



Forest Health Monitoring at Voyageurs National Park

2015–2016 Field Seasons

Natural Resource Report NPS/GLKN/NRR—2018/1788



ON THE COVER

Clockwise from top left: black ash forest (©Alison Paulson), *Pyrola* sp. (NPS photo), red pine forest (©Alison Paulson), vegetation monitoring transect (NPS/Erin Blow)

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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 particularly relevant within the southern boreal forest where many species are near their southern range limits, and compositional change is expected to be great. Voyageurs National Park 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 environmental variation progresses. A comprehensive forest monitoring program was initiated at Voyageurs National Park in 2008 with the establishment of 37 permanent plots; between 2015 and 2016 we resampled the original 37 plots and installed 16 more, bringing the total to 53. We classified plots into one of five broad forest types, and present the current status, and short-term change, of multiple metrics of forest health.

Forests in 2015/16 are dominated by *Abies balsamea* (L.) Mill (balsam fir) in all five forest types, with *Acer rubrum* L. (red maple) generally being the most abundant hardwood. Fire-adapted species, *Pinus banksiana* Lamb. (Jack pine) and *P. resinosa* Aiton (red pine) were only present as a few scattered individuals throughout the park, except in Red Pine/Jack Pine forests. Here, *P. banksiana* existed primarily as large individuals 20–40 cm diameter at breast height (DBH), while *Pinus resinosa* was present throughout a wider range of size classes (2.5–45 cm DBH), but at low densities throughout. *Quercus* spp. L. (oaks) were only common in Red Pine/Jack Pine forests, and were present across a range of size classes. *Fraxinus nigra* Marsh. (black ash) was only abundant in Black Ash/mixed hardwood forests, which supported it across all size classes.

Overall tree density was higher in 2015/16 ($2,461/\text{ha} \pm 113$) than in 2008 ($2,223/\text{ha} \pm 132$), although basal area varied little between time periods. Sapling density was also higher during the second sampling period ($18,317 \pm 1,923$ saplings/ha vs. $12,081 \pm 1,753$ saplings/ha) and also varied greatly among forest types. This was higher in Black Ash/Mixed Hardwood forests than the other four forest types.

The collective results of several indices suggest there was reduced deer browse pressure between the two sampling periods. In addition to higher sapling density during the second sampling event, the summed frequencies of eight preferred browse species were also higher during the later sampling period, as was height of two target browse species, on which we collected additional data.

The impacts of earthworms on soils varied although 17 of the 51 plots assessed did not show any evidence of earthworm invasion. These were generally located in the vicinity of the inland lake chain, and in the land between Namakan and Mukooda lakes. Organic horizon thickness was highest (7.90 cm) in Black Ash/Mixed Hardwood forests and lowest in Red Pine/Jack Pine forests.

Our work demonstrates the dominance of *A. balsamea*, a species whose suitable habitat is projected to ultimately shift out of the region as environmental variation continues. We also demonstrate the regeneration failure of fire-adapted species, many of which occupy habitat that is anticipated to remain in the area of the park, despite ongoing environmental variation. Mesophication is now

occurring, as this shift to species with fire dampening properties continues. If park managers wish to retain resilient forests into the next several decades, active management is needed.

If the park is able to stem mesophication, and promote *Pinus* spp., as well as *Quercus* spp., it will likely be more resilient as species migration continues. Species from these two groups share many functional characteristics with both *Carya* spp. (Nutt., hickories) as well as other *Quercus* spp. These characteristics include aboveground linkages, such as wildlife with nesting and denning habitat and with food preferences, while belowground linkages include nutrient cycling with fungal and arthropod composition. Maintaining overstory assemblages with similar functional characteristics should result in ecosystems with greater long-term resilience.

While burning may be the most direct way to achieve this, numerous fiscal and social limitations present obstacles. The park should investigate alternative measures to promote desirable species, including active planting and thinning. Identifying a few key areas in the park where this is more practical, developing a plan, and consulting with key personnel will facilitate the process should the opportunity or funding arise in the future.

The 53 permanent monitoring plots will be resampled in 2025; trend assessments can be made at that time.

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Introduction

The southern reaches of the boreal forest extend as far south as the northern tier of Minnesota (Frelich and Reich 1995). Here, mature stands of iconic boreal conifer species, including *Pinus strobus* L. (eastern white pine), *P. resinosa* Aiton (red pine), *P. banksiana* Lamb. (Jack pine), *Abies balsamea* (L.) Mill (balsam fir), and *Picea glauca* (Moench.) Voss (white spruce) form closed canopies. Hardwoods such as *Populus tremuloides* Michx. (trembling aspen), *P. grandidentata* Michx. (bigtooth aspen), and *Betula papyrifera* Marshall (paper birch) occupy younger stands which were initiated by natural causes, including fire (Bergeron and Dansereau 1993), wind (Lain et al. 2008), and insect outbreaks (Batzler and Popp 1985, McCarthy and Weetman 2007), as well as by early 20th century logging (Friedman and Reich 2005).

Voyageurs National Park (VOYA) lies within this southern boreal zone and, along with the Boundary Waters Canoe Area Wilderness and Quetico Provincial Park in Ontario, Canada, is part of a largely contiguous tract of terrestrial and aquatic habitats. Forest dynamics here differ from those of the surrounding landscape in that they are largely not managed for timber, with natural processes often allowed to play out. This region spans the area between the Lake Superior and the other Great Lakes to the east, and grasslands to the west and may serve as a conduit for northward and northeastward migrating species. This underscores the need to document ongoing change in these forests.

The Great Lakes Inventory and Monitoring Network (GLKN) of the National Park Service (NPS) initiated a forest monitoring program at VOYA. At the inception of this program in 2008, we established and sampled 37 permanent monitoring plots. These plots were each resampled in either 2015 or 2016; during that time, we established an additional 16 plots, bringing the total to 53 in the park. Here we present basic measures of forest health, placing these values into context, and comparing the current sampling data with that obtained in 2008 to look at short-term change. Metrics reported on include tree density and basal area, seedling density, coarse woody material, groundlayer, browse, earthworm impacts, and community-wide shifts.

Methods

Study Area and Sampling Design

Voyageurs National Park is an 88,200 ha complex of lakes, bogs, wet meadows, and forests in north central Minnesota, with 48,325 ha (55%) of this, forested. The park is situated near the southern boundary of the Canadian Shield; as such, thin soils (typically ≤ 10 cm) are common and exposed bedrock outcroppings are ubiquitous. Upland forests typically have a significant conifer component while low lying forests are often wet and dominated by *Fraxinus nigra* Marsh. (Kurmish et al. 1986). This park is contiguous with the 441,000 ha Boundary Waters Canoe Area Wilderness and Quetico Provincial Park, a 460,000 ha expanse in Ontario, Canada. All three areas are largely untimbered and form a composite area of just under one million hectares.

The Park is located within the Laurentian Upland section (212La) of the Laurentian Mixed forest province (Ecoregion 212) (Cleland et al. 1997). The mean July temperature high and low in International Falls, Minnesota for the time period of 1986–2015 were 25.5°C and 11.7°C, respectively. For January during that same time period, the mean high and low were –8.9°C and –20.6°C, respectively. Mean annual precipitation from 1986–2015 was 62.60 cm, with 55% falling from May through August (www.climateanalyzer.org).

Sampling was conducted at VOYA 5 June–28 August 2015 and 4 June–29 August 2016. Site selection was made in 2008 prior to the initial sampling event using a generalized random-tessellation stratified design (Stevens and Olsen 2004). Two tenets of this design are that sampling locations are 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 1) 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 all herbaceous, vine, and shrub species present, and counted 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*, *Acer rubrum* L.). Individual sprouts (i.e., both ramets and genets) were deemed “saplings” if no aboveground connections between them and a parent tree were visible. We measured coarse woody material (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, small and large end diameters, length, decay class (Woodall and Williams 2007) and, if possible, 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. Finally, we performed a half-hour time-delimited search of the entire 50 m $\times$ 100 m plot area to locate any additional species present, but not recorded in any other sampling.

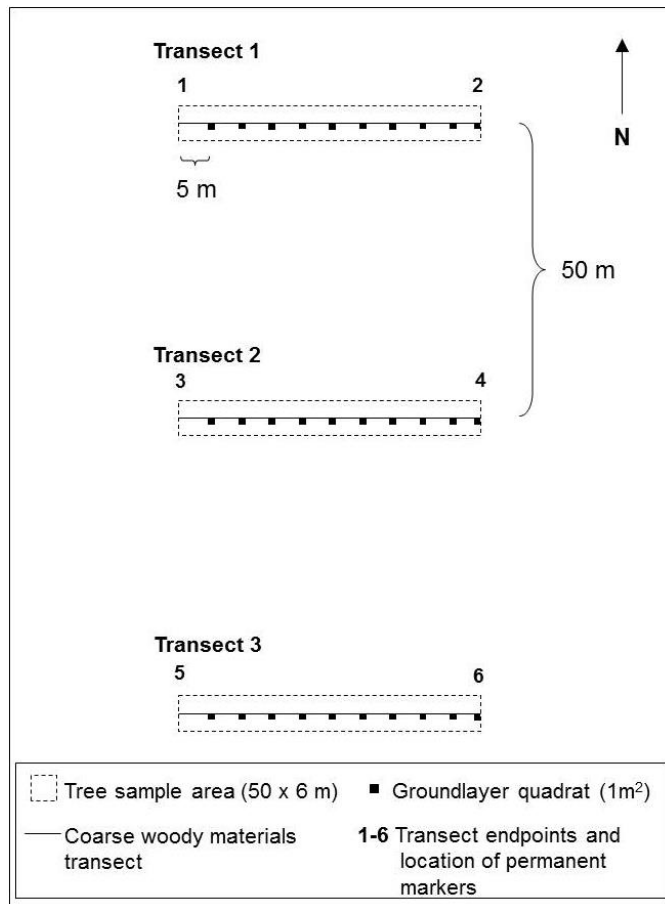


Figure 1. Great Lakes Network Hybrid plot showing three parallel transects (solid lines), tree sampling areas (bounding dashed rectangles), and quadrat locations (solid squares).

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 seven 50-m transects, for a total of 68 direct browse circles per plot, equal to a total sampling area of 213.5 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 where we observed any evidence of deer or moose browse, and on which species in the circle this occurred. 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.

Direct browse data were used to calculate the *Proportion of Browse* (Frerker and Waller 2013) for each species, plot, and forest type. At the species level ($PB_{species}$), for each plot, we divided the total number of circles in which browse was observed on Species_A by the total number of circles in which Species_A was present. For each species, we then calculated the parkwide mean. At the plot level (PB_{plot}), the numerator is sum of the number of circles in which browse was observed for all species while the denominator is the sum of them number of circles present for all species. For example, Species_A was browsed in 7 of 23 circles present, Species_B in 12 of 20, and Species_C in 9 of 34. Species_D, Species_E, and Species_F were present in 45, 37, and 28 circles, respectively, but not browsed. PB_{plot} would be:

$$PB_{plot} = \frac{7 + 12 + 9 + 0 + 0 + 0}{23 + 20 + 34 + 45 + 37 + 28}$$

with $PB_{plot} = 0.149$. At the forest type level, $PB_{ForestType}$ was the mean of PB_{plot} for all plots in that forest type. The direct browse methods employed in 2015/16 differed considerably from those of 2008 when we simply noted the three 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.

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 look at *Summed Frequency of Presence* of these preferred species. We do not count individual species in the groundlayer quadrats, but instead have frequencies of quadrats in which each species is present. We then used frequencies of presence as a measure of abundance. For this indicator, we summed frequencies of the eight 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 (*Clintonia borealis* (Aiton) Raf. (bluebead lily), *Streptopus* spp. Michx. (twistedstalk), and *Trillium cernuum* L. (nodding trillium) within each quadrat where they were present. For each taxon, we then calculated

Maximum Height, as the mean value of the tallest individual of each target taxa in each quadrat present in the plot. We elected to replace one of our 2008 target taxa (*Maianthemum canadense* Desf. [Canada mayflower]) with a different species in 2015/16 (*T. cernuum*), leaving only two taxa in common between the two sampling periods for comparison.

