question focused on browse impacts. We tested two indirect browse indices: the frequency of quadrats in each plot supporting at least one preferred browse species, and the mean plot height of preselected target taxa. Again, we used two-way repeated measures ANOVA and tested whether these indices differed between years and habitats.

Our third question asked how plant communities differ; we answered this using a suite of approaches. We first tested whether plot-level species richness and the mFQI differed between years or habitats, using two-way repeated measures ANOVA. For all 20 plots that were resampled, we then used non-metric multidimensional scaling (NMS) (McCune and Grace 2002) to view the similarity of plots relative to one another, in ordination space. We applied vectors to denote the change in each plot between the two sampling events. Because we are assessing change in only a seven year interval, we performed separate analyses for the overstory (trees) and understory (herbs and shrubs). We felt the changes observed in the overstory would largely be due to longer-term successional dynamics, while variation in the understory would likely be in response to shorter-term impacts, including variation in browse pressure and precipitation. As with cluster analysis, the NMS was based on the importance value of trees for the overstory analysis and the frequency of herbs and shrubs for the understory analysis. We limited our dataset to taxa with at least three occurrences over the two sampling events. We also eliminated data on plants only identified to *Carex* sp. L. and *Poaceae* (grasses) due to the broad ecological width occupied by these two groups. We used an automated procedure beginning with 250 runs of real data and 250 runs to evaluate stability. These resulted in solutions with a final stress of 8.67 in the overstory dataset and 10.85 for the understory data.

Results

A total of 23 plots were sampled in 2014, 20 of which were initially sampled in 2007. From among all 23 plots, we identified 20 tree species, 31 shrub and woody vine taxa, and 148 taxa of herbs. A complete list of species located in 2014 sampling is presented in Appendix A; a list of those considered invasive, along with plot numbers are presented in Appendix B. Plots were classified to one of two habitat types: upland spruce-fir-aspen (18 plots) and wet mesic mixed conifer/hardwood (5 plots) (Table 1, Figure 4). The National Vegetation Classification System classifications of plots are shown in Appendix C.

Table 1. The two habitat types sampled and the plots classified in each. Plots in bold font are those that were sampled in 2007 as well as 2014.

Habitat type	Plots
Upland	2002, 2004, 2005, 2006, 2008, 2011, 2012, 2013, 2014, 2015, 2018, 2019, 2020, 2021, 2022, 2023, 2025, 2027
Wet mesic	2003, 2007, 2010, 2024, 2026

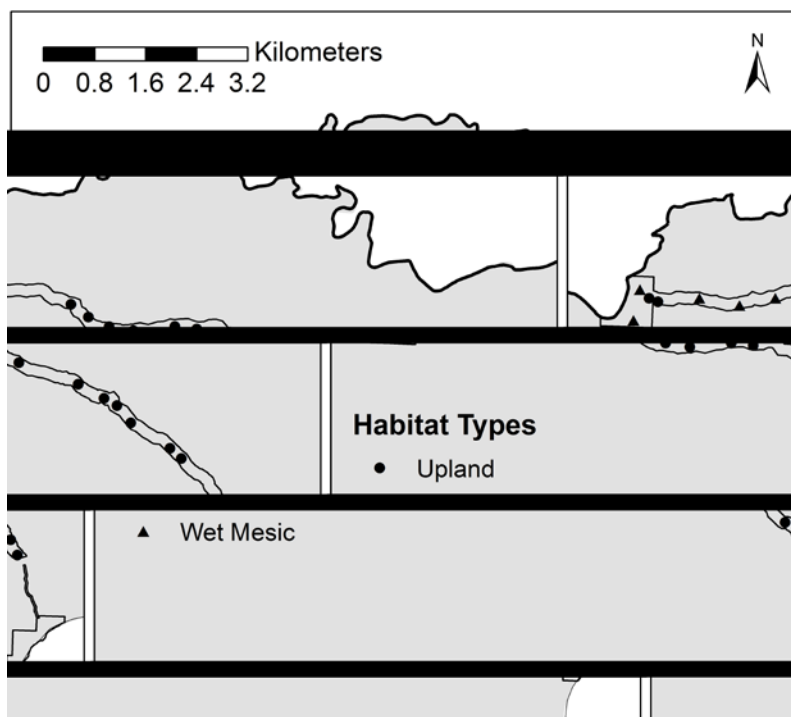


Figure 4. Distribution of plots, by habitat type, at Grand Portage National Monument.

2014 Status

Upland Habitat

Upland sites were characterized by abundant *A. balsamea* across small and medium size classes, abundant *P. tremuloides* in smaller size classes, and a small amount of *Picea glauca* (Moench) Voss

(white spruce) across all size classes (Table 2, Figure 5). *Betula papyrifera* was also present in limited amounts in the smallest size classes.

Seedling density was highest (7,185 seedlings/ha) for *A. spicatum*, a species that typically does not get much larger than 5 cm DBH (Table 3). Seedling density was also high for *A. balsamea* (4,093 seedlings/ha) and *P. tremuloides* (1,130 seedlings/ha). Seven shrub species were present at greater than 20% frequency including *Corylus cornuta*, *Rubus parviflorus* Nutt. (thimbleberry), *Alnus incana* ssp. *rugosa* (Du Roi) R.T. Clausen (speckled alder), and *Diervilla lonicera* Mill. (bush honeysuckle) (Table 4).

Characteristic understory species in upland habitat were the shrub, *R. parviflorus* ($p = 0.0472$), the sedge, *Carex pedunculata* Muhl. ex Willd. (longstalk sedge) ($p = 0.0404$), and three forbs: *Pyrola asarifolia* Michx. (pink shinleaf) ($p = 0.0026$), *A. nudicaulis* ($p = 0.0014$), and *Eurybia macrophylla* (L.) Cass. (bigleaf aster) ($p = 0.0018$).

Table 2. Basal area and density of live trees (≥ 2.5 cm DBH) in upland habitat.

Latin name	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood			
<i>Acer saccharum</i>	sugar maple	<0.01	1.85
<i>Acer spicatum</i>	mountain maple	0.53	520.99
<i>Betula papyrifera</i>	paper birch	2.06	124.07
<i>Fraxinus nigra</i>	black ash	0.15	48.77
<i>Populus balsamifera</i>	balsam poplar	0.01	3.09
<i>Populus tremuloides</i>	quaking aspen	9.27	436.42
<i>Prunus pensylvanica</i>	pin cherry	0.01	2.47
<i>Prunus virginiana</i>	chokecherry	0.01	11.11
<i>Salix bebbiana</i>	gray willow	0.01	6.17
<i>Sorbus decora</i>	northern mountain ash	0.01	9.26
<i>Ulmus americana</i>	American elm	<0.01	0.62
Conifer			
<i>Abies balsamea</i>	balsam fir	10.59	1,401.85
<i>Picea glauca</i>	white spruce	2.04	74.07
<i>Picea mariana</i>	black spruce	0.13	5.56
<i>Pinus strobus</i>	white pine	2.18	16.05
<i>Thuja occidentalis</i>	northern white cedar	0.29	4.32
Total		27.30	2,666.67

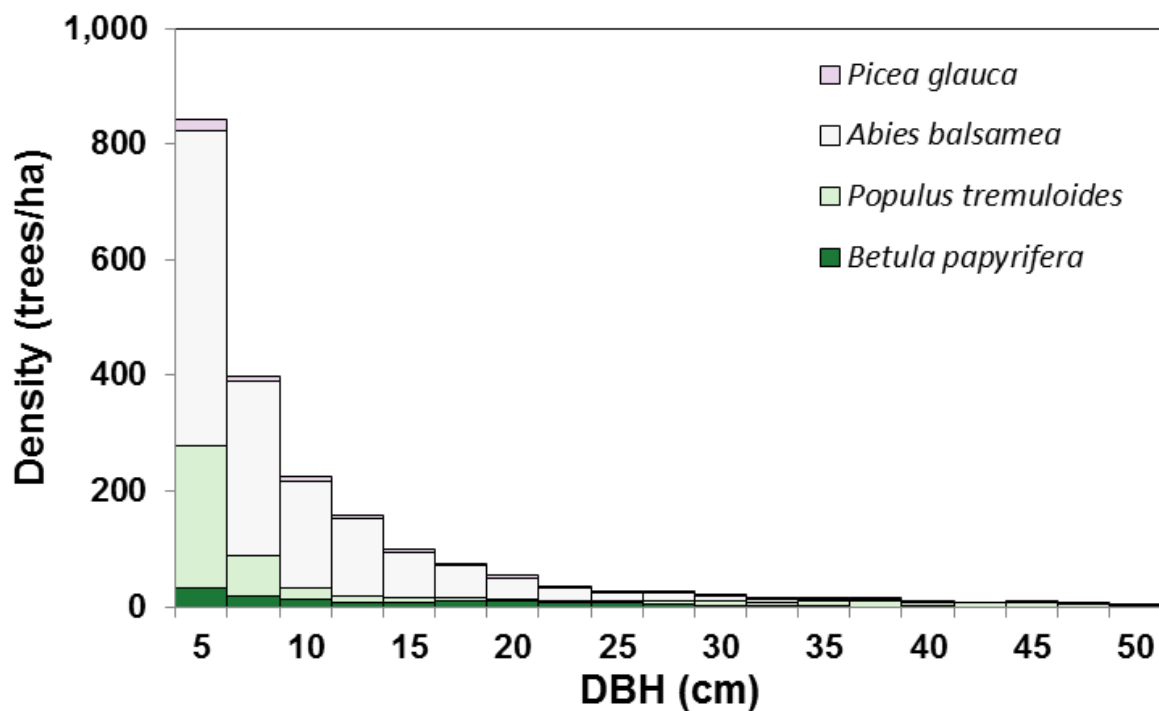


Figure 5. Density-diameter graph of common overstory species in upland habitat.

