



Forest Health Monitoring at Apostle Islands National Lakeshore

2021 Field Season

Natural Resource Report NPS/GLKN/NRR—2022/2488



ON THE COVER

Clockwise from top left: field crew member recording tree diameters (NPS); transect through herbaceous layer on Basswood Island (NPS); overstory tree on Raspberry Island (NPS); transect through Canada yew on Outer Island (NPS).

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Natural Resource Report NPS/GLKN/NRR—2022/2488

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Executive Summary

Apostle Islands National Lakeshore (APIS), situated in western Lake Superior, is composed of 21 islands and a mainland unit. The park supports 17,037 ha of forested land, with much of that (80%) designated as wilderness. In 2021, the Great Lakes Inventory and Monitoring Network (GLKN) resampled permanent forest monitoring sites in the park, marking the second assessment of these sites, which were established and initially sampled in 2011. The goal of this long-term monitoring project is to provide managers with routine updates on which to base management decisions; these data can also be used to tease apart impacts and elucidate causal agents when novel problems or situations arise.

We initiated the comprehensive forest monitoring program at APIS in 2011, establishing 48 sites at that time; in 2021, we resampled those sites and established an additional two. Our sampled and derived metrics included trees (density and basal area of live trees, seedlings, and snags), understory (herb and shrub frequency), deer browse (bite marks on woody species and presence and height of herbaceous species), coarse woody material, and species richness. Following the 2011 field season, we classified sites into five broad forest types (hemlock-hardwood, aspen-birch, cedar, mountain maple-black ash, and balsam fir); following the 2021 sampling season, we examined changes over the 10-year interval.

In addition to the five forest types, we recognized three deer management zones within the park. Zone 1 is composed of 11 islands managed for few to no deer and includes 18 of our sampling sites. Within Zone 2, nine islands are managed for deer density at or below 3.86 deer/km² (10 deer/mi²); here there are 27 sampling sites. Five permanent monitoring sites are located within the Mainland zone, which is part of a larger deer management unit that extends beyond park boundaries. Deer density goals in this third zone are established by the Wisconsin DNR.

Analysis of the 2021 data shows some forest types are transitioning away from aspen-birch. Many of these stands are now approximately 75 years old and are becoming maple (*Acer* spp. L.)-dominated. Regeneration of both hemlock (*Tsuga canadensis* (L.) Carrière) and yellow birch (*Betula alleghaniensis* Britton) continues in hemlock-hardwood sites, but these species have experienced small declines in density between sampling events. Similarly, yellow birch continues to regenerate, but density in balsam-dominated sites has declined over the past 10 years.

We found broadscale declines in taxa richness and abundance throughout the park but particularly in balsam fir forests (7.5 fewer taxa/site across all zones) and hemlock-hardwood sites (1.8 fewer taxa/site across all zones). We also observed notable declines at Zone 1 sites, where deer impacts are minimal: hemlock-hardwood sites lost 3.6 taxa/site, while mountain maple-black ash sites declined 7.0 taxa/site. It appears that there is no single cause for these declines, but likely several contributing factors. Work by others cites deer browse, fire history, Canada yew (*Taxus canadensis* Marshall) cover, island size, and location within the archipelago as possible causal factors. Here, we also tie in the role of browse by snowshoe hare, as well as the influence of canopy closure. Hare were particularly abundant on Devils Island, where one of the four balsam fir sites is located, partially contributing to the sharp declines observed in that forest type. Canopy closure is a slow process,

gradually limiting light availability on the forest floor. As stands age, conditions for ruderal species, typically more common at open sites, become less favorable, and therefore, these species can slowly become less common. This may explain some of the losses in hemlock-hardwood sites.

Park-wide declines in richness make it difficult to understand browse impacts. The three taxa on which we collected demographic data—*Aralia nudicaulis* L. (wild sarsaparilla), *Streptopus* spp. (both *S. lanceolatus* var. *roseus* (Michx) Reveal [rosy twistedstalk] and *S. amplexifolius* [L.] DC. [clasping twistedstalk]), and *Clintonia borealis* (Aiton) Raf (bluebead lily)—were found at fewer sites and at generally lower frequency within those plots during the second visit. Nonetheless, we did not see a clear relationship between the lower frequencies and plant height, as we would expect under high browse conditions. Further, declines in richness on islands with no or limited deer (Zone 1 sites) additionally confound the situation. A better understanding of broadscale species decline is needed before we can truly interpret browse impacts, both to herbaceous and woody species.