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

Species	Common name
<i>Actaea pachypoda</i> Elliott	white baneberry
<i>Actaea rubra</i> (Aiton) Willd.	red baneberry
<i>Aralia nudicaulis</i> L.	wild sarsaparilla
<i>Clintonia borealis</i> (Aiton) Raf.*	bluebead lily
<i>Maianthemum racemosum</i> (L.) Link	false Solomon's seal
<i>Streptopus amplexifolius</i> (L.) DC.*	clasping twistedstalk
<i>Streptopus lanceolatus</i> var. <i>roseus</i> (Michx.) Reveal*	rosy twistedstalk
<i>Trillium cernuum</i> L.*	nodding trillium

*Target taxa for assessing more detailed height, reproductive, and browse measures.

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 2008, 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.

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. L. (shinleaf), 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) 2014).

Analysis and Classification Methods

Forest Type Identification

We classified all plots in the field using both the Kotar classification system (Kotar and Burger 2000) and the National Vegetation Classification System (NVCS) (Faber-Langendoen et al. 2007), with each system resulting in our plots falling into a large number of types with only one or a small number of plots in each type. Because we wanted to explore and summarize data in an efficient and practical manner, following the field season, we grouped plots into similar broad forest types using cluster analysis (McCune and Grace 2002); thus groups were identified that supported similar plots but which were significantly different from other groups. To do this, we constructed a multivariate matrix based on abundance indices of both tree and groundlayer species within each plot, based on data from 2017. 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 frequency 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 10% (6 of 53) 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 ($\beta = -0.25$). Forest 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.

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 VOYA. 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 2014) where mFQI is simply the mean of the CoC values for all species present within that plot.

Community Change

For all 37 plots that were sampled in both time periods, 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-eight 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. and Poaceae (grass family) 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.

Earthworm Impacts

Earthworm assessments were conducted at vegetation monitoring plots to determine the extent of invasive earthworm presence at VOYA. Earthworm presence was determined using a simple visual assessment 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). The forest floor assessment involved determining if the forest floor was composed of fresh litter, duff, and/or organic matter. In addition, the presence of earthworm casts, or excretions, were noted. We also noted the presence of middens, which are piles of cast material created by the nightcrawler (*Lumbricus terrestris* L.) (Hale and Host 2005). The soil core allows for a visual inspection of the depth of the organic layer. Forests experiencing an earthworm invasion show a decrease in organic matter, and a thickening of the A soil horizon (Hale et al. 2005, Hale et al. 2008). From these assessments, samples can be ranked 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; and no evidence of earthworm casts or middens. 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). Four earthworm assessments were conducted at each monitoring plot, in areas that were estimated to be representative of the plot overall. No earthworm assessments were carried out in 2008, so comparisons in earthworm impacts between the two time periods will not be made.

Ash Coverage

To quantify the location and amount of area within the park under the greatest threat due to emerald ash borer (*Agrilus planipennis* Fairmaire), we first identified used the National Vegetation Classification System map (Faber-Langendoen et al. 2007) to identify all map classification names with “ash.” We then identified all polygons in the park described as such, and quantified the extent.

Results

All 37 plots originally sampled in 2008 were resampled, along with an additional 16, bringing the total plots in the park to 53 (Figure 2). The taxa sampled included 16 tree species, 49 shrubs and woody vines, 202 herb taxa, and 23 fern species (Appendix A). The plots classified into five distinct forest types (Figure 2, Table 2).

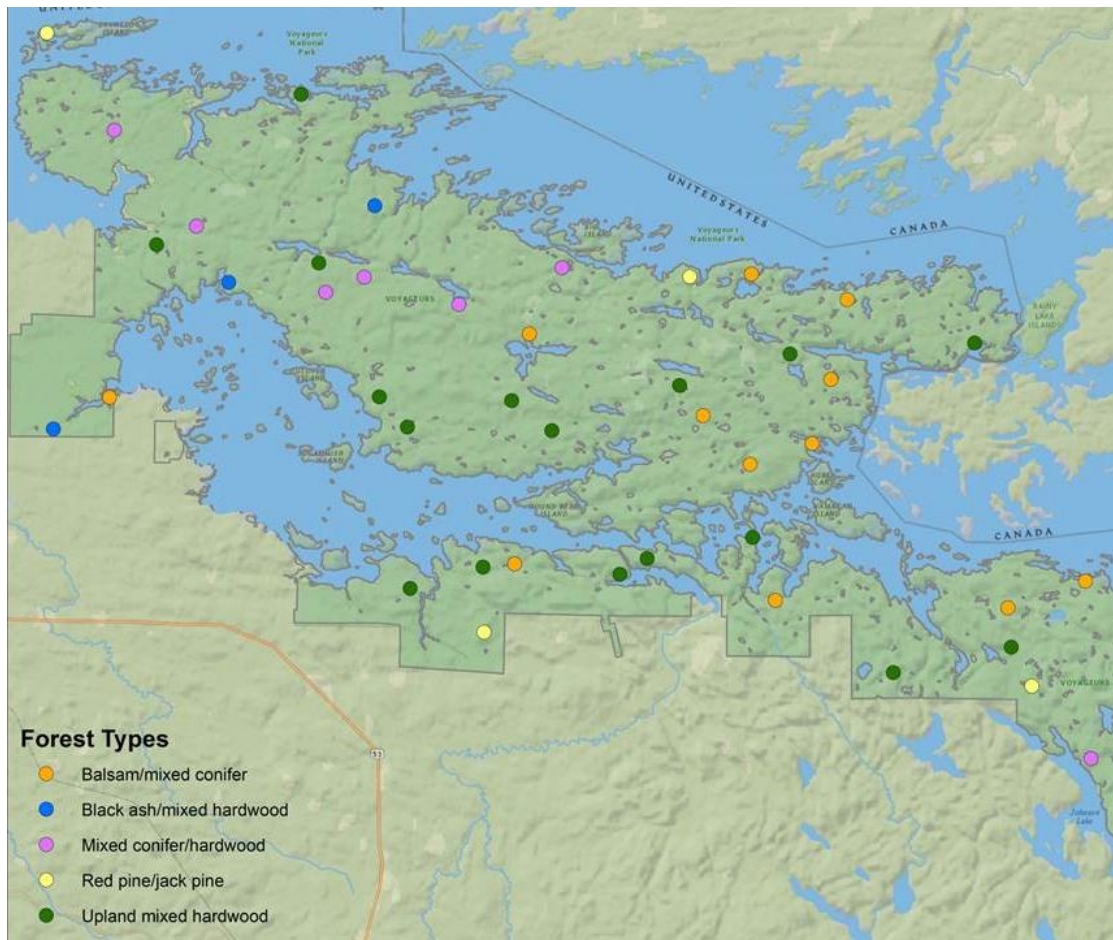


Figure 2. Long-term monitoring plot locations, showing the five broad forest types of each.

Table 2. Five forest types and the plots classified in each. Plots in bold were sampled in 2008; all other plots were established and sampled for the first time in 2015–2016.

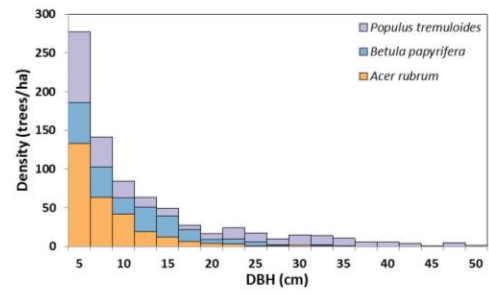
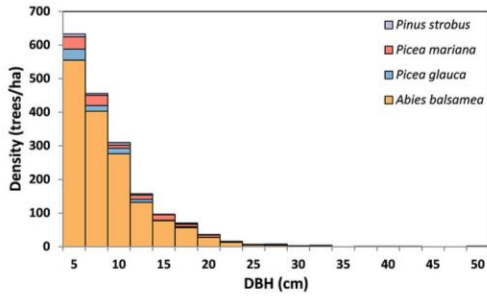
Forest type	Plots
Balsam fir/mixed conifer	9007, 9009, 9026 , 9030, 9034 , 9037, 9039, 9040, 9047, 9048, 9049, 9061 , 9063, 9066, 9067
Black ash/mixed hardwood	9006, 9010 , 9038, 9052, 9065
Mixed conifer/hardwood	9013, 9017, 9023, 9024 , 9028, 9029, 9035, 9042, 9059, 9064
Red pine/Jack pine	9015, 9016, 9043, 9069
Upland mixed hardwood	9001, 9002, 9005, 9008, 9012, 9020, 9021, 9022, 9025, 9031 , 9033, 9036, 9041 , 9045, 9051, 9053, 9054, 9058, 9060

Trees: 2015–2016 Status

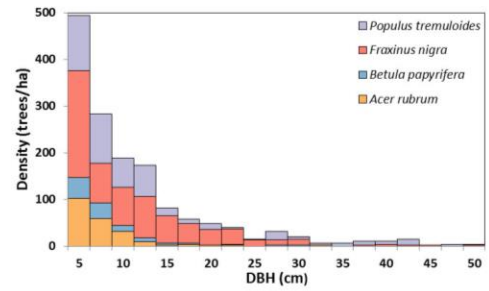
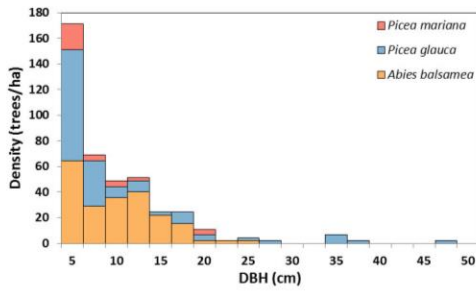
Ingrowth of *Abies balsamea* dominated the conifer component of plots in all forest types except Black Ash/Mixed Hardwood (Figure 3). *Picea glauca* and *P. mariana* (Mill.) Britton, Sterns & Poggenb. (black spruce) were generally the next most abundant species, except in Upland Mixed Hardwood, where *Pinus strobus* was common. Fire-dependent conifers, *Pinus banksiana* and *P. resinosa*, were only present as a few scattered individuals throughout the park, except in Red Pine/Jack Pine forests. Here, *P. banksiana* existed primarily as large individuals 20–40 cm DBH, while *Pinus resinosa* was present throughout a wider range of size classes (2.5–45 cm DBH), but at low densities throughout.

Among hardwoods, *Acer rubrum* L. (red maple) dominated all forest types, composing at least half the total density in three forests types, mostly as smaller individuals (Tables B-1, B-3, B-5, B-7, B-9). *Quercus* spp. L. (oaks) were only common in Red Pine/Jack Pine forests, and were present across a range of size classes. Similarly, *Fraxinus nigra* was only abundant in Black Ash/mixed hardwood forests, which supported it across all size classes.

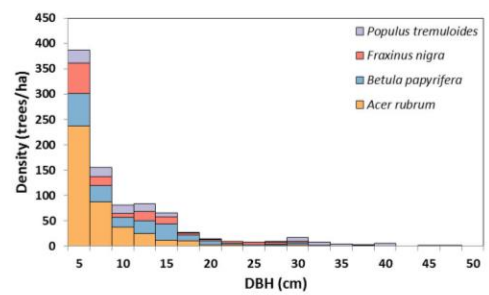
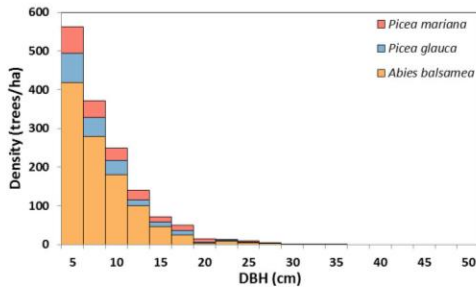
Balsam Fir-Mixed Conifer



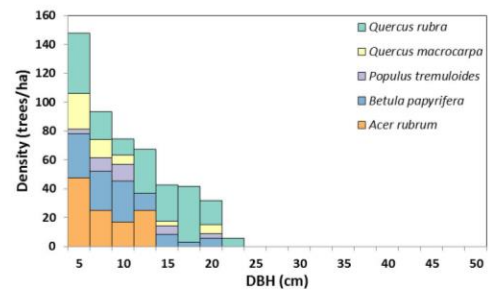
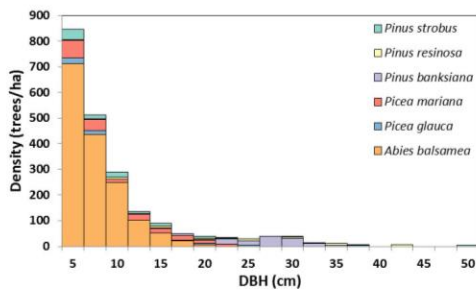
Black Ash-Mixed Hardwood



Mixed Conifer-Hardwood



Red Pine-Jack Pine



Upland Mixed Hardwood

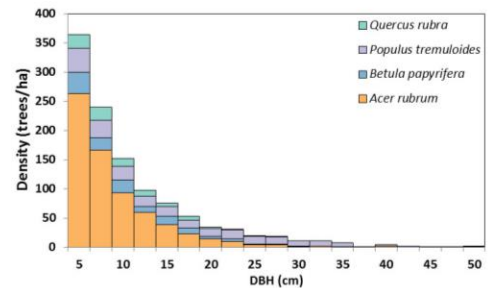
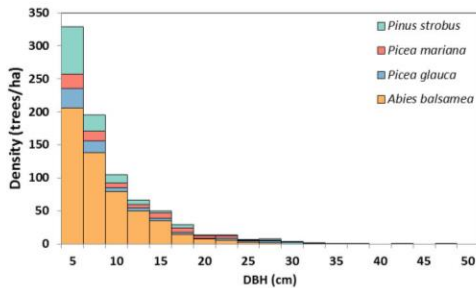


Figure 3. Density by diameter size classes for plots in five forest types with conifers in left column and hardwoods in right. Note the scales of the y-axes vary.