Table 3. Seedling density of overstory species in upland habitat.

Species	Common name	Density (seedlings/ha)
Hardwood		
<i>Acer spicatum</i>	mountain maple	7,185.19
<i>Betula papyrifera</i>	paper birch	148.15
<i>Fraxinus nigra</i>	black ash	314.81
<i>Populus tremuloides</i>	quaking aspen	1,129.63
<i>Prunus pensylvanica</i>	pin cherry	148.15
<i>Prunus virginiana</i>	chokecherry	814.81
<i>Sorbus decora</i>	northern mountain ash	407.41
Conifer		
<i>Abies balsamea</i>	balsam fir	4,092.59
<i>Picea glauca</i>	white spruce	240.74
<i>Picea mariana</i>	black spruce	18.52
<i>Pinus strobus</i>	white pine	74.07
<i>Thuja occidentalis</i>	northern white cedar	18.52
Total		14,592.59

Table 4. Shrub frequency in upland habitat.

Species	Common name	Frequency
<i>Corylus cornuta</i>	beaked hazel	0.482
<i>Rubus pubescens</i>	dwarf red blackberry	0.439
<i>Rubus parviflorus</i>	thimbleberry	0.402
<i>Diervilla lonicera</i>	bush honeysuckle	0.230
<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder	0.226
<i>Cornus sericea</i>	gray dogwood	0.215
<i>Rosa acicularis</i>	prickly rose	0.213
<i>Lonicera canadensis</i>	fly honeysuckle	0.162
<i>Ribes triste</i>	swamp red currant	0.153
<i>Amelanchier</i> sp. (Group 3)	serviceberry	0.116
<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	red raspberry	0.108
<i>Amelanchier</i> sp. (Group 2)	serviceberry	0.093
<i>Alnus viridis</i> ssp. <i>crispa</i>	green alder	0.079
<i>Lonicera hirsuta</i>	hirsute honeysuckle	0.041
<i>Ribes hirtellum</i>	hairystem gooseberry	0.034
<i>Ribes glandulosum</i>	skunk currant	0.012
<i>Taxus canadensis</i>	Canada yew	0.007
<i>Ribes lacustre</i>	prickly currant	0.004
<i>Symphoricarpos albus</i>	snowberry	0.003
<i>Salix</i> sp.	willow	0.002
<i>Viburnum opulus</i> var. <i>americanum</i>	American cranberrybush	0.002
<i>Viburnum rafinesqueanum</i>	downy arrowwood	0.002
<i>Juniperus communis</i> var. <i>depressa</i>	common juniper	0.001
<i>Salix planifolia</i>	diamondleaf willow	0.001
<i>Sambucus racemosa</i>	red elderberry	0.001
<i>Viburnum edule</i>	squashberry	0.001

Wet Mesic Habitat

Like the upland habitat, wet mesic sites contained a large amount of *P. tremuloides* and *A. balsamea*, along with *P. glauca* (Table 5, Figure 6). Wet mesic sites were distinguished from upland sites, however, by also supporting *Thuja occidentalis* L. (eastern white cedar), *Picea mariana* (Mill.) Britton, Sterns & Poggenb. (black spruce), and *F. nigra*, three species often found in moist or even hydric habitats.

Seedling density was at least 1,000 seedlings/ha for five species in wet mesic habitat, including *T. occidentalis* at 2,600 seedlings/ha (Table 6). Nine shrub species were present at greater than 20% frequency including *C. cornuta*, *R. parviflorus*, *A. incana* ssp. *rugosa*, and *Lonicera canadensis* Bartram & W. Bartram ex Marshall (American fly honeysuckle) (Table 7).

Characteristic understory species in wet mesic habitat were *Calamagrostis canadensis* (Michx.) P. Beauv. (bluejoint) ($p = 0.0876$), *Impatiens capensis* Meerb. (jewelweed) ($p = 0.0162$), and *Galium triflorum* Michx. (fragrant bedstraw) ($p = 0.0512$).

Table 5. Basal area and density of live trees (≥ 2.5 cm DBH) in wet mesic habitat.

Latin name	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood			
<i>Acer rubrum</i>	red maple	0.06	8.89
<i>Acer spicatum</i>	mountain maple	0.27	293.33
<i>Betula papyrifera</i>	paper birch	2.53	115.56
<i>Fraxinus nigra</i>	black ash	0.91	157.78
<i>Populus balsamifera</i>	balsam poplar	<0.01	2.22
<i>Populus tremuloides</i>	quaking aspen	10.40	842.22
<i>Prunus virginiana</i>	chokecherry	0.01	6.67
<i>Salix bebbiana</i>	gray willow	0.02	13.33
<i>Sorbus decora</i>	northern mountain ash	0.02	15.56
Conifer			
<i>Abies balsamea</i>	balsam fir	3.19	737.78
<i>Picea glauca</i>	white spruce	0.79	57.78
<i>Picea mariana</i>	black spruce	0.59	20.00
<i>Pinus strobus</i>	white pine	3.84	26.67
<i>Thuja occidentalis</i>	northern white cedar	5.09	288.89
Total		27.71	2,586.67

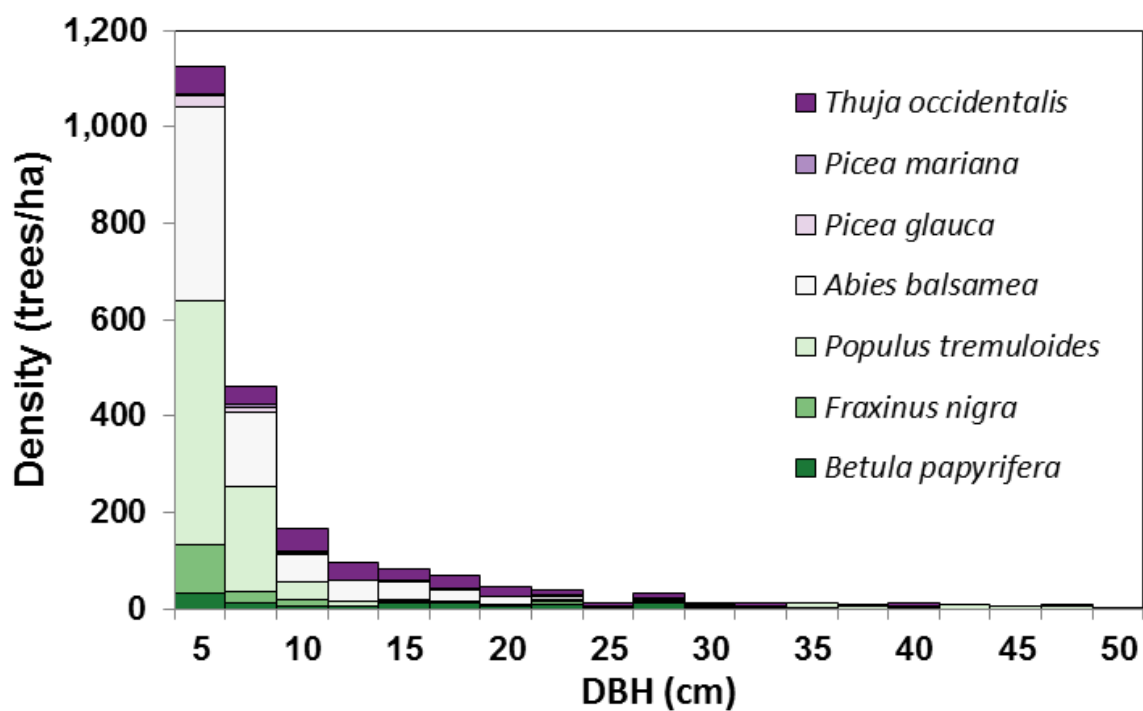


Figure 6. Density-diameter graph of common overstory species in wet mesic habitat.