The frequency of Canada yew, an understory shrub highly preferred by white-tailed deer and of management interest, remained unchanged in 25 of the 48 sites sampled both years. In sites where frequency did change, this was typically only by a decline or increase in one of the thirty sample circles per site (corresponding to frequency changes of -0.033 , 0.033 , or, in the case of Manitou Island, 0.05). However, yew frequency declined by more than this at all three sites on Sand Island, one site on Cat Island, and one site on Stockton Island, while increasing most on South Twin and one site each on Otter, Stockton, and Outer islands.

We note here three potential actions for managers. First, in conifer forests, assessments of the coarse woody structure for marten (*Martes martes* Turton) habitat would be informative. This will inform biologists of the coarse woody material available in areas of known marten occupancy and permit projections about other areas or islands that may be suitable marten habitat. Second, continue monitoring for invasive species, particularly invasive plant species. We did not detect any invasive plant species, but we did detect five non-native plant taxa at sites in 2021. These were each limited to a small number of sites. Finally, we suggest managers monitor regeneration of yellow birch. Park-wide, we found a 32% decline in the abundance of small yellow birch saplings, with this drop most pronounced in hemlock-hardwood and balsam fir forests.

The current status of park forests is generally favorable. Managers must remain vigilant, however, to any adverse alterations in metrics related to ecosystem health. Maintaining ecosystem structure or function is viable; restoring ecological integrity, however, may not be.

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Introduction

Apostle Islands National Lakeshore (APIS, or “the Lakeshore”), a unit of the U.S. National Park Service (NPS), is composed of a mainland unit in northern Wisconsin and 21 islands situated in western Lake Superior (Figure 1). Here, forests dominate the landscape, co-occurring within a matrix of other vegetation that includes perched bogs, sedge meadows, beaver flowages, and alder thickets (Judziewicz and Koch 1993). Ecologically, the Apostle Islands are distinguished from nearby lands on several accounts. Disturbances, such as white-tailed deer (*Odocoileus virginianus* Zimmerman) occupancy and logging, have occurred only on a subset of islands; as such, the park serves as a natural laboratory (Stockton et al. 2005, Sfenthourakis and Triantis 2017) to gauge these impacts. Further, islands with no history of deer harbor plant species and assemblages not commonly seen elsewhere in the region. These includes numerous western and Arctic disjunct species (Johnson 2021), as well as Canada yew (*Taxus canadensis* Marsh.) (Allison 2006). This shrub has largely been extirpated from the mainland due to fire, logging, and overbrowsing by deer (Windels and Flaspohler 2014), but it is abundant on several islands within the park (Johnson et al. 2021). While most abundant on islands with no known history of deer, it is also common on those islands where the deer populations are historic, i.e., not currently found. Finally, stands of old growth forests are scattered throughout the park, composed of white pine (*Pinus strobus* L.), yellow birch (*Betula alleghaniensis* Britton), and eastern hemlock (*Tsuga canadensis* (L.) Carrière) (Judziewicz and Koch 1993). Despite the relatively favorable status at present, park forests face numerous threats.

Current and potential issues for APIS forests include invasive plant, insect, and pathogen species (Tobin et al. 2010); overabundant deer browse, which can simplify park forests (Mudrak et al. 2009); altered disturbance regimes (such as high wind events); and climate change (Davis et al. 2000, Handler et al. 2020). While some of these threats can impart rather quick changes, noticeable to the casual observer, others may result in slight nuances over several years, barely perceptible from one year to the next. Further, multiple threats can confound impacts of one another on the vegetation, making it difficult to ascertain cause and effect. One way to tease apart these impacts is through repeated, detailed monitoring of the vegetation (Blossey 1999, Pureswaran et al. 2015).