Trees: Short-Term Change

Overall tree density increased from 2008 ($2,223/\text{ha} \pm 132$) to 2015/16 ($2,461/\text{ha} \pm 113$), although basal area was similar between time periods (Figure 4).

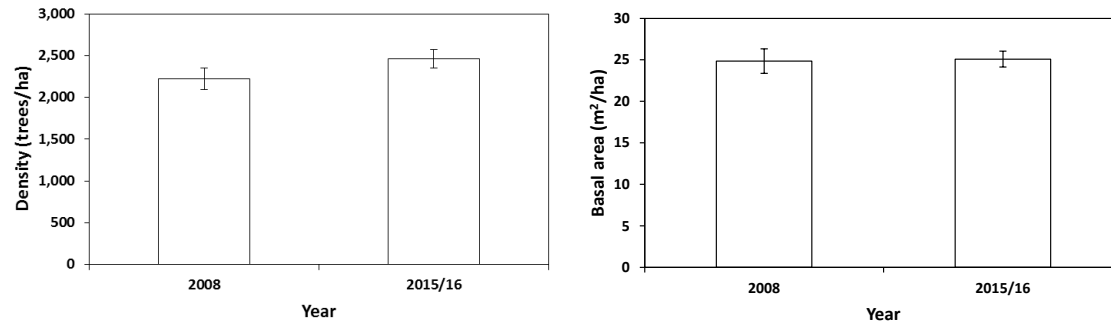


Figure 4. Tree density (*left*) and basal area (*right*), pooled across all forest types for both 2008 and 2015/16.

For all plots collectively, density was generally higher in 2015/16 for size classes below 25 cm DBH, but lower in larger size classes (Figure 5).

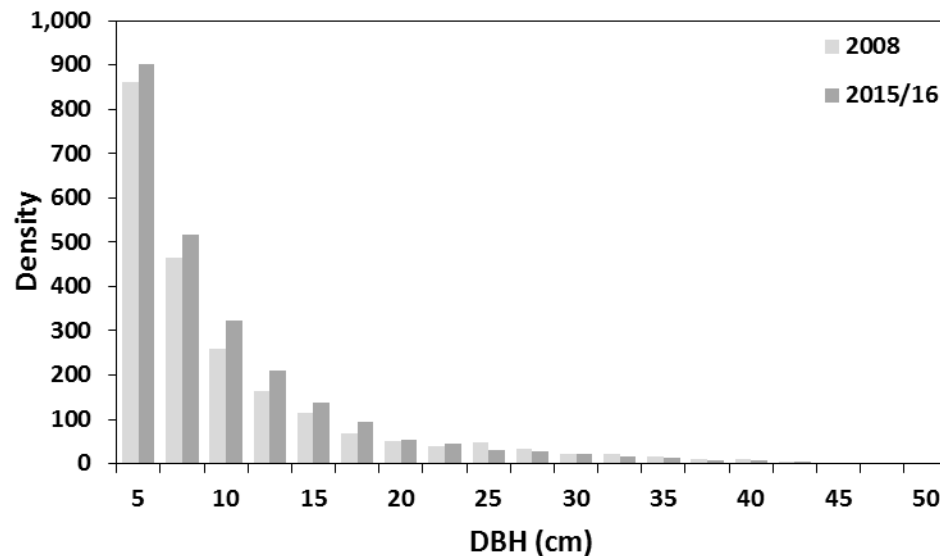


Figure 5. Tree density by diameter classes in 2008 and 2015/16 for all plots. In general, densities were greater in 2015/16 for size classes up to 22.5 cm DBH; for larger trees, densities were greater in 2008.

Sapling density increased between sampling periods ($12,081 \pm 1,753$ saplings/ha vs. $18,317 \pm 1,923$ saplings/ha) (Figure 6) and also varied greatly among forest types. This was higher in Black Ash/Mixed Hardwood forests than the other four forest types.

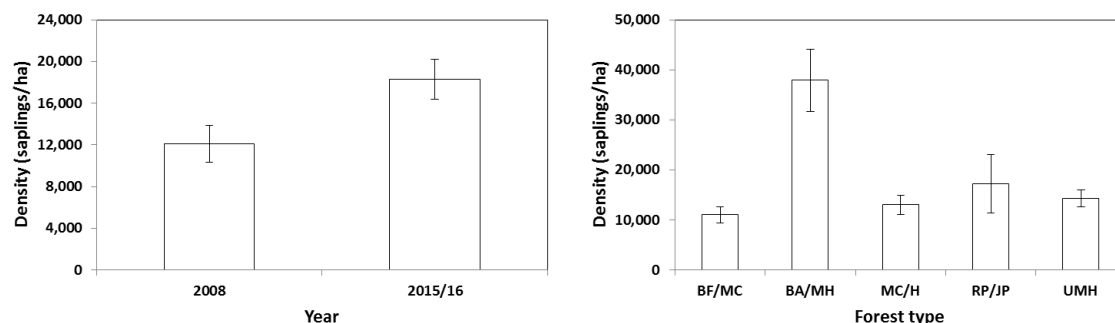


Figure 6. Sapling density, pooled across both time periods (*left*) and across all forest types (*right*). BF/MC: balsam fir/mixed conifer, BA/MH: black ash/mixed hardwood, MC/H: mixed conifer/hardwood, RP/JP: red pine/Jack pine, UMH: upland mixed hardwood.

Coarse Woody Material and Standing Dead Trees

Density of coarse woody material was higher in 2015/16 for all size classes except 30–39.9 cm (Table 3). Overall density was also higher for the second time period, although volume and biomass were higher during the first sampling event (Table 4). The density of pieces desirable for wildlife (≥ 2 m in length, ≥ 30 cm diameter at transect intercept, and decay class 3 or 4) was $8.72 \pm 2.25/\text{ha}$ in 2008 and $6.79 \pm 1.51/\text{ha}$ in 2015/16. Density of standing dead trees, or *snags*, ≥ 30 cm DBH was highest for Upland Mixed Hardwood plots (29.24 snags/ha, Table 5) and lowest for those in Red Pine/Jack Pine forest (14.6 snags/ha). For the other three forest types, this ranged from $24.44/\text{ha}$ to $26.67/\text{ha}$ (Table 5).

Table 3. Coarse woody material density by size classes. This reflects all 38 plots sampled in 2008 and 53 plots sampled during 2015/16.

Year	Diameter at transect intercept			
	7.5–19 cm	20–29.9 cm	30–39.9 cm	≥ 40 cm
2008	495.00 ± 47.71	88.97 ± 13.01	12.71 ± 2.84	0.23 ± 0.16
2015/16	684.31 ± 47.72	98.87 ± 11.27	10.78 ± 2.38	0.80 ± 0.48

Table 4. Volume, biomass, and density of coarse woody material for both time periods. This reflects all 38 plots sampled in 2008 and 53 plots sampled during 2015/16.

Year	Volume (m^3/ha)	Biomass (kg/ha)	Density (pieces/ha)
2008	67.61 ± 8.23	$19,281.53 \pm 2,489.35$	596.91 ± 56.82
2015/16	59.57 ± 5.38	$17,451.00 \pm 1,619.34$	794.76 ± 52.37

Table 5. Density of standing dead trees ≥ 30 cm DBH for all forest types in the 2015/16 sampling period.

Forest type	Density (snags/ha)
Balsam Fir/Mixed Conifer	25.92
Black Ash/Mixed Hardwood	26.67
Mixed Conifer/Hardwood	24.44
Red Pine/Jack Pine	14.60
Upland Mixed Hardwood	29.24

Browse and Disease

Browse on woody species varied greatly. At the species level, across all forest types, $PB_{Species}$ (Proportion Browse on species) was $>20\%$ for *Cornus rugosa* Lam. (roundleaf dogwood) and *Alnus viridis* ssp. *crispa* (Aiton) Turrill (green alder, Table 6). Ten other taxa had bite marks in $>10\%$ of the circles in which they were present (Table 6).

Across three forest types in 2015/16 (Balsam/Mixed Conifer, Black Ash/Mixed Hardwoods, and Mixed Conifer/Hardwood), the $PB_{ForestType}$ did not vary greatly, ranging from 0.199–0.218 (Figure 7). $PB_{ForestType}$ in Red Pine/Jack Pine forests was approximately half that (0.104), while nearly a third (0.284) of species-circle combinations in Upland/Mixed Hardwood plots were browsed.

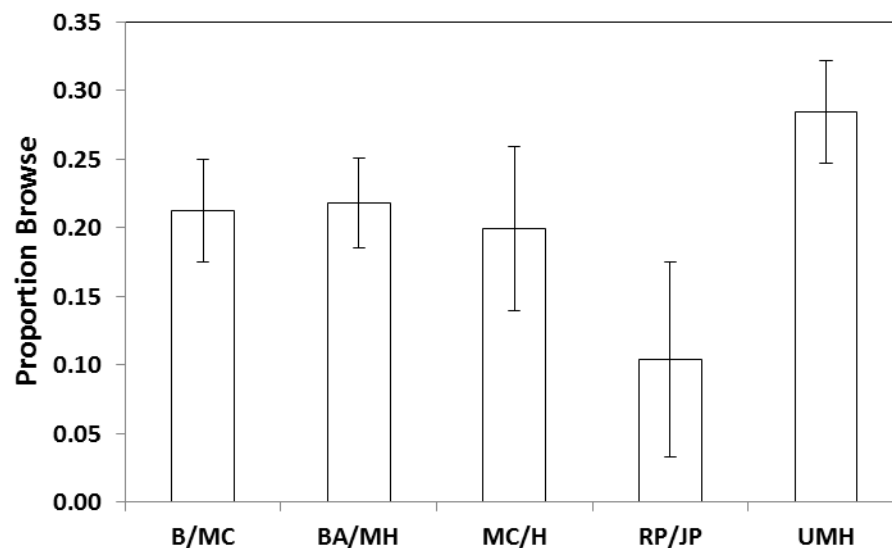


Figure 7. Proportion browse by forest type. Error bars represent $\pm$ one standard error. For forest type names, see Figure 6.

Table 6. Proportion browse for all woody species present in at least six plots.