Table 6. Seedling density of overstory species in wet mesic habitat.

Species	Common name	Density (seedlings/ha)
Hardwood		
<i>Acer spicatum</i>	mountain maple	4,800.00
<i>Betula papyrifera</i>	paper birch	200.00
<i>Fraxinus nigra</i>	black ash	666.67
<i>Populus tremuloides</i>	quaking aspen	1,133.33
<i>Prunus virginiana</i>	chokecherry	1,000.00
<i>Salix bebbiana</i>	gray willow	200.00
Conifer		
<i>Abies balsamea</i>	balsam fir	2,666.67
<i>Picea mariana</i>	black spruce	66.67
<i>Pinus strobus</i>	white pine	133.33
<i>Thuja occidentalis</i>	northern white cedar	2,600.00
Total		13,466.67

Table 7. Shrub frequency in wet mesic habitat.

Species	Common name	Frequency
<i>Corylus cornuta</i>	beaked hazel	0.582
<i>Rubus pubescens</i>	dwarf red blackberry	0.459
<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	red raspberry	0.315
<i>Rosa acicularis</i>	prickly rose	0.247
<i>Lonicera canadensis</i>	fly honeysuckle	0.232
<i>Ribes triste</i>	swamp red currant	0.224
<i>Rubus parviflorus</i>	thimbleberry	0.224
<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder	0.218
<i>Cornus sericea</i>	gray dogwood	0.218
<i>Diervilla lonicera</i>	bush honeysuckle	0.200
<i>Amelanchier</i> sp. (Group 3)	serviceberry	0.129
<i>Amelanchier</i> sp. (Group 2)	serviceberry	0.074
<i>Ribes hirtellum</i>	hairystem gooseberry	0.068
<i>Lonicera hirsuta</i>	hirsute honeysuckle	0.044
<i>Ribes glandulosum</i>	skunk currant	0.044
<i>Viburnum rafinesqueanum</i>	downy arrowwood	0.038
<i>Viburnum edule</i>	squashberry	0.009
<i>Viburnum opulus</i> var. <i>americanum</i>	American cranberrybush	0.009
<i>Vaccinium angustifolium</i>	lowbush blueberry	0.006
<i>Crataegus</i> sp.	hawthorn	0.003
<i>Lonicera oblongifolia</i>	swamp fly honeysuckle	0.003
<i>Rhamnus alnifolia</i>	alderleaf buckthorn	0.003
<i>Ribes lacustre</i>	prickly currant	0.003
<i>Sambucus racemosa</i>	red elderberry	0.003
<i>Vaccinium myrtilloides</i>	velvetleaf blueberry	0.003

Coarse Woody Material and Standing Dead Trees

Coarse woody material volume was 133 m³/ha in upland habitat and 116 m³/ha in wet mesic habitat (Table 8) although larger diameter pieces (≥ 33 cm diameter) were more abundant in wet mesic sites (Table 9). Large snags (≥ 30 cm DBH) were nearly twice as dense in the upland type (61/ha) compared with the wet mesic type (36/ha) (Table 10).

Table 8. Coarse woody material volume and biomass by habitat.

Habitat	Number of plots in habitat type	Volume (m ³ /ha)	Biomass (kg/ha)	Biomass (tons/ha)
Upland	18	132.81	42,739.65	19.07
Wet mesic	5	115.80	33,116.39	14.77

Table 9. Density of coarse woody material by diameter class for both habitat types.

Habitat	Density (pieces/ha) for each diameter class (cm)				Total pieces/ha
	7.5-19.99	20.0-32.9	33.0-45.9	>46.0	
Upland	951.19	228.44	22.10	2.07	1,203.81
Wet mesic	801.47	200.39	29.56	0.00	1,031.43

Table 10. Density of standing dead trees ≥ 30 cm DBH by habitat.

Habitat	Density (trees/ha)
Upland	60.51
Wet mesic	35.55

Browse and Disease

We did not observe any leaf stripping or any other browse (such as bark stripping) that we felt was attributable to moose; all woody direct browse data presented here are assumed to be due to white-tailed deer. In 2014, the proportion of browse across the whole park was relatively low, with only 3.99% of woody species assessed for bite marks in the direct browse circles showing evidence of recent browse. The proportion of browse was 0.0457 in upland plots and 0.0196 in wet mesic plots. Three species stood out as being browsed in a large proportion of the circles in which they were present: *Cornus sericea* L. (redosier dogwood) (34.4.6% of circles where present), *Acer spicatum* (11.6%), and *Diervilla lonicera* (9.1%). The individual plot with the highest proportion of browse (27.7%) was located close to the trail intersection with Highway 61. Additional plots with relatively high proportions of browse in the park were located between the trail's intersection with Cowboys Road and the beaver pond, and also near Poplar Creek.

Target indirect browse herbaceous species heights ranged from 13.2 to 24.5 cm in upland habitat and 12.0 to 21.5 cm in wet mesic habitat (Table 11) in 2015.

Table 11. Summary of indirect browse (plant presence and height) on three target herbaceous taxa.

Habitat	Taxon	Percent of quadrats where present	Mean maximum height per quadrat
Upland	<i>Clintonia borealis</i>	22.4	13.2
	<i>Streptopus</i> sp.	16.1	19.9
	<i>Trillium cernuum</i>	4.3	24.5
Wet mesic	<i>Clintonia borealis</i>	46.7	15.4
	<i>Streptopus</i> sp.	17.3	21.5
	<i>Trillium cernuum</i>	0.6	12.0

In both habitats, the majority of overstory species exhibited only very small frequencies of pest or pathogen signs. The exception to this was *P. tremuloides* where 6.8% of individuals in upland habitat and 5.8% of individuals in wet mesic habitat displayed signs of pests or pathogens. The most common damage sign was defoliation and was noted on 5.4% and 3.7% of the trees in upland and wet mesic habitat, respectively. Other pest and pathogen damage included dieback and discolored foliage.

Community Indices

Mean plot species richness was 71.0 taxa/plot in upland plots and 82.2 taxa/plot in wet mesic plots. The mFQI values were high for both habitat types. In the upland plots, mFQI was 4.91, while mFQI was 4.98 in the wet mesic plots.

Pooled across both habitat types, the majority of taxa were perennial and native, with 65% of taxa being herbaceous (grasses and forbs) and 35%, woody (shrubs and trees) (Table 12). Also pooled across habitat types, 64% of taxa were biotically pollinated.

Table 12. Mean species richness within classes of each functional group for both habitat types.

Functional group	Class	Habitat	
		Upland	Wet mesic
Life history	annual	1.11	2.60
	biennial	0.28	0.60
	perennial	69.61	79.00
Growth form	forb	37.06	42.60
	graminoid	8.89	10.60
	woody	25.05	29.00
Pollination	abiotic	20.72	23.20
	biotic	45.17	52.40
	N/A	5.11	6.60
Nativity	native	66.45	78.80
	non-native	4.33	3.20
	native/non-native	0.22	0.20

2007-2014 Forest Change

Our first question addressed whether tree density and/or basal area changed between sampling intervals. For all tree species collectively, both total density and total basal area increased between the two sampling periods (density: $p < 0.0001$; basal area: $p = 0.0400$), although neither differed between habitats (Table 15, Figure 7).

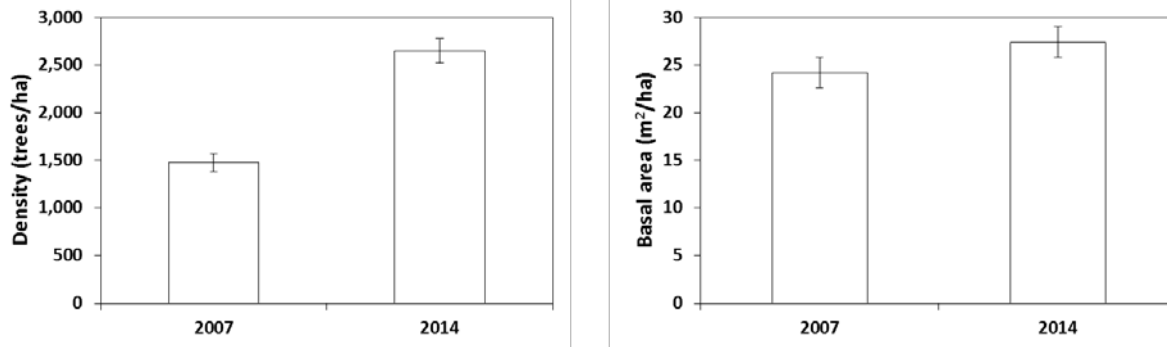


Figure 7. Density and basal area for live trees of all species in both 2007 and 2014. Results are pooled across both habitat types. Both indices were greater in 2014.