The NPS Great Lakes Network initiated a long-term forest vegetation monitoring program at APIS in 2011, establishing 48 permanent sites at that time (Sanders and Grochowski 2012). This program includes extensive sampling of both trees and the groundlayer (Sanders and Grochowski 2014b) and includes assessments of browse impacts. In 2021, we resampled these 48 sites and added an additional two, bringing the total to 50. Here, we report on the current (2021) status of APIS forests, noting changes in metrics over the 10-year-period between sampling events. We also discuss these findings in light of known drivers and stressors.

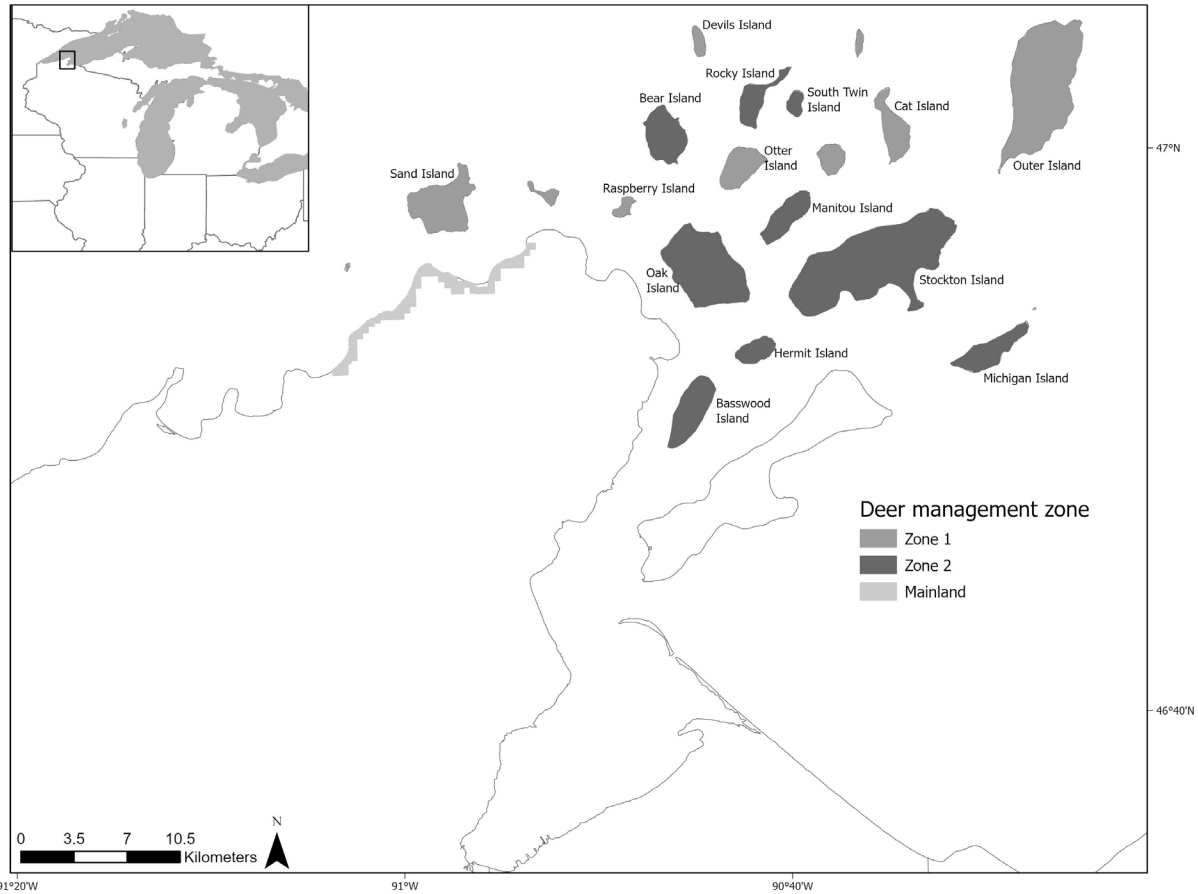


Figure 1. Great Lakes region (*inset*) and Apostle Islands National Lakeshore (*main map*). Zones define deer density management targets. Zone 1: managed for few to no deer; Zone 2: managed for deer densities at or below 10 per square mile; Mainland unit: part of a larger deer management unit with target densities established by the Wisconsin Department of Natural Resources (DNR).