Species	Proportion Browsed*
<i>Cornus rugosa</i>	0.2537
<i>Alnus viridis</i> ssp. <i>crispa</i>	0.2381
<i>Cornus sericea</i> ssp. <i>sericea</i>	0.1935
<i>Acer spicatum</i>	0.1872
<i>Viburnum opulus</i> var. <i>americanum</i>	0.1765
<i>Corylus cornuta</i>	0.1524
<i>Amelanchier</i> sp. Group 3.	0.1429
<i>Amelanchier</i> sp. Group 2.	0.1275
<i>Betula papyrifera</i>	0.1262
<i>Populus grandidentata</i>	0.1154
<i>Cornus alternifolia</i>	0.1111
<i>Prunus pensylvanica</i>	0.1111
<i>Ostrya virginiana</i>	0.0833
<i>Sorbus decora</i>	0.0833
<i>Viburnum rafinesqueanum</i>	0.0827
<i>Acer rubrum</i>	0.0816
<i>Fraxinus nigra</i>	0.0686
<i>Salix bebbiana</i>	0.0667
<i>Tilia americana</i>	0.0667
<i>Prunus virginiana</i>	0.064
<i>Populus tremuloides</i>	0.0624
<i>Quercus rubra</i>	0.0513
<i>Salix</i> sp.	0.0513
<i>Lonicera canadensis</i>	0.0468
<i>Pinus strobus</i>	0.0406
<i>Quercus ellipsoidalis</i>	0.0294
<i>Diervilla lonicera</i>	0.0279
<i>Comptonia peregrina</i>	0.0275
<i>Alnus incana</i> ssp. <i>rugosa</i>	0.0268
<i>Ribes hirtellum</i>	0.0241
<i>Quercus macrocarpa</i>	0.0133
<i>Rosa acicularis</i>	0.0114
<i>Ribes triste</i>	0.0092
<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	0.0047
<i>Vaccinium angustifolium</i>	0.0043
<i>Abies balsamea</i>	0.0034
<i>Vaccinium myrtilloides</i>	0.0034

*Species for which no browse was recorded were: *Juniperus communis*, *Lonicera dioica*, *L. hirsuta*, *Picea glauca*, *P. mariana*, *Pinus banksiana*, *P. resinosa*, *Rhododendron groenlandicum*, *R. glandulosum*, *R. hudsonianum*, *Rubus pensilvanicus*, *Thuja occidentalis*, *Toxicodendron rydbergii*, *Vaccinium cespitosum*, *V. macrocarpon*.

For the eight indirect preferred browse species (Table 1), among plots sampled both time periods, *Summed Frequency of Presence* ranged from 1.07–1.58 across the five forest types in 2015/16 which was slightly higher than those same plots in 2008 (Figure 8).

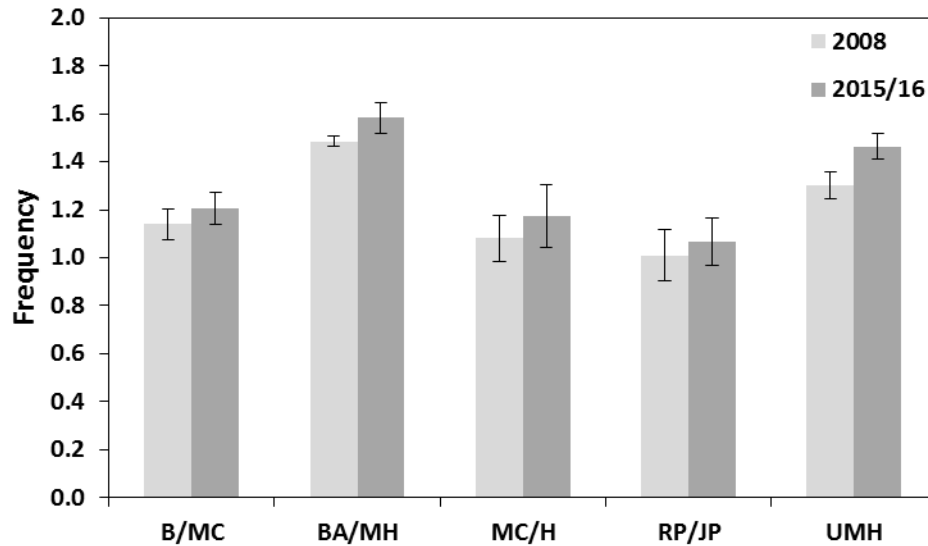


Figure 8. The summed frequency of presence for eight preferred browse species. For all forest types, this was slightly higher during the second sampling interval. Error bars represent $\pm$ one standard error.

Differences in the frequency of quadrats supporting target indirect browse taxa were minimal between the two sampling periods (Figure 9a) although the maximum height of these taxa in quadrats (Figure 9b) and the frequency of quadrats supporting reproductive individuals (Figure 9c) increased over the interval. During the same time period, browse pressure (the frequency of quadrats in which at least one individual has been browsed) nearly doubled for *C. borealis*, while this was nearly halved for *Streptopus* spp.

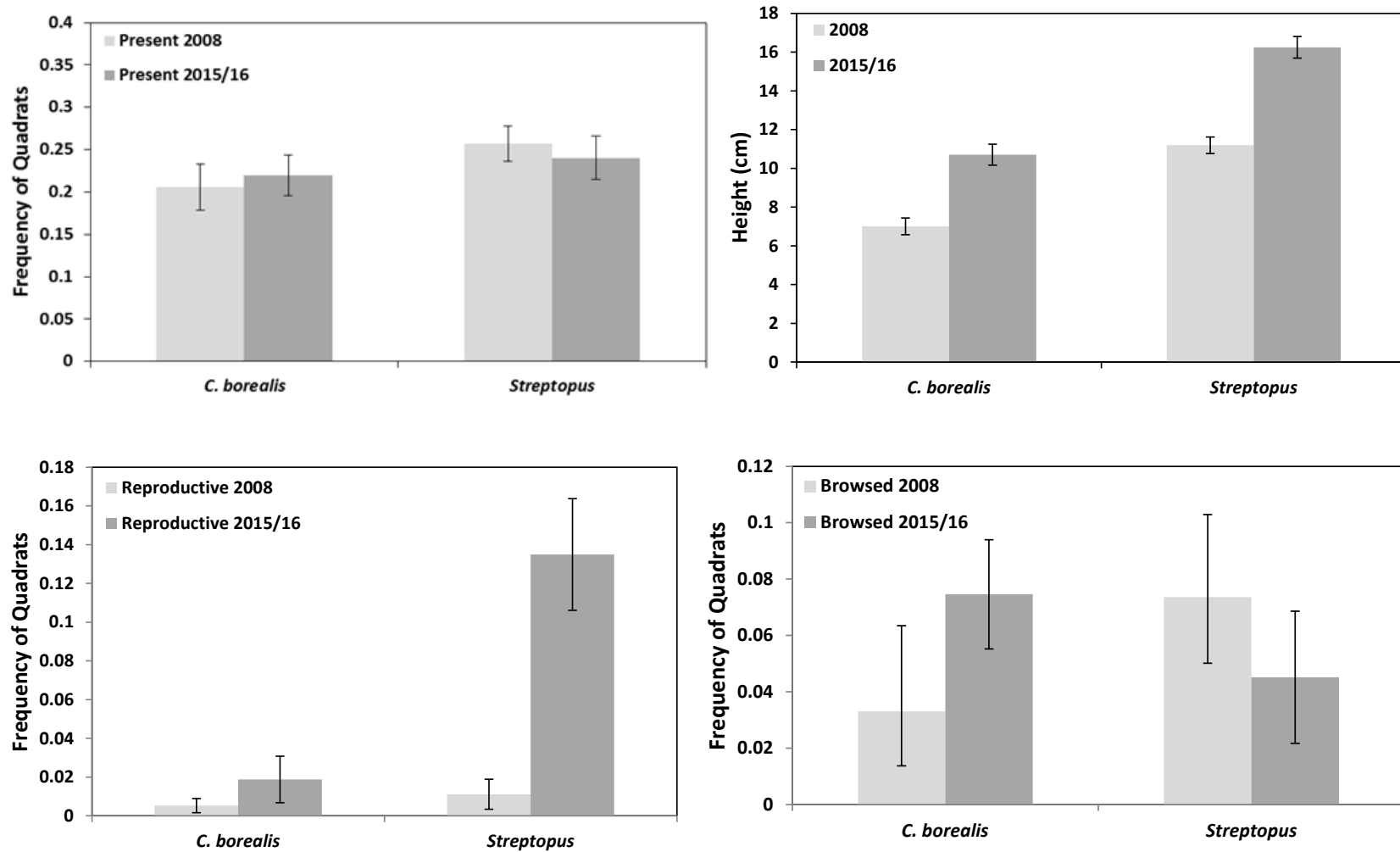


Figure 9. Indirect indices of browse on two target taxa. *From left to right, starting at top:* A) Frequency of quadrats per plot supporting target species; B) maximum height of target taxa in quadrats; C) frequency of quadrats with reproductive individuals and D) frequency of quadrats with browsed individuals.

Tree Health

No large-scale or consistent tree health concerns emerged from the 2015/16 sampling. While we did note several instances of tree dieback, it was within normal levels, and in all forest types, across several tree species.

Community Indices

Species richness was increased between sampling periods (57.6 ± 2.13 species/plot in 2008 to 76.8 ± 2.03 species/plot in 2015/16) (Figure 10). When pooled across both time periods, species richness varied across forest types and was highest in Black Ash/Mixed Hardwood forests (Figure 10).

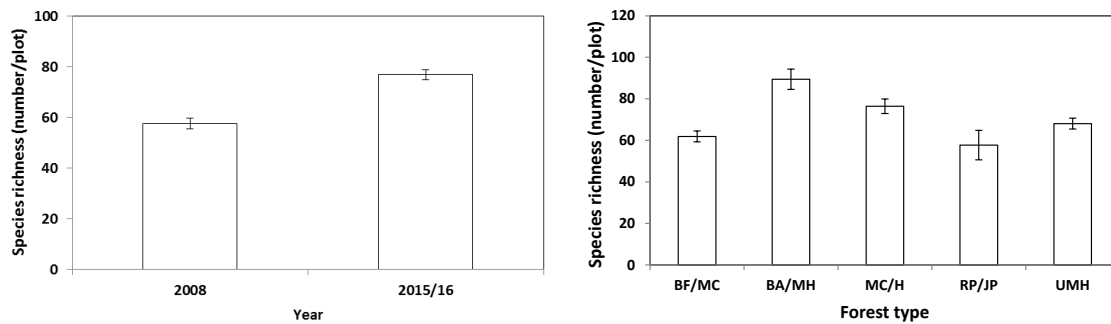


Figure 10. Species richness in each sampling interval (*left*) and in each of the five forest types (*right*). See Figure 6 for forest type names.

The mFQI was 5.16 and 5.18 over the two sampling periods (Figure 11). Across all forest types, this ranged from 5.10 to 5.38.

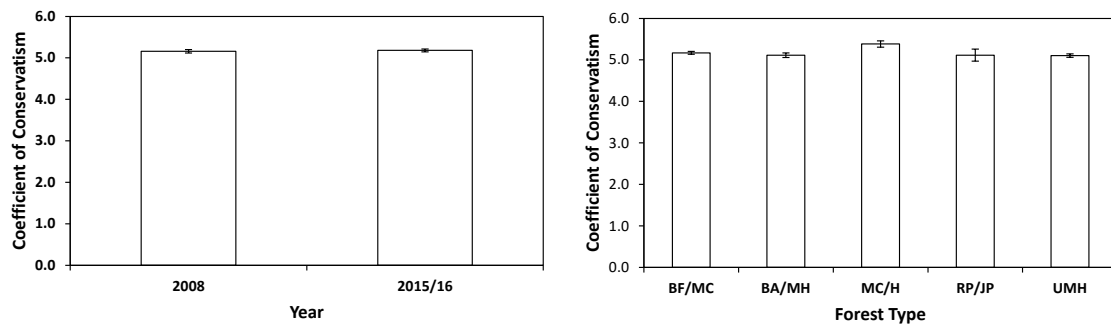


Figure 11. The modified floristic quality index (mFQI) for the two time periods (*left*) and among forest types (*right*). See Figure 6 for forest type names.

Community Change

Successional vectors connecting each pair of 38 plots between the two sampling periods reveal little directional change in the overstory. For trees (Figure 12a), only one plot stood out as exhibiting more change than the others. Plot 9022, represented by the long, purple arrow pointing downward towards Axis 2, contained a great deal of dead *B. papyrifera*, along with a large number of young *A. rubrum* recruits.