As part of this first question, we also wanted to know if and how density and basal area are changing, for key tree species of interest. *Abies balsamea* density and basal area increased between years and also differed between habitats; both metrics were greater in 2014 and in upland habitat (Table 13, Figure 8). Density of *P. tremuloides* was greater in 2014, but did not differ between habitats (Figure 9); *P. tremuloides* basal area did not differ between habitats or years (Table 13). For *B. papyrifera*, neither metric differed between habitats or years. Likewise, neither metric for *P. strobus* changed between years sampled; we could not test for differences between habitats due to inadequate sample size. *Fraxinus nigra* density did not depend on year or habitat, although basal area tended toward being greater in 2007 (Table 13, Figure 10).

Table 13. ANOVA *p* values for density, basal area, and their interaction, of five key species of interest. Those significant at $p \leq 0.05$ are shown in bold.

Species	Metric	Habitat	Year	Habitat × Year
<i>Abies balsamea</i>	density	0.0161	<0.0001	0.7287
	basal area	0.0002	0.0034	0.1159
<i>Populus tremuloides</i>	density	0.0710	0.0002	0.1042
	basal area	0.9996	0.3461	0.1556
<i>Betula papyrifera</i>	density	0.6964	0.2028	0.8989
	basal area	0.5271	0.6437	0.6258
<i>Pinus strobus</i> ¹	density		0.2053	
	basal area		0.1951	
<i>Fraxinus nigra</i>	density	0.2209	0.0973	0.8342
	basal area	0.0856	0.0552	0.8931

¹Inadequate sample size precluded tests of habitat and interactive effects on *Pinus strobus*.

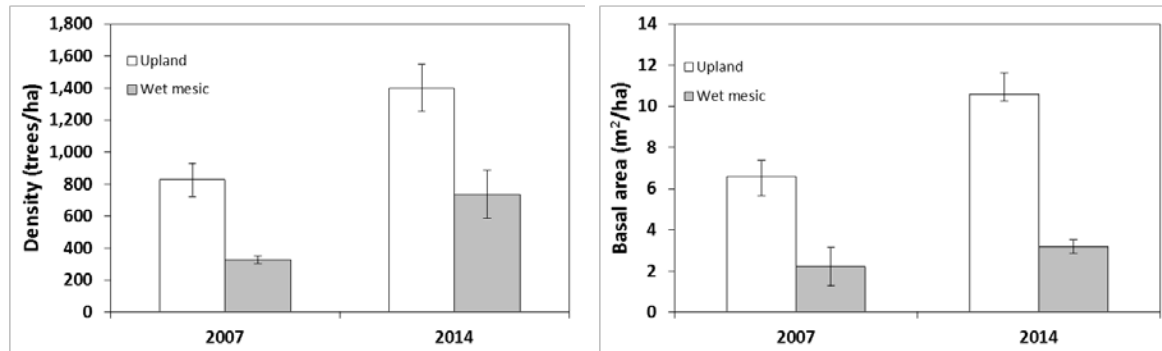


Figure 8. Density and basal area of *Abies balsamea* in both habitats and years. Both metrics were greater in 2014 and in upland habitat.

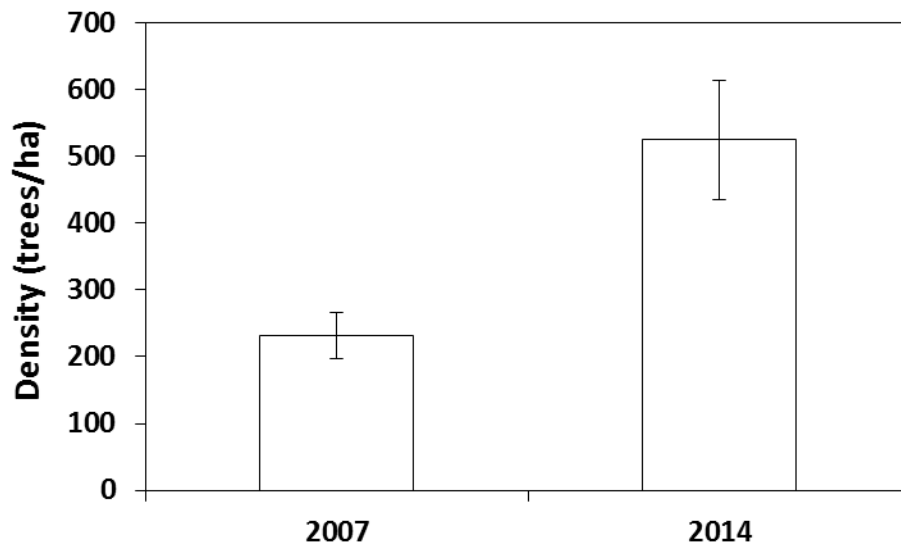


Figure 9. *Populus tremuloides* density was greater in 2014 than 2007. Results are pooled across habitats.

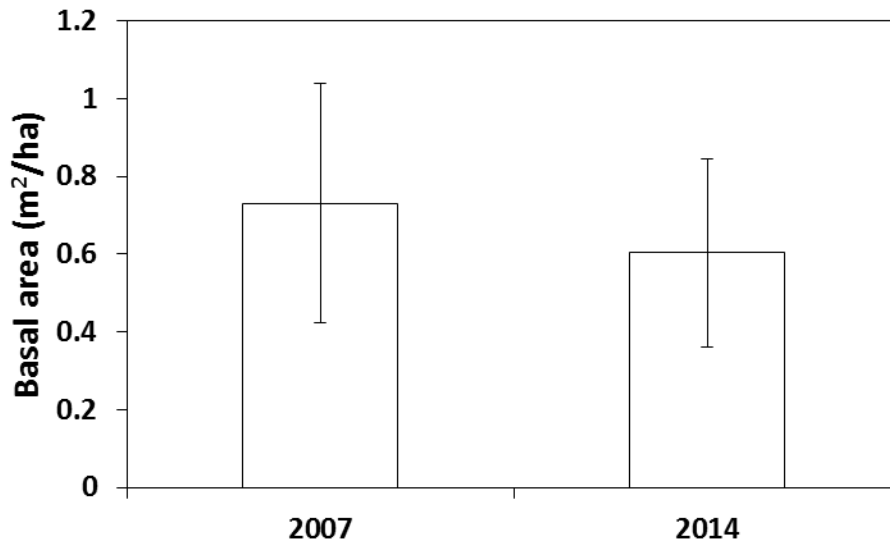


Figure 10. *Fraxinus nigra* basal area tended toward being greater in 2007 than 2014. Results are pooled across habitats.

Pooled across all species, seedling density was greater in 2014, when mean plot density was 14,349 seedlings/ha (Figure 11). Seedling density did not differ between habitats.

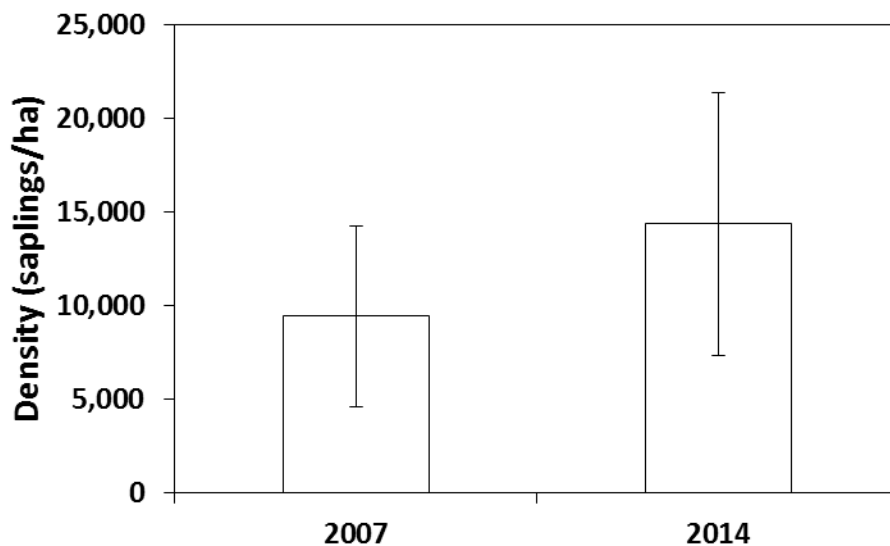


Figure 11. Seedling density, shown pooled across both habitats, was greater in 2014 than 2007.