Methods

Study Location

The Apostle Islands lie within the northern hardwood ecoregion (Omernik 1987). Pre-settlement forests of the archipelago were largely composed of mixed conifer-hardwood species and included eastern hemlock, white pine, sugar maple (*Acer saccharum* Marsh.), and yellow birch (Finley 1976, Frederick and Rakestraw 1976). Early logging efforts depleted most of the white pine by the turn of the twentieth century (Busch 2008), while extraction of hemlock and northern hardwood species, including sugar maple and yellow birch, continued through the first half of the century. By 1970, the year of park establishment, only a small amount of old-growth forest remained in the archipelago with the majority of forests being second growth; paper birch (*Betula papyrifera* Marshall), and trembling (*Populus tremuloides* Michx) and big-tooth (*Populus grandidentata* Michx) aspen were common.

Present-day forests are shaped by both logging and fire history, as well as deer browse. Within the 21 islands composing the Lakeshore, deer occupation has varied in both space and time. While some islands are believed to have never harbored deer (North Twin, Outer, Raspberry), others have supported deer for the entire historical record (Oak, Basswood) (APIS 2014). Deer have been lost due to a combination of hunting pressures and natural processes on several islands that supported this species at least as recently as 1958 (Allison 1990, Mudrak et al. 2009). Finally, two islands, Sand and York, were colonized by deer in approximately 2000 and 2004, respectively (APIS 2014). Sugar maple and yellow birch are common on most islands, with eastern hemlock in pockets throughout the park. Cedar (*Thuja occidentalis* L.) forms dense stands in some low-lying areas, while speckled alder (*Alnus incana* ssp. *rugosa* (Du Roi) R.T. Clausen), mountain maple (*Acer spicatum* Lam), and black ash (*Fraxinus nigra* Marshall) occupy others. On islands with either a limited history or no history of deer occupancy, a dense understory of Canada yew has formed (Johnson et al. 2021). Because yew is slow-growing and highly palatable to deer, it is uncommon on the mainland. On islands where deer are present, forests have undergone losses in perennial forb abundance, including wild sarsaparilla (*Aralia nudicaulis* L.) and rosy twisted-stalk (*Streptopus lanceolatus* var. *roseus* (Michx) Reveal) (Mudrak et al. 2009).

Sampling Design and Field Methods

Sampling Design

Site selection was made in 2011 prior to the initial sampling event (Sanders and Grochowski 2012), using a sampling design that ensured sites were both randomly located and spatially balanced throughout the park (Stevens and Olsen 2004). Resampling was conducted at APIS 12 June–22 August 2021.

Basic Measurements: Trees, Groundlayer, and Coarse Woody Material

We sampled trees, seedlings, coarse woody material, herbs, and browse at each site using the Hybrid plot (Johnson et al. 2006, Johnson et al. 2008) (Figure 2). Three 50-m parallel transects compose the plot, with each in an east-west orientation and permanently monumented with below-ground rebar. We recorded the species, diameter at breast height (DBH), live/dead status, and any significant

damage or disease (see below) for all trees with a DBH ≥ 2.5 cm and standing within 3 meters of the central transect line (Sanders and Grochowski 2014b). The total area sampled for trees was 300 m² for each transect, or 900 m² for the entire plot. At one site, located at the northern tip of Manitou Island, we did not resample one of the three transects in 2021 because of safety concerns associated with a recent blowdown.