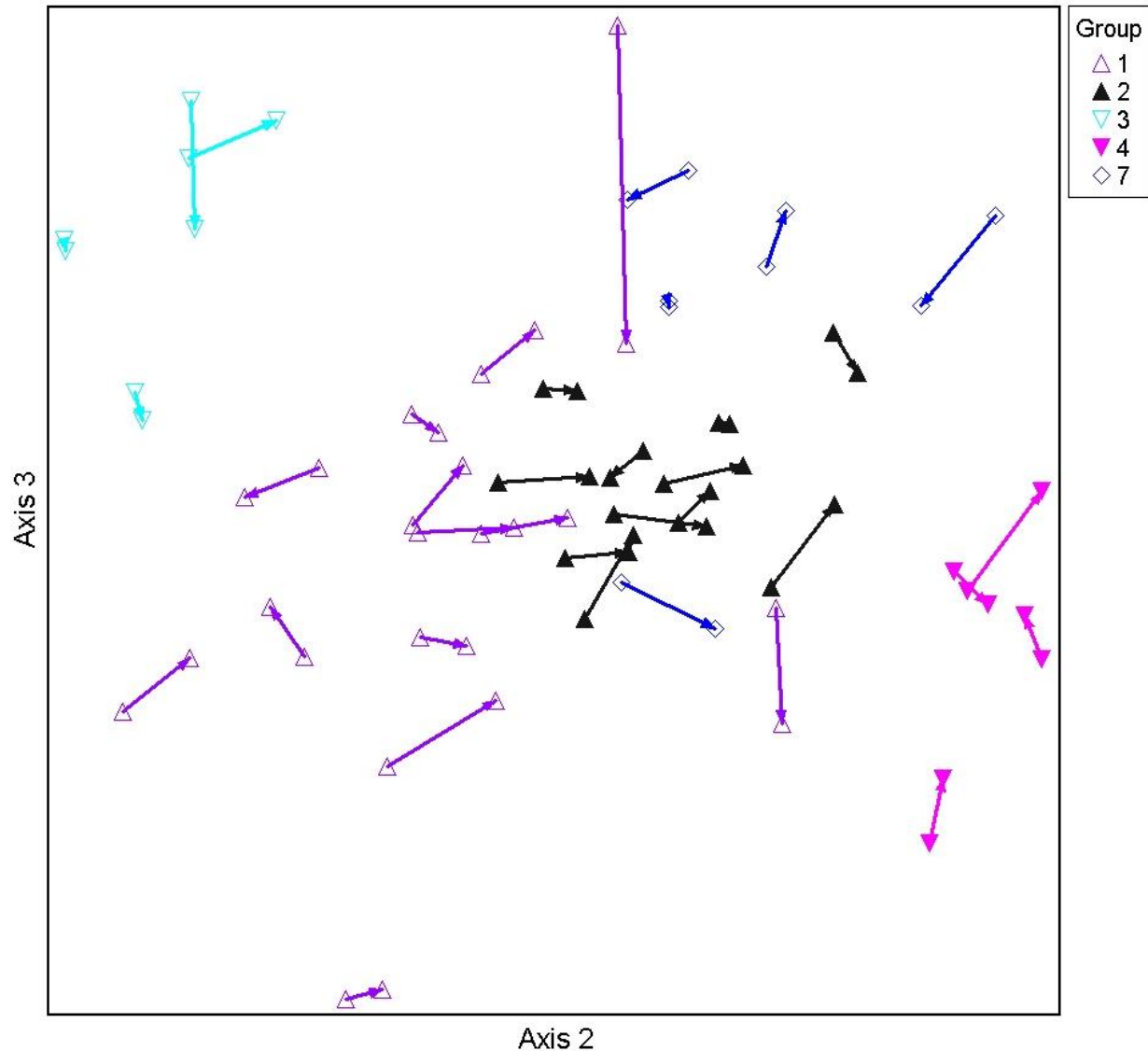


Figure 12a. Successional vectors of non-metric multidimensional scaling (NMS) on trees. Group 1 (purple): Upland/Mixed Hardwood; Group 2 (black): Balsam Fir/Mixed Conifer; Group 3 (teal): Black Ash/Mixed Hardwood; Group 4 (pink): Red Pine/Jack Pine; Group 7 (blue): Mixed Conifer/Hardwood. The purple arrow at the top pointing downward is Plot 9022.

A few more patterns were evident in the groundlayer data. The four plots in the Red Pine/Jack Pine forest type (Figure 12b, Group 4) changed in a similar manner in ordination space. These four plots were characterized by decreases in the frequencies of *Gaultheria procumbens* L. (wintergreen) and *Eurybia macrophylla* (L.) Cass (bigleaf aster) and increases in *Aralia nudicaulis* L. (wild sarsaparilla) and *Oryzopsis asperifolia* Michx. (roughleaf ricegrass). In Mixed Conifer/Hardwood forests (Figure 12b, Group 7), four of the five plots changed similarly in ordination space. General patterns of change within plots in this forest type included decreases in *Rubus sachalinensis* var. *sachalinensis* H. Lév. (red raspberry), *Trientalis borealis* Raf. (starflower), and *Lycopodium annotinum* L. (clubmoss), with increases in the frequencies of *O. asperifolia* and *A. nudicaulis*.

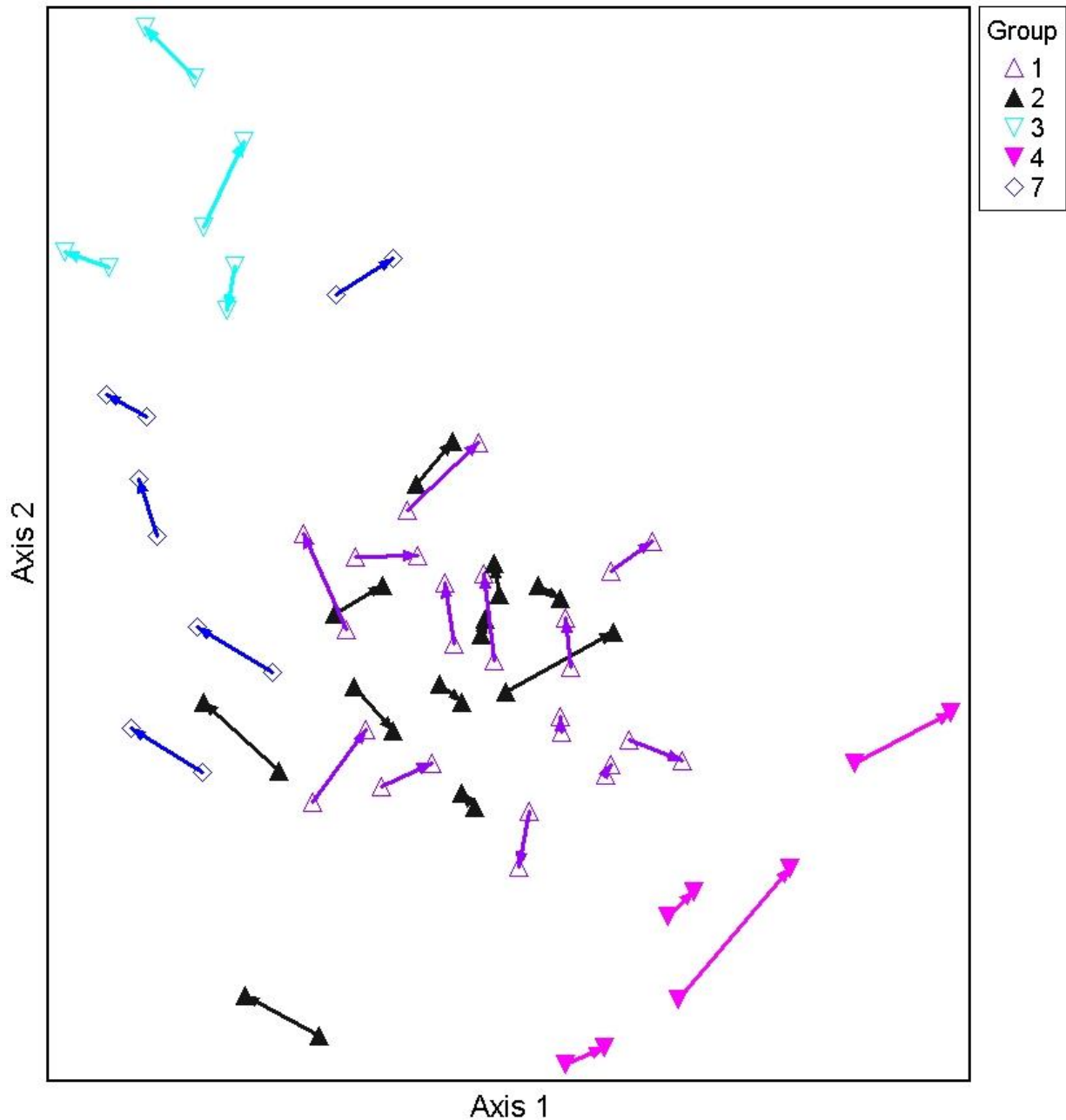


Figure 12b. Successional vectors on non-metric multidimensional scaling (NMS) of groundlayer. Group 1 (purple): Upland/Mixed Hardwood; Group 2 (black): Balsam Fir/Mixed Conifer; Group 3 (teal): Black Ash/Mixed Hardwood; Group 4 (pink): Red Pine/Jack Pine; Group 7 (blue): Mixed Conifer/Hardwood.

Earthworm Impacts

The impacts of earthworms on soils varied although 17 of the 51 plots assessed did not show any evidence of earthworm invasion (Figure 13). These were generally located in the vicinity of the inland lake chain, and in the land between Namakan and Mukooda lakes. Organic horizon thickness was highest (7.90 cm) in Black Ash/Mixed Hardwood forests and lowest in Red Pine/Jack Pine forests (Table 7).

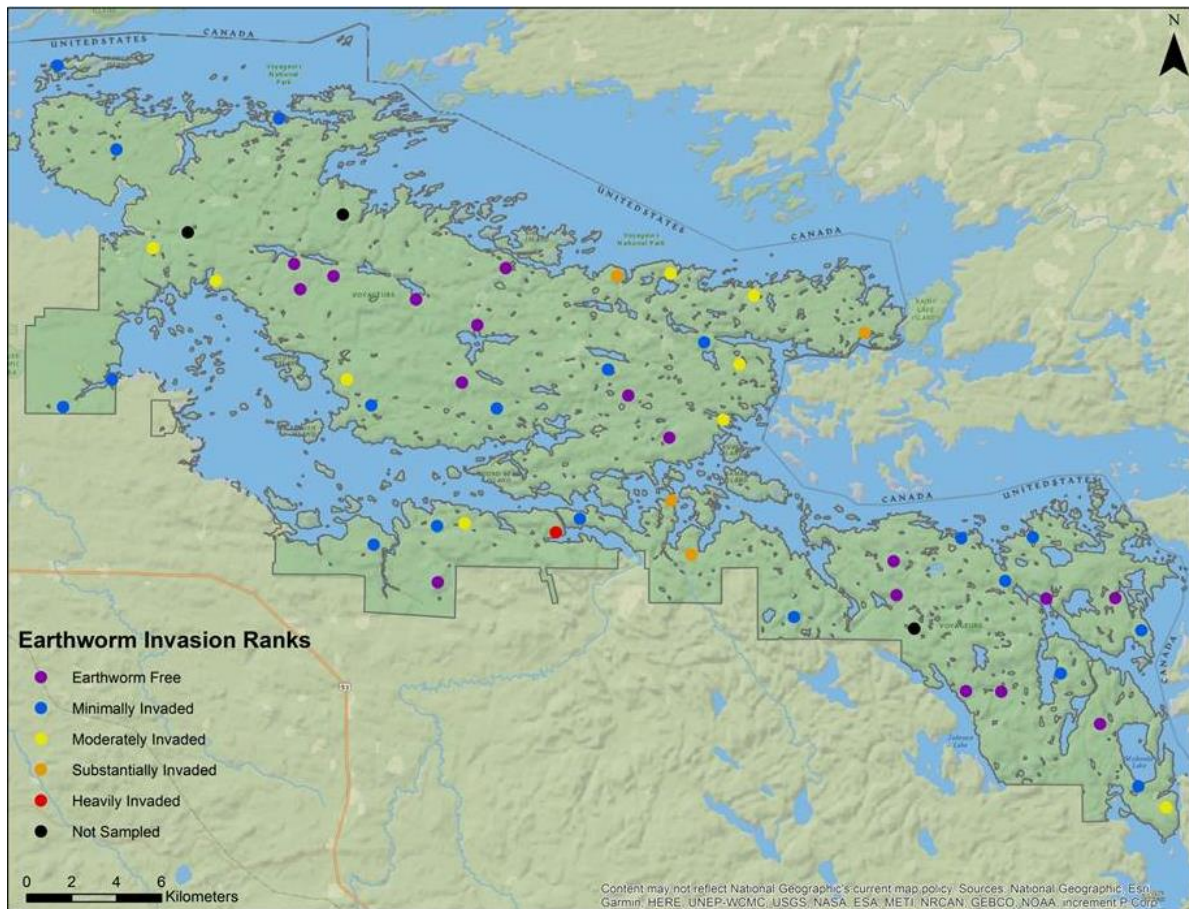


Figure 13. Earthworm invasion ranks at each plot. These designations show the highest level of impairment of the four assessments completed at each plot.