Across both habitat types, the density-diameter class distributions differed between the two sampling periods (Kolmogorov-Smirnov test; $p < 0.0001$) (Figure 12).

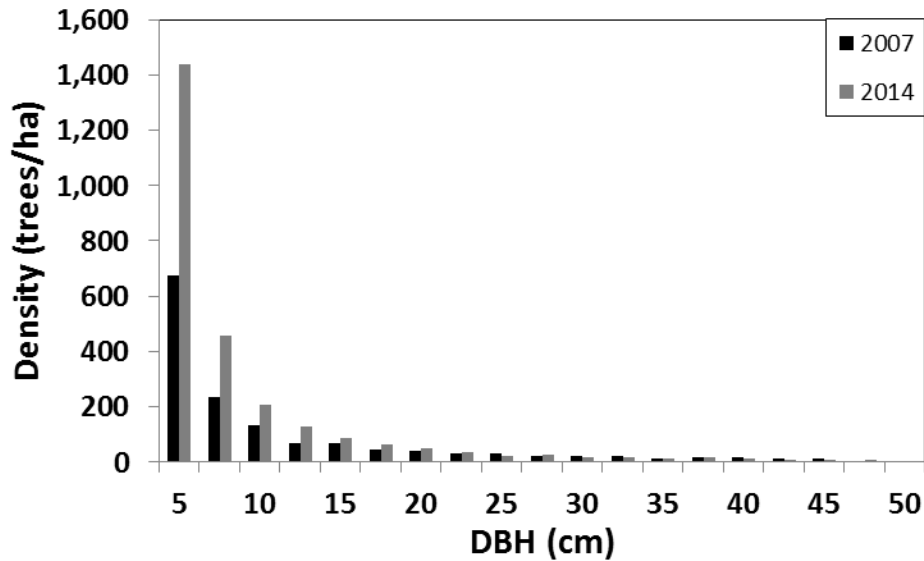


Figure 12. Density-diameter distributions for trees differed between the two sampling periods. Results are pooled across both habitat types and included all species.

Our second question addressed browse impacts. A test of the indirect impact of browse on herb abundance showed that the frequency of quadrats supporting at least one preferred browse species did not differ between years ($p = 0.5846$) although it tended to depend on habitat ($p = 0.0572$). Across both years, 81% of quadrats in upland plots supported at least one preferred browse species, while only 66% of wet mesic sites did so (Figure 13).

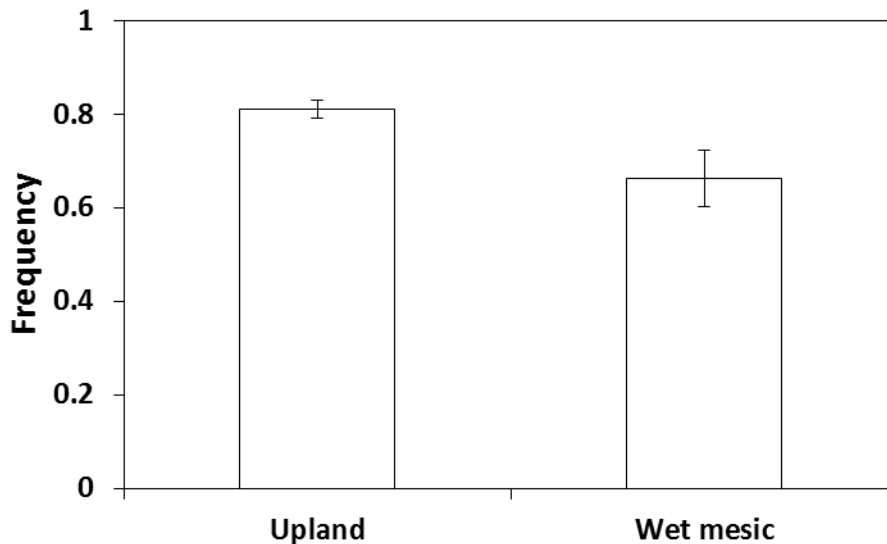


Figure 13. Frequency of quadrats supporting at least one preferred browse species was greater in upland than wet mesic habitat. Data are pooled across both sampling periods.

We also examined the indirect impact of browse on herbaceous height using two targeted preferred browse taxa. For *C. borealis*, mean height within plots depended on year ($p = 0.0344$) with a tendency for mean height to also differ between habitats ($p = 0.0698$) (Figure 14). Across both habitats, mean plot height of *C. borealis* was 12.4 cm in 2007 and 13.2 cm in 2014; across both years, mean height was 12.4 cm in upland habitat and 14.4 in wet mesic sites. *Streptopus* sp. height did not depend on habitat ($p = 0.3937$) or year ($p = 0.1183$).

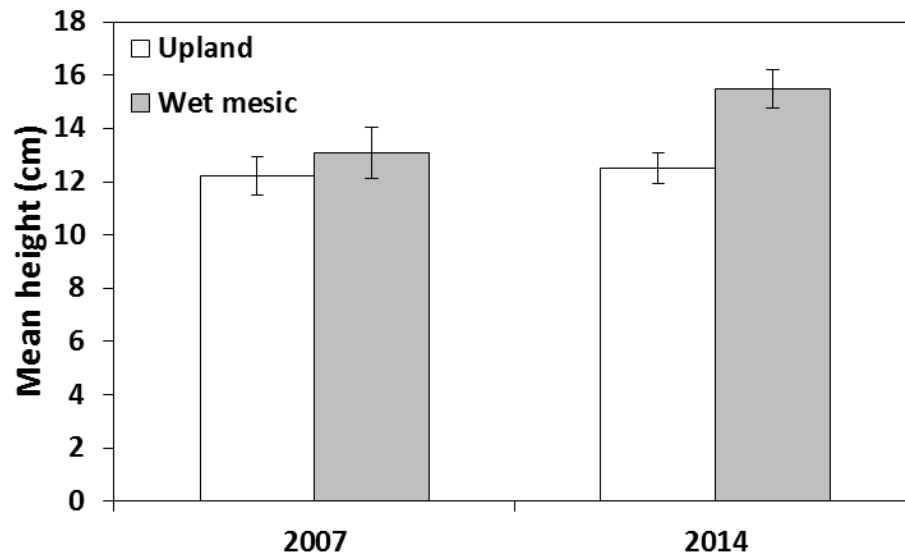


Figure 14. Height of *Clintonia borealis*, a target preferred browse species, in both habitats and sampling periods. Height was greater in 2014 and tended toward being greater in wet mesic habitats.

Our third question addressed changes in plant communities. The effect of sampling year on plot species richness differed between habitats (i.e., significant interaction, $p = 0.0020$) (Figure 15). In 2007, richness was greater in upland plots (61.2 vs. 59.5), although in 2014, richness was greater in wet mesic plots (82.2 vs. 71).

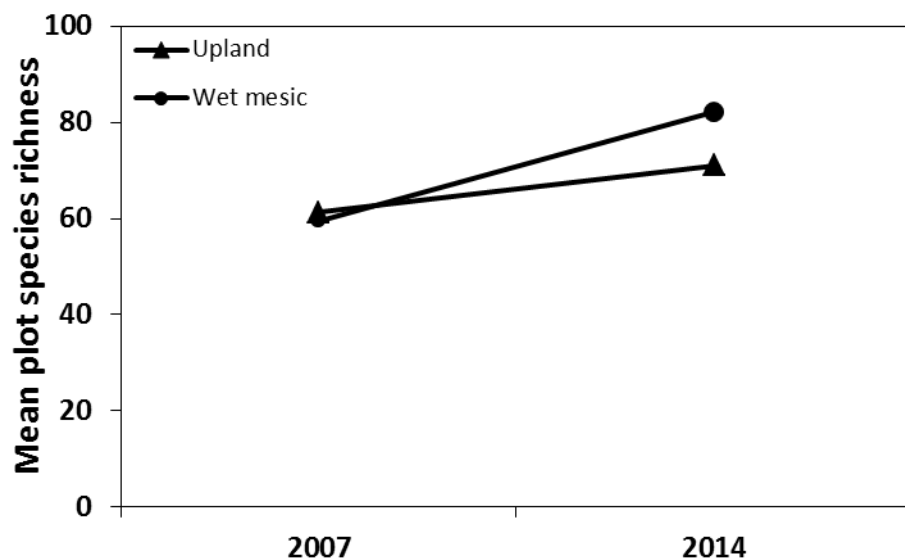


Figure 15. Mean plot species richness in both habitats and sampling periods.

The modified floristic quality index (mFQI) did not differ between years ($p = 0.7720$) although it did depend on habitat ($p = 0.0175$) (Figure 16). Pooled across both sampling years, mFQI was 4.88 in upland plots and 5.08 in wet mesic plots (Figure 16).