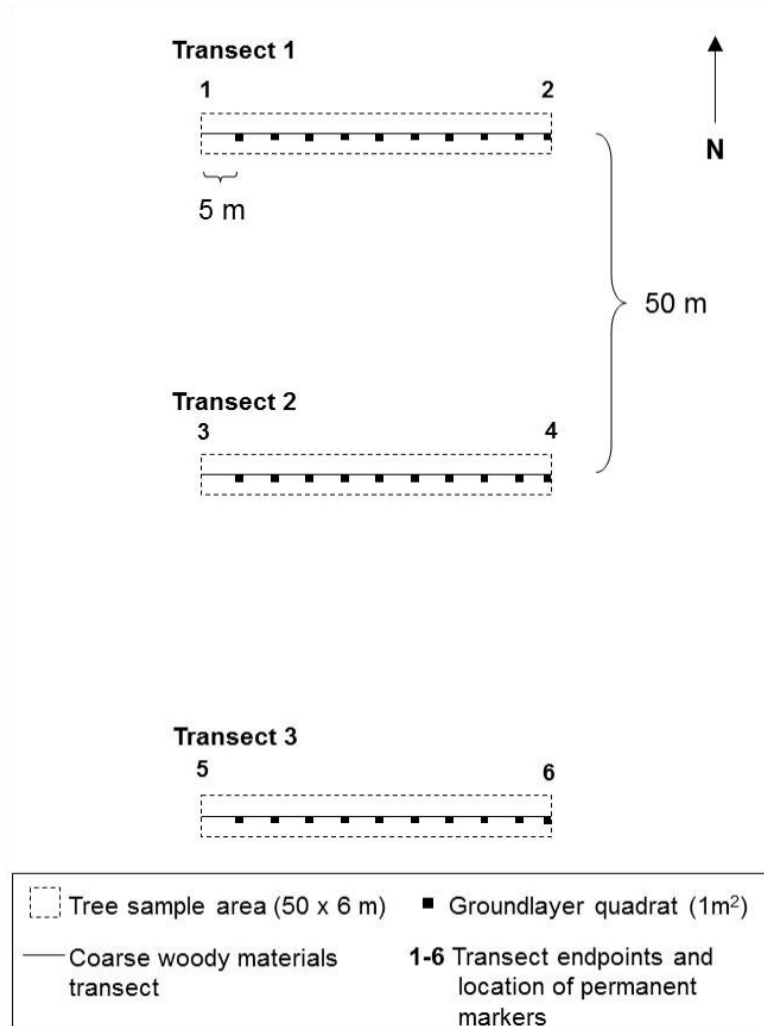


Figure 2. Great Lakes Network Hybrid plot showing three parallel transects (*solid lines*), tree sampling areas (*bounding dashed rectangles*), and quadrat locations (*solid squares*).

We assessed the groundlayer 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, allowing us to determine frequency for all species-plot combinations. We also counted seedlings, defined as tree species <2.5 cm DBH, but at least 15 cm in height and showing evidence of growth from the previous year (thus, we did not assess the current year’s seedlings). Some species we commonly encountered reproduce vegetatively (e.g., trembling aspen, red maple [*Acer rubrum* L.]). Individual

sprouts (i.e., both ramets and genets) were deemed “seedlings” if no aboveground connections between them and a parent tree were visible.

We assessed coarse woody material (CWM) using the planar intercept method (Brown 1974, Woodall and Monleon 2007). For all pieces with a diameter at transect intersect ≥ 7.5 cm and length ≥ 0.9 m, we measured the large end diameter, small end diameter, length, and decay class (Woodall and Monleon 2007). Our definition of CWM includes pieces with a diameter ≥ 7.5 cm; therefore, we recorded the length only along where the piece met this criterion. We summarized these data and present as density, volume, and biomass, all on a per hectare basis. We also present data on large, advanced-decay (LAD) pieces, defined as being ≥ 30 cm in diameter at transect intersect, ≥ 2.0 m in length, and either decay class 3 or 4. Logs with these characteristics are desired because they afford habitat to small wildlife (Fauteux et al. 2013, Gehring et al. 2019).

Browse

We examined browse pressure using two distinct measures. *Direct browse* is an assessment of white-tailed deer browse visible on *woody species*. This includes bite marks *directly evident and observable* on individual plants and determined to be from the current year’s growth. Our methods did not include browse attributable to snowshoe hare (*Lepus americanus* Erxleben). *Indirect browse* measures were used to assess the impacts of herbivory on *herbaceous species*. This type of assessment measures changes in herbaceous demography, which are often only *indirectly observed over time* (Webster et al. 2001, Kirschbaum and Anacker 2005). In the case of white-tailed deer browse, 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) and are well-documented in the literature (Williams et al. 2000, Knight 2003).