Table 7. Mean O horizon thickness, by forest type, and 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. Earthworms were not assessed at three plots.

Forest Type	O horizon thickness (cm)	Severity of invasion				
		Earthworm free	Minimally invaded	Moderately invaded	Substantially invaded	Heavily invaded
Balsam/mixed conifer	6.56	4	5	5	1	0
Black ash/mixed hardwood	7.90	1	2	1	0	0
Mixed conifer/hardwood	6.82	7	2	0	0	0
Red pine/jack pine	4.64	1	1	0	1	0
Upland mixed hardwood	6.47	4	9	3	2	1

Ash Coverage

Only two map classification names included “ash”: black ash-mixed hardwood swamp and white cedar-black ash swamp. Polygons with these two names, indicating *Fraxinus nigra* the dominant or co-dominant overstory component collectively total 8,900 hectares (Figure 14). Since the total forested acreage at VOYA is 48,352, black ash-dominated forests compose about 18%.

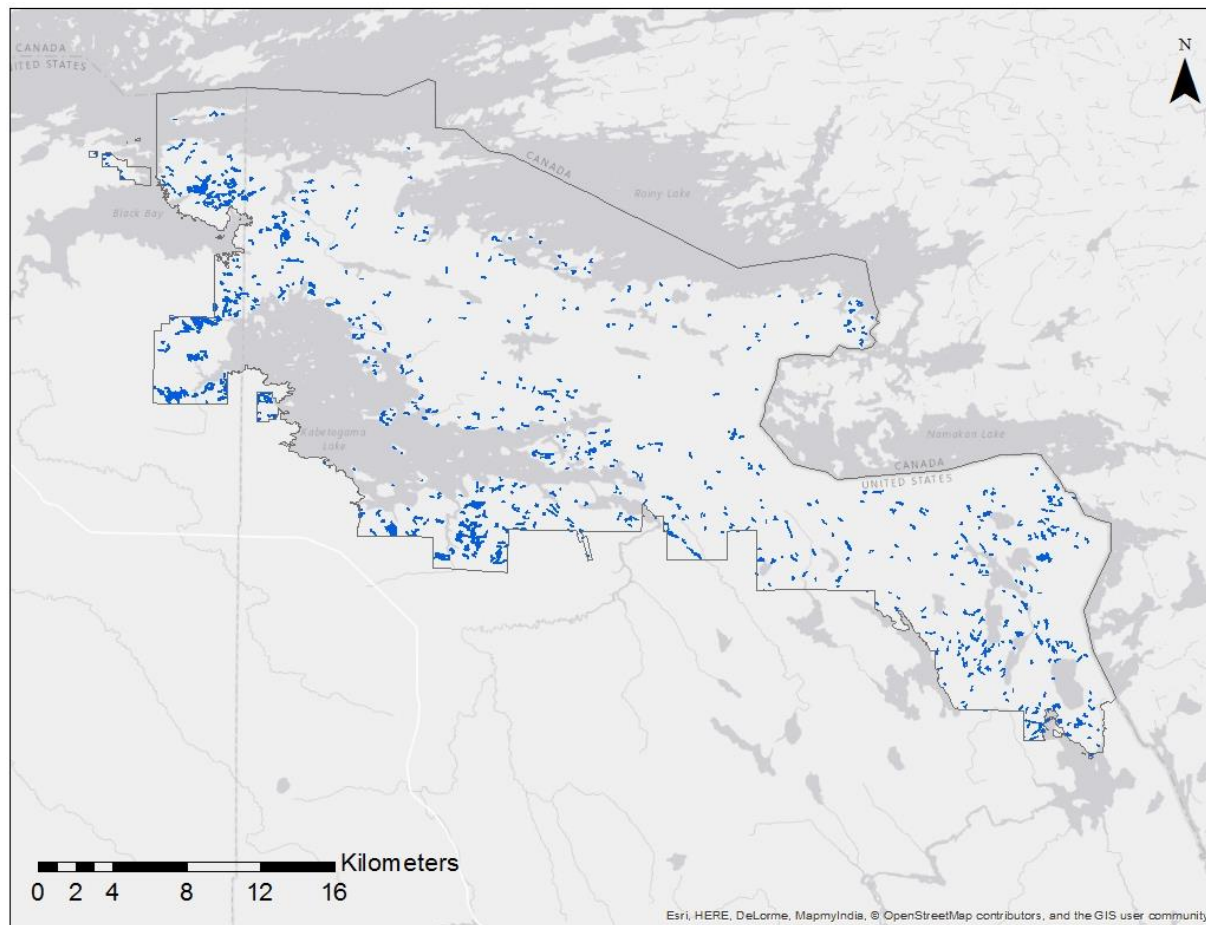


Figure 14. Distribution and extent of areas identified as either black ash-mixed hardwood swamp or white cedar-black ash swamp in Voyageurs National Park. These areas represent 8,900 hectares, or 18% of the total forested area within the park (outlined by the solid gray line).

Discussion

Our results demonstrate a mix of desirable conditions, as well as areas for caution relating to forest health at VOYA. Changes in the overstory between 2008 and 2015/16 largely reflect the forests moving between the mid- to late-successional states, but with no resetting of the successional clock.

Abies balsamea, a shade-tolerant, mid- to late-successional species, dominated the conifer portion of all forest types. This species typically does not become established until after canopy closure of primary successional species (e.g., *Pinus banksiana*, *P. resinosa*, *Populus tremuloides*, *Betula papyrifera*), which follow large-scale disturbance events including fire (Bergeron and Dubuc 1989), or in the case of VOYA, logging. In the absence of these events in southern boreal forests, *A. balsamea* gradually fills canopy gaps, becoming a seed source and, over time, occupying greater proportions of the canopy (Frelich and Reich 1995). Under normal disturbance processes (i.e., in the presence of fire), across a larger area such as a national park, a mosaic of successional states will exist. Shade-tolerant mid-successional fir forests may grow adjacent to, or in close proximity with, early successional aspen-birch or red pine-jack pine forests, for example. The latter forest type is often found in single age cohorts within a stand but, across a larger area (e.g., a national park) the stands collectively span a range of age-classes. In the absence of major disturbance, forests at VOYA do not exhibit this pattern. Both *Pinus banksiana* and *P. resinosa* are now only present in large size classes and are not successfully reproducing. With continued absence of large, stand-scale disturbance, these two species may become extirpated within the park.

In mixed and hardwood stands, *Acer rubrum*, which reproduces by seed and adventitious shoots (Tremblay et al. 2002), is becoming more abundant at VOYA (Figure 3). *Acer rubrum* competes well in a range of light conditions, both as seedlings (Marquis et al. 1983) and as subclimax individuals (Curtis and McIntosh 1951, Walters and Yawney 1990). This species has been encroaching on fire-prone forests types throughout its range, dampening their flammability in the process, via a series of feedback loops now widely known as *mesophication*. The leaves of *A. rubrum*, a fire-sensitive species, have a high moisture content and long drying period (Kreye et al. 2018) and as such, slightly inhibit flammability. Its broad leaves shade out light, creating a cooler and moister groundlayer microclimate than would exist under conifers (Nowacki and Abrams 2008). Under these conditions, coarse woody materials decay faster, reducing the overall amount of fuel in the system at any one time (Nowacki and Abrams 2008). These conditions tend to favor not only *A. rubrum*, but other hardwood species that are either poorly adapted, or not adapted to fire. Mineral soils under *A. rubrum* have higher rates of inorganic N cycling compared with those under *Quercus* spp. (Alexander and Arthur 2010), further impacting site conditions. As mesophytic, fire-sensitive species begin to establish, increased humidity and decreased wind in the understory further the transition (Nauertz et al. 2004). Eventually, structure, composition, and function are altered and it is possible for the system to shift to an alternative state (Nowacki and Abrams 2008). While change in the pattern of fire disturbance is altering forests at VOYA, it is acting in concert with browse to drive change.

Short-term changes in deer density and preferences, in response to climate, have been documented over time spans of a few years (Durmont et al. 2005). At VOYA, several indices collectively suggest the forests may be rebounding somewhat from earlier deer browse pressure. Seedling density (individuals of tree species at least 15 cm in height, but smaller than 2.5 cm diameter at breast height) increased 52% between the sampling periods (Table 6). In addition, smaller diameter trees increased slightly between the sampling periods for all size classes below 22.5 cm DBH (Figure 5). This could be a direct result of reduced browse pressure (i.e., fewer deer), general successional processes as forests move into late successional stages (with many large trees dying and creating gaps that facilitate new growth), or a combination of the two. Data of indirect browse impacts on herbaceous species also suggest that, in fact, there has been a reduction in browse pressure.

Across all plots, the summed frequencies of quadrats in which the eight preferred browse species were present increased from 1.20 to 1.31 between time periods and were higher during the second time period for all five forest types. While browse indirectly impacts groundlayer species, leading to fewer and smaller individuals (Webster et al. 2001, Rooney and Waller 2003), reducing this pressure can lead to more individuals, as is evidenced in this data. Browse pressure, and reduction of it, can also alter demographic characteristics, such as height and reproductive effort. The more focused data we collected on *Clintonia borealis* and *Streptopus* sp. further support our hypothesis of a reduction in browse pressure.

For both target taxa, there was little change in frequency of presence between the sampling periods (Figure 9a). However, the maximum height of *C. borealis* in plots increased from 7.0 cm to 10.7 cm, while that of *Streptopus* sp. increased from 11.2 cm to 16.2 cm (Figure 9b). Like height, reproductive effort also increased for both over the time period, with the frequency of quadrats supporting at least one reproductive individual of *C. borealis* increasing 0.005 to 0.019 and that of *Streptopus* spp. increasing from 0.01 to 0.13 (Figure 9c). The growth habit of these two perennials differs considerably. *Clintonia borealis* produces 1–3 basal leaves with an erect posture; when flowering, a prominent, erect scape emerges that is typically considerably taller than the tallest leaf. Thus, flowering individuals tend to be much more noticeable than those that are non-flowering. *Streptopus* spp., on the other hand, has a lax, arching, leafy stem; when flowering, small pendulous flowers emerge from the axils. These flowers are typically hidden by leaves, resulting in little, if any, difference in visibility between flowering and non-flowering individuals. This may explain the frequency of quadrats browsed. While that of *Streptopus* decreased 39% (Figure 9d), the frequency of quadrats with at least one browsed individual of *C. borealis* actually increased 39%. The reduction in browsing pressure likely resulted in a greater proportion of *C. borealis* being reproductive during the second sampling period, which also resulted in much greater apparency. Indeed, browse on the scape, but not the leaves was observed on several occasions.

Management and Recommendations

The lack of fire and deviation from historic disturbance processes is altering the terrestrial ecosystem at VOYA. The need for active management of forests there has been asserted repeatedly in the literature (Mechenich et al. 2015, Kipfmueller et al. 2017). Indeed, the park's general management plan notes the intent to reestablish the natural fire regime, to the extent possible, in order to meet

management objectives (Voyageurs National Park 2002). More recently, the park's foundation document (Voyageurs National Park 2016) has also underscored this need. Indeed, a limited number of prescribed burns have been carried out in pine stands in the southeast region of the park, with the goal of regeneration of red and jack pine. In addition, fires from two recent natural ignitions have been allowed to burn. The Shoepack Lake fire burned 570 hectares in 2004 and the Tooth Lake fire covered 120 hectares in 2011. Nonetheless, these limited efforts will likely not be enough to ameliorate impending change due to environmental variability.