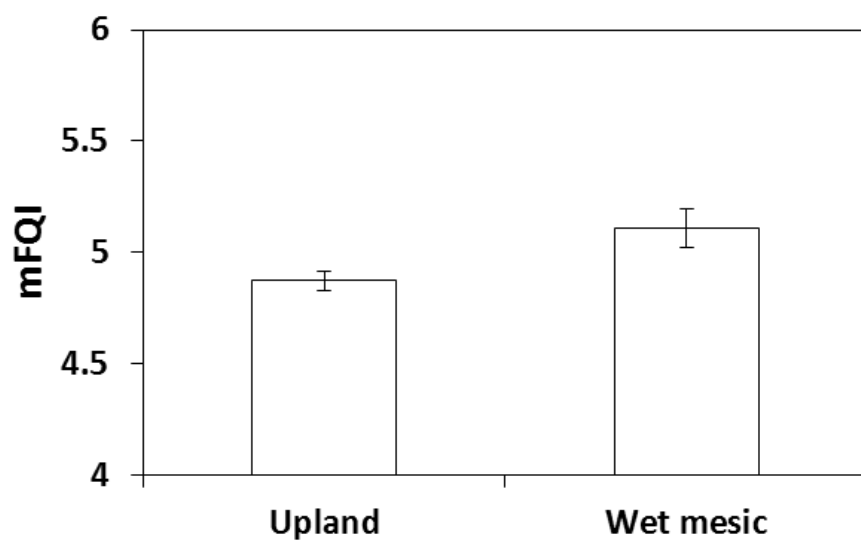


Figure 16. Modified floristic quality index (mFQI) in both habitats sampled. Data are pooled across both sampling periods.

The NMS ordination results support our other data showing marked increases in both *A. balsamea* and *P. tremuloides*. Vectors corresponding with increasing values of both Axes 1 and 2 (i.e., pointing toward the upper right, Figure 17) represent plots with large increases in density of *A. balsamea*. Higher Axis 1 positions may correspond with lower light levels. Those vectors pointing toward the upper left, representing decreasing values of Axis 1 and increasing values of Axis 2, correspond with plots with large density increases in both *A. balsamea* and *P. tremuloides*.

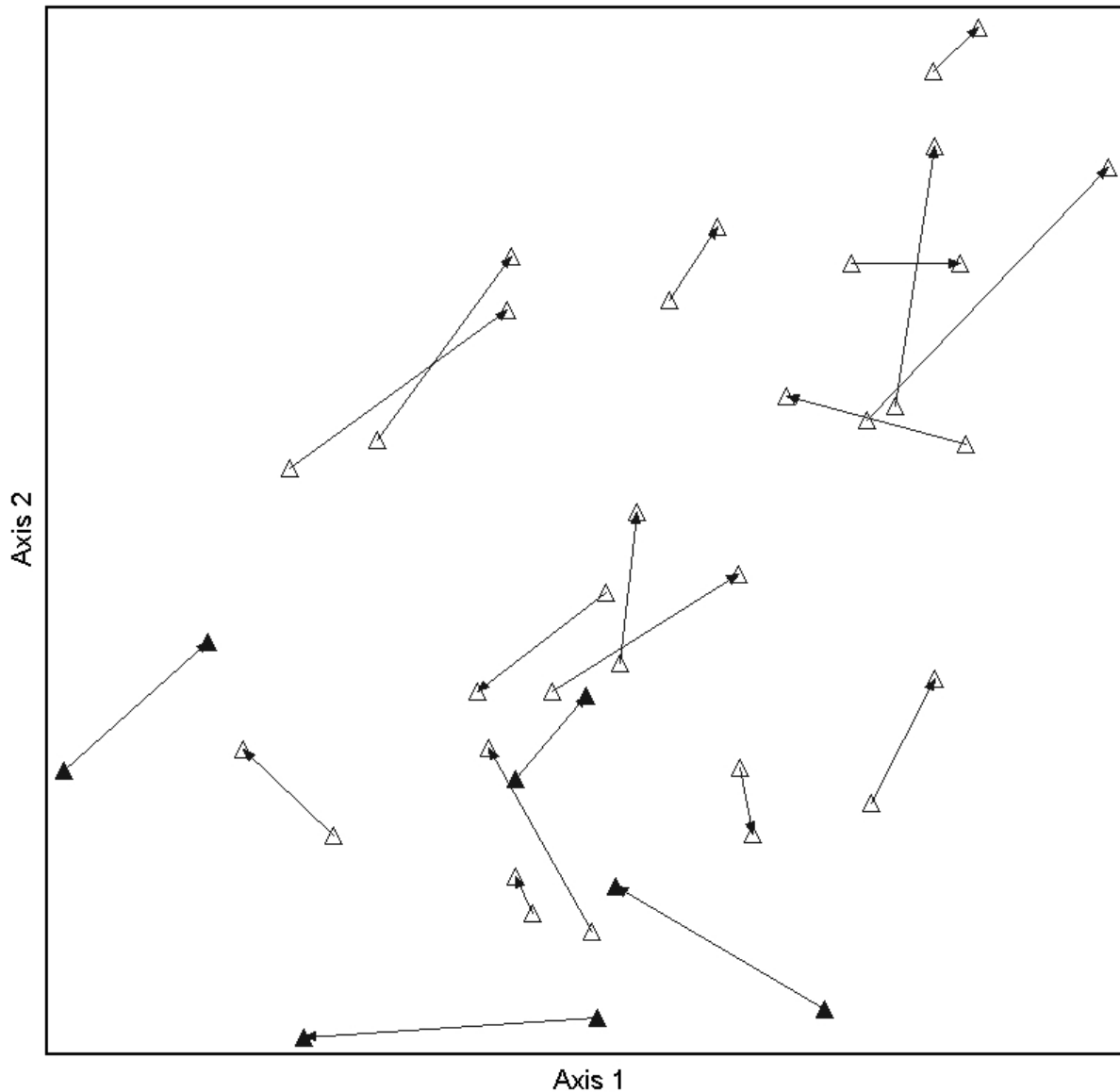


Figure 17. NMS ordination of overstory data with vectors drawn from the 2007 location to the 2014 location for each plot. Open triangles are plots in in upland habitat; solid triangles are plots in wet mesic habitat.

The NMS Ordination on understory abundance showed a strong directional pattern as well, with all plots increasing along Axis 2 (Figure 18). While this signal appeared particularly strong for a small

number of herbs (including *Anemone quinquefolia* L. [wood anemone] and *Cornus canadensis* L. [bunchberry]), the directional pattern was also present in plots where we observed decreases in these species.