We assessed direct browse in 3.14-m² (1-m radius) circles centered every five meters along each of the three 50-m transects, for a total of 30 direct browse circles per plot, equal to a total sampling area of 94.2 m²/site. Within each direct browse sampling circle, we recorded all woody species present within the browse zone—defined as the cylinder of space between ground level and 1.8 m in height. We noted the circles where we observed any evidence of deer browse, and we recorded the browsed species. For this method, plants did not need to be rooted within this zone; instead, we considered a species present if leaves were growing within the cylindrical space. Typically, woody browse surveys are conducted in the spring, prior to the new season’s growth, although we are unable to sample at that time. We acknowledge that this limitation introduces potential bias into our sampling, whereby those sites sampled later in the season would be expected to show more browse than sites sampled earlier. Nonetheless, numerous studies indicate a shift in food preference from woody to herbaceous in the spring (Crawford 1982, McCullough 1985), suggesting that the bias in our summer woody browse sampling may be minimized. Despite this preference, however, a consistent use of woody material throughout the year has also been shown (Kohn and Mooty 1971, Cypher et al. 1988). We feel that our assessments of woody browse in the field are valuable in that they provide insight on general levels of pressure and on species preferences, but our findings should be interpreted with these qualifiers in mind.

We used direct browse data to calculate the *proportion of browse* (Frerker and Waller 2013) at two levels. At the site level, pooling across species, the numerator is the total of the 30 circles in which any browse was observed, regardless of species, while the denominator is the number of circles where any woody species were present. Here, we present mean site-level proportion of browse by forest type. At the species level, for each species, we divided the total number of circles in which we observed browse by the total number of circles where it was present. We present this data park-wide.

We assessed the *indirect impacts* (typically evidenced by fewer and smaller plants) of summer browse on herbs by several means. We used existing literature (Knight 2007, Mudrak et al. 2009, Royo et al. 2010) and our personal knowledge to identify preferred browse species as those that are both relatively common in the park and favored by white-tailed deer (Table 1). We identified the *number of preferred herbaceous species* at each site, as well as the *abundance of preferred herbs*, determined by the total number of preferred species-quadrat combinations at each site. For example, a site where *Aralia nudicaulis* was present in 22 quadrats, *Maianthemum racemosum* (L.) Link (false Solomon’s seal) in 11 quadrats, and *Trillium cernuum* L. (nodding trillium) in three quadrats has three preferred browse species present at an abundance of 36 preferred species. To examine browse impacts on herb demographics (Koh et al. 2010, Wilbur et al. 2017), we selected three target taxa on which to collect additional data: *Aralia nudicaulis*, *Clintonia borealis* (Aiton) Raf. and *Streptopus* spp. (both *S. lanceolatus* var. *roseus* and *S. amplexifolius* (L.) DC.). For these taxa, in quadrats where they were present, we measured maximum height and noted whether any individual was reproductive. For each target species, where present, at the site level, we calculated the *target herb frequency*, based on the frequency of presence in the 30 quadrats; we then determined *target herb maximum height*, by calculating the site-level mean of the tallest individual (if present) in each quadrat.

Table 1. Preferred browse species at APIS for calculating *number of preferred herbs* and *abundance of preferred herbs*.

Species	Common name
<i>Aralia nudicaulis</i> L.	wild sarsaparilla
<i>Clintonia borealis</i> (Aiton) Raf.	bluebead lily
<i>Maianthemum canadense</i> Desf.	Canada mayflower
<i>Maianthemum racemosum</i> (L.) Link	false Solomon’s seal
<i>Polygonatum pubescens</i> (Willd.) Pursh	hairy 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
<i>Trillium grandiflorum</i> (Michx.) Salisb.	great white trillium
<i>Uvularia grandiflora</i> Sm.	largeflower bellwort
<i>Uvularia sessilifolia</i> L.	sessile-leaf bellwort

Tree Health

We used an evidence-based approach to assess tree health by examining 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.