The park needs to clearly identify desired conditions and develop management guidelines to meet these conditions. We suggest that this goal should focus on promoting resilience, and maintaining structure and function. This is especially pertinent with regard to species' migrations both into, and out of, the park. Work by Frelich and Reich (2009) in the adjacent Boundary Waters Canoe Area Wilderness suggests that *Abies balsamea*, *Picea mariana*, *P. glauca*, *Pinus banksiana*, and *P. resinosa* will likely become extirpated under a predicted warmer and wetter scenario, with *Betula papyrifera*, *Populus tremuloides*, and *P. grandidentata* decreasing in abundance. Under the same scenario, *Quercus* spp. (*Q. rubra*, *Q. macrocarpa*, *Q. ellipsoidalis*, and *Q. alba*) will likely become more abundant. Fisichelli et al. (2014) looked at 38 predictor variables to assess potential suitable forest for tree species at many eastern U.S. national parks. Their findings for VOYA were largely similar, but with two notable exceptions. Habitat availability for *Pinus resinosa* will remain unchanged or have a small increase while habitat availability for *P. banksiana* will remain unchanged.

If the park is able to stem mesophication, and promote *Pinus* spp., as well as *Quercus* spp., it will likely be more resilient as species migration continues. The work by Fisichelli et al. (2014) projects that species migrating into the area will include a number of oaks and hickories. Aboveground linkages include wildlife with nesting and denning habitat and food preferences, while belowground linkages include nutrient cycling with fungal and arthropod composition. Maintaining overstory assemblages with similar functional characteristics should result in ecosystems with greater long-term resilience.

While burning may be the most direct way to achieve this, numerous fiscal and social limitations present obstacles. The park should investigate alternative measures to promote desirable species, including active planting and thinning. Identifying a few key areas in the park where this is more practical, developing an outline, and consulting with key personnel will facilitate the process should the opportunity or funding arise in the future.

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Appendix A: List of all Species Sampled 2015–2016

*Indicates species that are considered Invasive

Herbaceous - Fern / Fern Allies

Dennstaedtiaceae

Pteridium aquilinum

Dryopteridaceae

Dryopteris carthusiana

Dryopteris cristata

Equisetaceae

Equisetum arvense

Equisetum palustre

Equisetum scirpoides

Equisetum sylvaticum

Lycopodiaceae

Huperzia lucidula

Lycopodium annotinum

Lycopodium clavatum

Lycopodium complanatum

Lycopodium dendroideum

Onocleaceae

Onoclea sensibilis

Matteuccia struthiopteris

Ophioglossaceae

Botrychium virginianum

Osmundaceae

Osmunda claytoniana

Osmundastrum cinnamomeum

Polypodiaceae

Polypodium virginianum

Thelypteridaceae

Phegopteris connectilis

Thelypteris palustris

Woodsiaceae

Athyrium filix-femina

Gymnocarpium dryopteris

Woodsia ilvensis

Herbaceous - Forb

Amaryllidaceae

Allium stellatum

Apiaceae

Cicuta bulbifera

Cicuta maculata

Osmorhiza claytonii

Osmorhiza longistylis

Sanicula marilandica

Apocynaceae

Apocynum androsaemifolium

Araceae

Arisaema triphyllum

Calla palustris

Araliaceae

Aralia nudicaulis

Aralia racemosa

Aristolochiaceae

Asarum canadense

Asparagaceae

Maianthemum canadense

Maianthemum stellatum

Maianthemum trifolium

Polygonatum pubescens

Asteraceae

Achillea millefolium

Anaphalis margaritacea

Antennaria howellii ssp. *neodioica*

Antennaria neglecta

Antennaria parlinii

Antennaria sp.

Arctium minus *

Cirsium arvense *

Cirsium muticum

Cirsium sp.

Cirsium vulgare *

Doellingeria umbellata

Erigeron annuus

Erigeron strigosus

Eupatorium perfoliatum

Eurybia macrophylla

Eutrochium maculatum

Hieracium aurantiacum *

Hieracium sp.

Hieracium umbellatum

Lactuca canadensis

Lactuca sp.

Petasites frigidus var. *palmatus*

Prenanthes alba

Rudbeckia hirta

Solidago canadensis

Solidago flexicaulis

Solidago gigantea

Solidago hispida

Solidago nemoralis

Solidago sp.

Symphyotrichum ciliolatum

Symphyotrichum lateriflorum var. *lateriflorum*

Symphyotrichum puniceum var. *puniceum*

Symphyotrichum sp.

Taraxacum officinale

Impatiens capensis

Cynoglossum virginianum var. *boreale*

Cardamine parviflora

Campanula aparinoides

Campanula rotundifolia

Stellaria longifolia

Stellaria sp.

Uvularia grandiflora

Uvularia sessilifolia

Cornus canadensis

Drosera rotundifolia

Chimaphila umbellata
Gaultheria hispidula
Gaultheria procumbens
Monotropa uniflora
Orthilia secunda
Pyrola asarifolia
Pyrola chlorantha
Pyrola elliptica
Pyrola sp.
Lotus corniculatus *
Trifolium pratense *

Balsaminaceae

Impatiens capensis

Boraginaceae

Cynoglossum virginianum var. *boreale*

Brassicaceae

Cardamine parviflora

Campanulaceae

Campanula aparinoides

Campanula rotundifolia

Caryophyllaceae

Stellaria longifolia

Stellaria sp.

Colchicaceae

Uvularia grandiflora

Uvularia sessilifolia

Cornaceae

Cornus canadensis

Droseraceae

Drosera rotundifolia

Ericaceae

Chimaphila umbellata

Gaultheria hispidula

Gaultheria procumbens

Monotropa uniflora

Pyrola chlorantha

Pyrola elliptica

Pyrola sp.

Fabaceae

Trifolium repens

Gentianaceae

Halenia deflexa

Geraniaceae

Geranium bicknellii

Geranium sp.

Hypericaceae

Hypericum majus

Hypericum sp.

Triadenum fraseri

Iridaceae

Iris versicolor

Lamiaceae

Clinopodium vulgare

Lycopus americanus

Lycopus uniflorus

Mentha arvensis
Prunella vulgaris
Scutellaria galericulata
Scutellaria lateriflora
Stachys tenuifolia

Liliaceae

Clintonia borealis
Streptopus lanceolatus var. *roseus*

Linnaeaceae

Linnaea borealis

Melanthiaceae

Trillium cernuum

Onagraceae

Chamerion angustifolium
Circaea alpina
Circaea canadensis ssp. *canadensis*
Epilobium ciliatum
Epilobium leptophyllum
Epilobium sp.

Orchidaceae

Corallorhiza sp.
Corallorhiza trifida
Cypripedium acaule
Cypripedium sp.
Dactylorhiza viridis
Goodyera sp.
Goodyera tessellata
Platanthera orbiculata
Platanthera psycodes

Orobanchaceae

Melampyrum lineare

Papaveraceae

Corydalis sempervirens

Polygonaceae

Polygonum sp.
Rumex acetosella *
Rumex crispis *

Pontederiaceae

Pontederia cordata

Primulaceae

Lysimachia ciliata
Lysimachia sp.
Trientalis borealis

Ranunculaceae

Actaea rubra
Actaea sp.
Anemone americana

Ranunculaceae

Anemone acutiloba
Anemone quinquefolia
Aquilegia canadensis
Caltha palustris
Clematis occidentalis
Coptis trifolia
Ranunculus abortivus
Ranunculus acris

Ranunculus pensylvanicus
Ranunculus recurvata
Thalictrum dasycarpum

Rosaceae

Agrimonia sp.
Comarum palustre
Fragaria virginiana
Geum macrophyllum
Geum sp.
Geum rivale
Potentilla norvegica
Sibbaldiopsis tridentata

Rubiaceae

Galium asprellum
Galium boreale
Galium tinctorium
Galium trifidum
Galium triflorum
Mitchella repens

Santalaceae

Comandra umbellata

Saxifragaceae

Heuchera richardsonii
Micranthes virginianensis
Mitella nuda

Urticaceae

Urtica dioica

Violaceae

Viola sp.

Herbaceous - Forb (vine)

Convolvulaceae

Calystegia spithamea

Fabaceae

Amphicarpaea bracteata
Lathyrus ochroleucus
Lathyrus palustris
Lathyrus sp.
Lathyrus venosus
Vicia americana
Vicia sp.

Polygonaceae

Fallopia cilinodis

Herbaceous - Graminoid

Cyperaceae

Carex arctata
Carex brunnescens
Carex canescens
Carex deweyana
Carex disperma
Carex gracillima
Carex gynandra
Carex intumescens
Carex lacustris

Carex leptalea
Carex leptoneura
Carex magellanica ssp. *irrigua*
Carex peckii
Carex pedunculata
Carex pellita

Cyperaceae

Carex pennsylvanica
Carex projecta
Carex sp.
Carex sprengei
Carex stipata
Carex tenera
Carex trisperma
Dulichium arundinaceum
Eriophorum sp.
Scirpus cyperinus
Scirpus sp.

Juncaceae

Juncus sp.
Juncus tenuis
Luzula acuminata

Poaceae

Agrostis gigantea
Agrostis sp.
Brachyelytrum erectum
Bromus ciliatus
Calamagrostis canadensis
Cinna latifolia
Danthonia spicata
Dichanthelium linearifolium
Dichanthelium sp.
Elymus hirtus
Elymus trachycaulus ssp. *trachycaulus*
Glyceria grandis
Glyceria sp.
Glyceria striata
Oryzopsis asperifolia
Phalaris arundinacea *
Phleum pratense
Piptatherum pungens
Poa compressa *
Poa pratensis
Poa sp.
Schizachne purpurascens

Shrub

Adoxaceae

Sambucus racemosa var. *racemosa*
Viburnum lentago
Viburnum opulus var. *americanum*
Viburnum rafinesqueanum

Anacardiaceae

Rhus typhina

Araliaceae

Aralia hispida

Betulaceae

Alnus incana ssp. *rugosa*
Alnus viridis ssp. *crispa*
Betula pumila
Corylus cornuta

Caprifoliaceae

Lonicera canadensis
Lonicera hirsuta
Lonicera oblongifolia
Lonicera sp.
Symphoricarpos albus

Cornaceae

Cornus alternifolia
Cornus rugosa
Cornus sericea ssp. *sericea*
Cornus sp.

Cupressaceae

Juniperus communis

Diervillaceae

Diervilla lonicera

Ericaceae

Arctostaphylos uva-ursi
Chamaedaphne calyculata
Kalmia polifolia
Rhododendron groenlandicum
Vaccinium angustifolium
Vaccinium cespitosum
Vaccinium macrocarpon
Vaccinium myrtilloides
Vaccinium oxycoccos

Grossulariaceae

Ribes americanum
Ribes glandulosum
Ribes hirtellum
Ribes hudsonianum
Ribes oxycanthoides
Ribes triste

Myricaceae

Comptonia peregrina
Myrica gale

Rhamnaceae

Rhamnus alnifolia

Rosaceae

Amelanchier sp. Group 2
Amelanchier sp. Group 3
Prunus pumila
Rosa acicularis
Rubus canadensis
Rubus pensilvanicus
Rubus pubescens
Rubus sachalinensis var. *sachalinensis*
Spiraea alba

Shrub - Woody Vine

Anacardiaceae

Toxicodendron rydbergii

Caprifoliaceae

Lonicera dioica

Vitaceae

Parthenocissus quinquefolia

Parthenocissus sp.

Tree

Betulaceae

Betula papyrifera

Ostrya virginiana

Cupressaceae

Thuja occidentalis

Fagaceae

Quercus ellipsoidalis

Quercus macrocarpa

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

Rosaceae

Prunus pensylvanica

Prunus virginiana

Sorbus decora

Salicaceae

Populus balsamifera

Populus grandidentata

Populus tremuloides

Salix bebbiana

Sapindaceae

Acer rubrum

Acer spicatum

Ulmaceae

Ulmus americana

Tree / Shrub

Rosaceae

Crataegus sp.

Salicaceae

Salix sp.

Appendix B: Tree and Sapling Summaries by Forest Type in 2015/16

Balsam Fir/Mixed Conifer

Table B-1. Basal area and density of live trees (≥ 2.5 cm DBH) in Balsam Fir/Mixed Conifer forests.