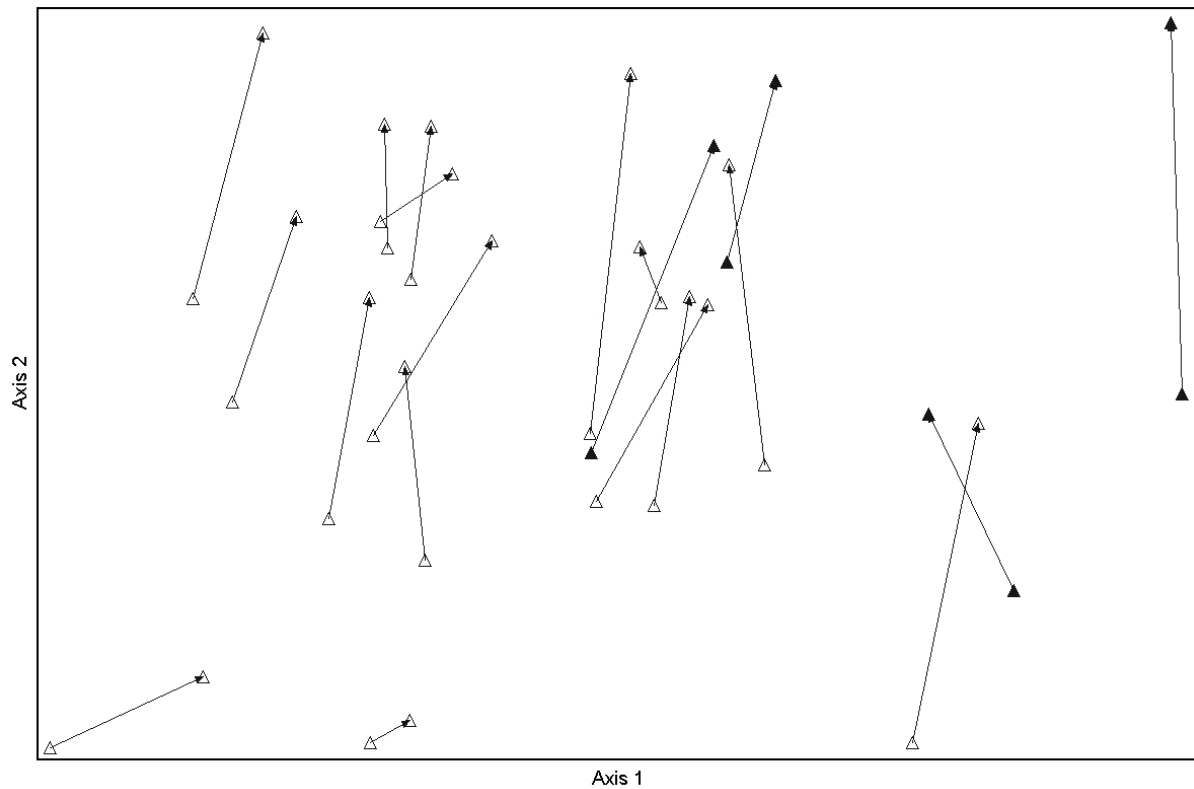


Figure 18. NMS ordination of herbaceous and shrub data with vectors drawn from the 2007 location to the 2014 location for each plot. Open triangles are plots in upland habitat; solid triangles are plots in wet mesic habitat.

Discussion

Our results of change in tree structure and composition observed over the seven-year sampling interval mirror those of other studies throughout the region (Friedman and Reich 2005, Frelich and Reich 2009a). As the early successional hardwoods established at the time of stand initiation aged, shade tolerant species dominated by balsam fir became established. As most stands are now nearing or beyond 100 years old, those early successional species, dominated by *P. tremuloides*, are being killed by a complex of factors, including windthrow, root disease, forest tent caterpillar (*Malacosoma disstria* Hubner), and drought. The gap-phase forest is now a mosaic of young *A. balsamea*, with *P. tremuloides* clones and *A. spicatum* colonizing the gaps. The previously common *Pinus strobus* now exists in low density across the landscape, an arrangement that limits the spatial extent of seed rain which, in turn, hinders regeneration. In the absence of fire, *A. balsamea* dominance will likely increase as other species adapted to fire become less prominent. One possible check on *A. balsamea* dominance, however, is a future outbreak of eastern spruce budworm (*Choristoneura fumiferana* (Clemens)), a native species which attacks spruce, fir, and several other conifer genera. An infestation in spruce-fir stands in Minnesota in the 1970s resulted in a reduction in stand basal area from 79% to 31% of the total (Batzner and Popp 1985).

The lower frequency of preferred browse species in wet mesic plots relative to upland sites suggests greater browsing pressure in these areas with wet pockets, or that these areas constitute poorer habitat for our target species, or possibly some combination of the two. Throughout the wet mesic plots were patches of *Calamagrostis canadensis* (Michx.) P. Beauv. (bluejoint), *Impatiens capensis* Meerb. (spotted Touch-me-not), and *Athyrium filix-femina* (L.) Roth (ladyfern). While we observed only a minimal amount of standing water at these sites during the time of sampling, these species suggest its presence was greater in the spring, likely limiting the areas where target species occur. In addition, neither deer, nor hare browse pressure is currently high in the area. While white-tailed deer abundance has increased over the previous decade on the Grand Portage Reservation, the density is still relatively low. Winter helicopter surveys conducted by the Grand Portage Band Natural Resources Program identified 56 individuals in 2007 and 205 individuals in 2014 over the 193 km² (75 mi²) reservation land base (Edmund Isaac, Grand Portage Band, personal communication). These correspond to summer densities of 0.29 and 1.08 deer/km², respectively. These densities are inline with pre-European settlement estimates of 3.1 - 4.2 km² for North America (McCabe and McCabe 1997) and 2 - 4 km² in deciduous and mixed deciduous-conifer forests of the upper Midwest (Alverson et al. 1988). As such, the current white-tailed deer density is not likely to suppress regeneration of these herbs. Snowshoe hare impacts are less clear. Hare densities peak, then crash on a 10-year cycle, driven largely by the interacting effects of predation and food availability (Krebs 2001). While the herbaceous dietary preferences of hare are similar to those of deer (Belovsky 1984; Rouleau et al. 2002; Frerker et al. 2013), Wolff (1978) showed that herbs composed about 50% of the diet of hare in central Alaska only during the month of May, while in April and in the summer, herbs represented only about 10% of the hare diet. In northern Minnesota, Snowshoe Hare density peaked in 2011 with nearly 5 hare/100 km of survey line (Erb 2014); hare densities at the time of

both of our sampling events (2007 and 2014) were at the cycle mid-point, half way between the high and low. We are unaware of any work quantifying the relationship between hare abundance and impacts to the herbaceous layer.

Precipitation differences between the two sampling periods may explain the patterns observed in herbaceous plant communities. Mean growing season (May-August) precipitation from 1992-2014 was 33.5 cm (www.climateanalyzer.org). The 2007 sampling occurred during a relatively dry period with 24.5 cm and 17.4 cm of precipitation during the 2006 and 2007 growing seasons, respectively. The climate was wetter during the later sampling; mean growing season precipitation totaled 39.0 cm in 2013 and 41.3 cm in 2014. In 2014, wet mesic sites supported 11.2 more species than upland sites while in 2007, a dry year, wet mesic sites support 1.7 fewer species. It seems probable that species adapted to more moist areas may have either exhibited widespread early senescence in 2007, or were simply reduced in abundance by more competitive generalists. Specialist species, by definition, will have higher coefficients of conservatism. Our finding of greater mFQI in wet mesic sites, relative to upland sites is therefore, not surprising.

The significant findings observed in this study are somewhat surprising, given the short time interval between sampling events. Dynamics such as deer abundance (and hence, browse), precipitation, and severe wind can vary highly between years leading to large differences between closely-timed sampling events. Analyses of vegetation change are often opportunistic resampling events on the order of 50 years (Jones et al. 1994, Johnson et al. 2013), rather than shorter-term studies with planned revisit schedules and pre-identified questions. (For an exception, see Taverna et al. (2005)). Interpretation of results of these long-term studies may warrant a brief discussion on the drivers and stressors that may be acting on the systems near the time of both the initial and follow-up sampling events. For this current project, we are scheduled to sample a third time in 2024 with repeated sampling approximately every nine to ten years. This should allow us to parse out long-term trends vs. shorter term variability.

Management and Recommendations

While our work here follows convention by using traditional statistical approaches to test for change, we caution against a strict interpretation. Forests may be in the early stages of displaying climate change-induced shifts and managers need to recognize these changes, whether statistically significant or not. Grand Portage National Monument is situated at the boundary between the boreal forest to the north and Laurentian mixed forest to the south. As such, many boreal species present in the park are near their southern range limits; favorable habitat conditions for their reproduction and growth are predicted to migrate northward and out of the region (Frelich and Reich 2009a). In their stead, the growing conditions are expected to become more favorable for *Quercus* sp. L. (oaks) and *Pinus* sp. L. (pines) (Frelich and Reich 2009b). It is currently unclear, however, whether the migration rates of these groups can keep pace with the migration rate of their climate envelope (Frelich and Reich 2009a).

Climate change resilience strategies focus on promoting the growth of species expected to remain in the area, while minimizing the spread of newly arriving invasive species. Park managers have

implemented a project to promote *P. strobus* regeneration within the park by outplanting for seed rain restoration, releasing advance regeneration, and also manually controlling *A. balsamea*. This project encourages current regeneration of *P. strobus* so that seed sources may be available for future regeneration once *A. balsamea* begins to die out. Managers may also wish to promote the growth of other species expected to remain in the area, including *B. papyrifera* and *T. occidentalis*. While the former species is often early successional, the latter can be slow growing and long-lived (Fowells 1965). Germination and seedling growth of *Thuja occidentalis* preferentially occurs under a *Thuja* canopy (Cornett et al. 1997) and on coarse wood substrates (Cornett et al. 2001); because of this feedback, maintaining and promoting existing populations and coarse woody structures should be a priority. Indeed, long-term goals of the park include promoting conifer cover in riparian corridors, in conjunction with *T. occidentalis* seed rain. This may create a feedback loop by promoting greater moisture and shading, and hence providing refugia for southern boreal conifers.

While climate change is an important concern to the park, a more immediate concern to park managers is the arrival of emerald ash borer (*Agrilus planipennis* Fairmaire). As of spring, 2015, this exotic insect is now established in Superior, Wisconsin, approximately 245 km to the southwest of GPNM. *Fraxinus nigra* was located in 16 of the 23 plots; most of these plots were located in the half of the trail nearer to the Pigeon River. None were in the nearest three kilometers to Lake Superior. In areas where we observed *F. nigra*, we also commonly observed populations of *A. incana* ssp. *rugosa*, with smaller inclusions of *Alnus viridis* ssp. *crispa* (Aiton) Turrill (green alder). It is likely that populations of these two species of alder will expand and fill niches left vacant by ash trees once emerald ash borer arrives and ash trees begin to succumb to it.

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Appendix A: List of all Species Sampled

Herbaceous: Ferns and Fern allies

Dennstaedtiaceae

Pteridium aquilinum ssp. *latiusculum*

Dryopteridaceae

Dryopteris carthusiana

Equisetaceae

Equisetum arvense

Equisetum sp.

Equisetum sylvaticum

Lycopodiaceae

Huperzia lucidula

Lycopodium annotinum

Lycopodium clavatum

Lycopodium complanatum

Lycopodium dendroideum

Onocleaceae

Matteuccia struthiopteris

Onoclea sensibilis

Osmundaceae

Osmunda claytoniana

Thelypteridaceae

Phegopteris connectilis

Woodsiaceae

Athyrium filix-femina

Gymnocarpium dryopteris

Herbaceous: Forbs

Alismataceae

Sagittaria latifolia

Apiaceae

Heracleum sphondylium ssp. *montanum*

Osmorhiza claytonia

Osmorhiza longistylis

Sanicula marilandica

Sium suave

Apocynaceae

Apocynum androsaemifolium

Araliaceae

Aralia nudicaulis

Aristolochiaceae

Asarum canadense

Asparagaceae

Maianthemum canadense

Asteraceae

Achillea millefolium

Anaphalis margaritacea

Antennaria plantaninifolia

Cirsium muticum

Cirsium vulgare

Doellingeria umbellata var. *pubens*

Eurybia macrophylla

Eutrochium maculatum

Hieracium piloselloides

Hieracium scabrum

Hieracium sp.

Hieracium umbellatum

Lactuca canadensis

Lactuca sp.

Leucanthemum vulgare

Petasites frigidus var. *palmatus*

Prenanthes alba

Solidago canadensis

Solidago nemoralis

Solidago sp.

Symphyotrichum lanceolatum

Symphyotrichum puniceum var. *puniceum*

Taraxacum officinale

Balsaminaceae

Impatiens capensis

Boraginaceae

Mertensia paniculata

Caryophyllaceae

Cerastium fontanum ssp. *vulgare*

Cornaceae

Cornus canadensis

Ericaceae

Chimaphila umbellata ssp. *cisatlantica*

Moneses uniflora

Monotropa uniflora

Orthilia secunda

Pyrola asarifolia

Pyrola elliptica

Pyrola sp.

Fabaceae

Trifolium pretense

Trifolium repens

Gentianaceae

Halenia deflexa

Iridaceae

Iris versicolor

Lamiaceae

Galeopsis tetrahit

Lycopus uniflorus

Mentha arvensis

Prunella vulgaris

Scutellaria galericulata

Scutellaria lateriflora

Liliaceae

Clintonia borealis

Streptopus amplexifolius

Streptopus sp.

Linnaeaceae

Linnaea borealis var. *longiflora*

Melanthiaceae

Trillium cernuum

Onagraceae

Chamerion angustifolium

Circaea alpine ssp. *alpine*

Epilobium ciliatum ssp. *ciliatum*

Epilobium coloratum

Orchidaceae

Corallorhiza maculata

Corallorhiza sp.

Corallorhiza striata

Corallorhiza trifida

Dactylorhiza viridis

Goodyera tessellata

Orobanchaceae

Melampyrum lineare

Papaveraceae

Corydalis sempervirens

Sanguinaria canadensis

Plantaginaceae

Chelone glabra

Plantago major

Polygalaceae

Polygala paucifolia

Primulaceae

Lysimachia terrestris

Trientalis borealis

Ranunculaceae

Actaea pachypoda

Actaea rubra

Actaea sp.

Anemone quinquefolia var. *quinquefolia*
Aquilegia canadensis
Caltha palustris
Coptis trifolia
Ranunculus acris
Ranunculus hispidus
Thalictrum dasycarpum

Rosaceae

Agrimonia struata
Fragaria virginiana
Geum aleppicum
Geum macrophyllum

Rubiaceae

Galium asprellum
Galium trifidum
Galium triflorum

Saxifragaceae

Mitella nuda

Violaceae

Viola pubescens var. *pubescens*
Viola sp.

Herbaceous: Vine

Fabaceae

Lathyrus ochroleucus
Lathyrus sp.
Lathyrus venosus
Vicia americana
Vicia villosa

Herbaceous: Graminoid

Cyperaceae

Carex arctata
Carex bebbii
Carex brunnescens
Carex canescens
Carex castanea
Carex deweyana var. *deweyana*
Carex disperma

Carex gracillima
Carex intumescens
Carex lacustris
Carex leptonervia
Carex peckii
Carex pedunculata
Carex retrorsa
Carex sp.
Carex stipata
Carex trisperma
Carex utriculata
Scirpus atrovirens
Scirpus cyperinus
Scirpus sp.

Juncaceae

Juncus tenuis
Lazula acuminata var. *acuminata*

Poaceae

Bromus ciliates
Calamagrostis canadensis
Cinna latifolia
Danthonia spicata
Deschampsia cespitosa
Glyceria sp.
Glyceria striata
Milium effusum
Oryzopsis asperifolia
Phleum pretense
Poa compressa
Poa palustris
Poa sp.
Schizachne purpurascens

Typhaceae

Typha latifolia

Shrub

Adoxaceae

Sambucus racemosa
Viburnum edule
Viburnum opulus var. *americanum*

Viburnum rafinesqueanum

Betulaceae

Alnus incana spp. *rugosa*

Alnus viridis ssp. *crispa*

Corylus cornuta

Caprifoliaceae

Lonicera canadensis

Lonicera hirsuta

Lonicera oblongifolia

Symphoricarpos albus

Cornaceae

Cornus sericea

Cupressaceae

Juniperus communis var. *depressa*

Diervillaceae

Diervilla lonicera

Ericaceae

Arctostaphylos uva-ursi

Vaccinium angustifolium

Vaccinium myrtilloides

Grossulariaceae

Ribes glandulosum

Ribes hirtellum

Ribes lacustre

Ribes triste

Rhamnaceae

Rhamnus alnifolia

Rosaceae

Amelanchier Group 2 sp.

Amelanchier Group 3 sp.

Rosa acicularis

Rubus parviflorus

Rubus pubescens

Rubus sachalinensis var. *sachalinensis*

Salicaceae

Salix discolor

Salix planifolia

Taxaceae

Taxus canadensis

Tree

Betulaceae

Betula papyrifera

Cupressaceae

Thuja occidentalis

Oleaceae

Fraxinus nigra

Pinaceae

Abies balsamea

Picea glauca

Picea mariana

Pinus banksiana

Pinus strobus

Rosaceae

Prunus pensylvanica

Prunus virginiana

Sorbus decora

Salicaceae

Populus balsamifera

Populus tremuloides

Salix bebbiana

Sapindaceae

Acer rubrum

Acer saccharum

Acer spicatum

Ulmaceae

Ulmus americana

Tree/Shrub
Rosaceae
Crataegus sp.

Appendix B: List of Invasive Species Encountered

Species	Common name	Plots where located
<i>Cirsium vulgare</i>	Bull thistle	2007
<i>Hieracium piloselloides</i>	Tall hawkweed	2004
<i>Leucanthemum vulgare</i>	Oxeye-daisy	2005, 2011, 2019, 2025
<i>Poa compressa</i>	Flatstem bluegrass	2004, 2005, 2011, 2013, 2018, 2019, 2020, 2024, 2026
<i>Trifolium pratense</i>	Red clover	2004, 2005, 2008, 2010, 2011, 2014, 2015, 2019, 2020, 2021, 2022, 2023, 2025, 2026, 2027

Appendix C: National Vegetation Classification System (NVCS) Type for all Plots

NVCS type	Plots
2449: <i>Thuja occidentalis</i> / <i>Abies balsamea</i> – <i>Acer spicatum</i> forest	2026
2466: <i>Populus tremuloides</i> – <i>Betula papyrifera</i> / (<i>Abies balsamea</i> , <i>Picea glauca</i>) forest	2002, 2006, 2008, 2011, 2020, 2024
2475: <i>Picea glauca</i> – <i>Abies balsamea</i> – <i>Populus tremuloides</i> /mixed herbs forest	2003, 2004, 2005, 2007, 2010, 2012, 2013, 2014, 2015, 2018, 2019, 2021, 2022, 2023, 2025, 2027

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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