Type	Species	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood	<i>Acer rubrum</i>	red maple	1.51	285.93
	<i>Acer spicatum</i>	mountain maple	0.07	68.15
	<i>Betula papyrifera</i>	paper birch	2.14	208.15
	<i>Fraxinus nigra</i>	black ash	0.57	36.30
	<i>Fraxinus pennsylvanica</i>	green ash	0.02	2.22
	<i>Populus grandidentata</i>	bigtooth aspen	0.75	27.41
	<i>Populus tremuloides</i>	quaking aspen	8.49	279.26
	<i>Prunus virginiana</i>	chokecherry	<0.01	0.74
	<i>Quercus ellipsoidalis</i>	northern pin oak	<0.01	1.48
	<i>Quercus macrocarpa</i>	bur oak	0.01	1.48
	<i>Quercus rubra</i>	northern red oak	0.04	8.89
	<i>Salix bebbiana</i>	gray willow	<0.01	0.74
Conifer	<i>Abies balsamea</i>	balsam fir	8.95	1,551.85
	<i>Larix laricina</i>	tamarack	<0.01	0.74
	<i>Picea glauca</i>	white spruce	0.74	84.44
	<i>Picea mariana</i>	black spruce	1.37	128.15
	<i>Pinus banksiana</i>	Jack pine	1.69	31.11
	<i>Pinus resinosa</i>	red pine	0.57	7.41
	<i>Pinus strobus</i>	white pine	0.31	32.59
	<i>Thuja occidentalis</i>	northern white cedar	0.51	6.67
Total	—	—	27.75	2,763.70

Table B-2. Density of seedlings in Balsam Fir/Mixed Conifer forests.

Species	Common name	Density (seedlings/ha)
<i>Betula papyrifera</i>	paper birch	467
<i>Thuja occidentalis</i>	northern white cedar	67
<i>Quercus macrocarpa</i>	bur oak	67
<i>Quercus rubra</i>	northern red oak	289
<i>Fraxinus nigra</i>	black ash	467
<i>Abies balsamea</i>	balsam fir	1,689
<i>Picea glauca</i>	white spruce	156
<i>Picea mariana</i>	black spruce	156
<i>Pinus strobus</i>	white pine	156
<i>Prunus virginiana</i>	chokecherry	133
<i>Populus grandidentata</i>	bigtooth aspen	44
<i>Populus tremuloides</i>	quaking aspen	1,200
<i>Salix bebbiana</i>	gray willow	22
<i>Acer rubrum</i>	red maple	7,067
<i>Acer spicatum</i>	mountain maple	2,000
<i>Ulmus americana</i>	American elm	22
Total	—	14,000

Black Ash/Mixed Hardwood

Table B-3. Basal area and density of live trees (≥2.5 cm DBH) in Black Ash/Mixed Hardwood forests.

Type	Species	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood	<i>Acer rubrum</i>	red maple	1.00	215.56
	<i>Acer spicatum</i>	mountain maple	0.29	286.67
	<i>Betula papyrifera</i>	paper birch	0.76	113.33
	<i>Fraxinus nigra</i>	black ash	9.95	704.44
	<i>Fraxinus pennsylvanica</i>	green ash	0.01	4.44
	<i>Ostrya virginiana</i>	ironwood	<0.01	2.22
	<i>Populus balsamifera</i>	balsam poplar	0.21	28.89
	<i>Populus tremuloides</i>	quaking aspen	9.71	466.67
	<i>Prunus virginiana</i>	chokecherry	0.01	6.67
	<i>Quercus macrocarpa</i>	bur oak	0.02	6.67
	<i>Quercus rubra</i>	northern red oak	0.03	6.67
	<i>Ulmus americana</i>	American elm	0.24	37.78
Conifer	<i>Abies balsamea</i>	balsam fir	1.64	213.33
	<i>Picea glauca</i>	white spruce	2.06	171.11
	<i>Picea mariana</i>	black spruce	0.21	35.56
	<i>Pinus strobus</i>	white pine	<0.01	2.22
	<i>Thuja occidentalis</i>	northern white cedar	0.32	4.44
Total	—	—	26.46	2,306.67

Table B-4. Seedling density in Black Ash/Mixed Hardwood forests.

Species	Common name	Density (seedlings/ha)
<i>Betula papyrifera</i>	paper birch	667
<i>Thuja occidentalis</i>	northern white cedar	267
<i>Tilia americana</i>	American basswood	467
<i>Fraxinus nigra</i>	black ash	8,333
<i>Abies balsamea</i>	balsam fir	467
<i>Picea glauca</i>	white spruce	267
<i>Picea mariana</i>	black spruce	67
<i>Pinus strobus</i>	white pine	800
<i>Prunus virginiana</i>	chokecherry	1,200
<i>Populus tremuloides</i>	quaking aspen	1,600
<i>Acer rubrum</i>	red maple	3,733
<i>Acer spicatum</i>	mountain maple	24,800
<i>Ulmus americana</i>	American elm	267
Total	—	42,933

Mixed Conifer/Hardwood

Table B-5. Basal area and density of live trees (≥ 2.5 cm DBH) in Mixed Conifer/Hardwood forests.

Type	Species	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood	<i>Acer rubrum</i>	red maple	2.30	426.67
	<i>Acer spicatum</i>	mountain maple	0.10	91.11
	<i>Betula papyrifera</i>	paper birch	2.12	203.33
	<i>Fraxinus nigra</i>	black ash	1.40	138.89
	<i>Populus grandidentata</i>	bigtooth aspen	0.10	6.67
	<i>Populus tremuloides</i>	quaking aspen	3.08	112.22
	<i>Prunus pensylvanica</i>	pin cherry	<0.01	1.11
	<i>Quercus ellipsoidalis</i>	northern pin oak	0.06	10.00
	<i>Quercus rubra</i>	northern red oak	0.22	22.22
	<i>Salix bebbiana</i>	gray willow	0.01	4.44
	<i>Sorbus decora</i>	northern mountain ash	<0.01	1.11
	<i>Tilia americana</i>	American basswood	<0.01	1.11
Conifer	<i>Abies balsamea</i>	balsam fir	5.19	1,066.67
	<i>Larix laricina</i>	tamarack	0.15	1.11
	<i>Picea glauca</i>	white spruce	1.49	212.22
	<i>Picea mariana</i>	black spruce	1.64	211.11
	<i>Pinus resinosa</i>	red pine	0.31	11.11
	<i>Pinus strobus</i>	white pine	0.49	25.56
	<i>Thuja occidentalis</i>	northern white cedar	3.89	51.11
Total	—	—	22.57	2,597.78

Table B-6. Density of seedlings in Mixed Conifer/Hardwood forests.

Species	Common name	Density (seedlings/ha)
<i>Betula papyrifera</i>	paper birch	1,100
<i>Thuja occidentalis</i>	northern white cedar	67
<i>Quercus macrocarpa</i>	bur oak	33
<i>Quercus rubra</i>	northern red oak	167
<i>Fraxinus nigra</i>	black ash	1,800
<i>Abies balsamea</i>	balsam fir	600
<i>Picea glauca</i>	white spruce	433
<i>Picea mariana</i>	black spruce	267
<i>Pinus strobus</i>	white pine	300
<i>Prunus pensylvanica</i>	pin cherry	67
<i>Prunus virginiana</i>	chokecherry	67
<i>Populus balsamifera</i>	balsam poplar	67
<i>Populus tremuloides</i>	quaking aspen	700
<i>Acer rubrum</i>	red maple	3,867
<i>Acer spicatum</i>	mountain maple	4,167
Total	–	13,700

Red Pine/Jack Pine

Table B-7. Basal area and density of live trees (≥ 2.5 cm DBH) in Red Pine/Jack Pine forests.

Type	Species	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood	<i>Acer rubrum</i>	red maple	0.49	114.24
	<i>Betula papyrifera</i>	paper birch	0.73	114.01
	<i>Populus grandidentata</i>	bigtooth aspen	0.12	5.56
	<i>Populus tremuloides</i>	quaking aspen	0.30	33.40
	<i>Prunus pensylvanica</i>	pin cherry	<0.01	3.13
	<i>Quercus ellipsoidalis</i>	northern pin oak	0.01	6.27
	<i>Quercus macrocarpa</i>	bur oak	0.33	53.26
	<i>Quercus rubra</i>	northern red oak	2.30	188.89
Conifer	<i>Abies balsamea</i>	balsam fir	5.81	1,580.66
	<i>Picea glauca</i>	white spruce	0.74	51.42
	<i>Picea mariana</i>	black spruce	1.73	198.29
	<i>Pinus banksiana</i>	Jack pine	7.46	148.35
	<i>Pinus resinosa</i>	red pine	2.69	53.20
	<i>Pinus strobus</i>	white pine	1.73	116.37
Total	–	–	24.44	2,667.04

Table B-8. Density of seedlings in Red Pine/Jack Pine forests.

Species	Common name	Density (seedlings/ha)
<i>Betula papyrifera</i>	paper birch	83
<i>Thuja occidentalis</i>	northern white cedar	96
<i>Quercus ellipsoidalis</i>	northern pin oak	865
<i>Quercus macrocarpa</i>	bur oak	288
<i>Quercus rubra</i>	northern red oak	2,167
<i>Abies balsamea</i>	balsam fir	3,603
<i>Picea mariana</i>	black spruce	667
<i>Pinus strobus</i>	white pine	667
<i>Prunus pensylvanica</i>	pin cherry	83
<i>Prunus virginiana</i>	chokecherry	167
<i>Populus tremuloides</i>	quaking aspen	744
<i>Acer rubrum</i>	red maple	2,917
Total	—	12,346

Upland Mixed Hardwood

Table B-9. Basal area and density of live trees (≥ 2.5 cm DBH) in Upland/Mixed Hardwood forests.

Type	Species	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood	<i>Acer rubrum</i>	red maple	4.76	684.21
	<i>Acer spicatum</i>	mountain maple	<0.01	5.85
	<i>Betula papyrifera</i>	paper birch	1.23	126.32
	<i>Fraxinus nigra</i>	black ash	0.60	33.92
	<i>Fraxinus pennsylvanica</i>	green ash	0.01	1.75
	<i>Ostrya virginiana</i>	ironwood	0.04	12.87
	<i>Populus grandidentata</i>	bigtooth aspen	2.00	80.12
	<i>Populus tremuloides</i>	quaking aspen	6.00	226.90
	<i>Prunus pensylvanica</i>	pin cherry	<0.01	0.58
	<i>Prunus virginiana</i>	chokecherry	<0.01	2.34
	<i>Quercus ellipsoidalis</i>	northern pin oak	0.25	20.47
	<i>Quercus macrocarpa</i>	bur oak	0.07	11.11
	<i>Quercus rubra</i>	northern red oak	0.73	87.72
	<i>Salix bebbiana</i>	gray willow	<0.01	1.75
	<i>Tilia americana</i>	American basswood	0.26	10.53
Conifer	<i>Abies balsamea</i>	balsam fir	3.00	540.35
	<i>Larix laricina</i>	tamarack	<0.01	0.58
	<i>Picea glauca</i>	white spruce	0.91	76.02
	<i>Picea mariana</i>	black spruce	0.77	73.68
	<i>Picea sp.</i>	spruce	0.01	0.58
	<i>Pinus banksiana</i>	Jack pine	0.14	4.09
	<i>Pinus resinosa</i>	red pine	1.33	12.28
	<i>Pinus strobus</i>	white pine	1.94	132.16
Total	—	—	24.07	2,146.20

Table B-10. Density of seedlings in Upland/Mixed Hardwood forests.

Species	Common name	Density (seedlings/ha)
<i>Betula papyrifera</i>	paper birch	509
<i>Ostrya virginiana</i>	ironwood	140
<i>Quercus macrocarpa</i>	bur oak	140
<i>Quercus rubra</i>	northern red oak	1,579
<i>Tilia americana</i>	American basswood	158
<i>Fraxinus nigra</i>	black ash	1,298
<i>Fraxinus pennsylvanica</i>	green ash	18
<i>Abies balsamea</i>	balsam fir	1,475
<i>Picea glauca</i>	white spruce	316
<i>Picea mariana</i>	black spruce	228
<i>Pinus resinosa</i>	red pine	53
<i>Pinus strobus</i>	white pine	775
<i>Prunus pensylvanica</i>	pin cherry	18
<i>Prunus sp.</i>	cherry	18
<i>Prunus virginiana</i>	chokecherry	193
<i>Populus grandidentata</i>	bigtooth aspen	53
<i>Populus tremuloides</i>	quaking aspen	1,298
<i>Salix bebbiana</i>	gray willow	105
<i>Salix sp.</i>	willow	0
<i>Acer rubrum</i>	red maple	7,485
<i>Acer spicatum</i>	mountain maple	1,302
Total	—	17,160

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