Plant Identification

We generally identified all plants to the species level while on site. In a small number of instances, we collected plant material for later identification. For some genera and families, it was not possible to distinguish between multiple species unless they were flowering or fruiting, which often was not the case. When this occurred, we identified only to the genus or family level. Examples include *Carex* sp. L. (sedge) and Poaceae (grass family). All nomenclature follows that of the Integrated Taxonomic Information System (ITIS 2021).

Classifications and Summaries

Forest Type Classification

We classified the 48 initial sites into five groups following the 2011 field season (Sanders and Grochowski 2012). This cluster analysis was based on importance values of overstory species, derived as the mean of the relative basal area and relative density of each species-plot combination. The two additional sites added in 2021 were placed on one of the existing forest type classifications based on authors' knowledge of the sites and park.

Browse Zones

We followed the classification by the park, placing sites into zones based on deer management goals (APIS 2014) (Figure 1). Zone 1 is composed of those islands managed for few to no deer and include Cat, Devils, Eagle, Gull, Ironwood, North Twin, Otter, Outer, Raspberry, Sand, and York islands. Of the 50 sampling sites at APIS, 18 lie within this zone. Within Zone 2, islands are managed for deer density at or below 10 per square mile. This zone includes Basswood, Bear, Hermit, Manitou, Michigan, Oak, Rocky, South Twin, and Stockton islands; 27 of our sampling sites are within Zone 2. The Mainland unit is part of a larger unit, with deer management goals established by the state (Wisconsin DNR 2021). We have five permanent monitoring sites in this zone.

Taxa Richness, Coefficients of Conservatism, and the Modified Floristic Quality Index

We identified all sampled individuals to the lowest taxonomic level possible; this was typically to species although, as noted above, at times only to genus. In general, sites sampled in mid- to late-July had most individuals in reproductive status, thus biased higher species richness. Further, actual site-level richness was sometimes unknown due to identification problems. For example, species richness at a site where we recorded both *Actaea pachypoda* Elliott and *Actaea* sp. L. is unclear; this may truly represent two unique taxa if *Actaea* sp. is *A. rubra* (Aiton) Willd., or only one species if it is another individual of *A. pachypoda*. In order to avoid this bias, for some genera, we condensed all individuals into genus (Table 2). Here we report the metric, *taxa richness*, including genera, rather than species, in these instances. Because all sedges are in the same genus (*Carex* sp.) and because it was often not possible to identify grasses even to the genus level, we do not include them in the calculation of this index. We view the use of the taxa richness metric, not as a comprehensive measure of a site characteristic, but as an unbiased way to assess change within sites over time.

Table 2. Species in the sampling data that we recognized at the genus level (condensed classification, third column) for purposes of assessing taxa richness.

Field identification	Field identification common name	Condensed classification	Condensed classification common name
<i>Actaea pachypoda</i> Elliott	white baneberry	<i>Actaea</i> sp. De Haan	baneberry
<i>Actaea rubra</i> (Aiton) Willd.	red baneberry	<i>Actaea</i> sp. De Haan	baneberry
<i>Amelanchier arborea</i> (F. Michx.) Fernald	common serviceberry	<i>Amelanchier</i> sp.* Medik.	serviceberry
<i>Cypripedium acaule</i> Aiton	pink lady's slipper	<i>Cypripedium</i> sp. L.	lady's slipper
<i>Epilobium ciliatum</i> ssp. <i>ciliatum</i> Raf.	fringed willowweed	<i>Epilobium</i> sp. L.	willowweed
<i>Epilobium coloratum</i> Biehler	purpleleaf willowweed	<i>Epilobium</i> sp. L.	willowweed
<i>Osmorhiza claytonii</i> (Michx.) C.B. Clarke	hairy sweet-cicely	<i>Osmorhiza</i> sp. Raf.	sweet-cicely
<i>Osmorhiza longistylis</i> (Torr.) DC.	aniseroot	<i>Osmorhiza</i> sp. Raf.	sweet-cicely
<i>Pyrola americana</i> Sweet	American wintergreen	<i>Pyrola</i> sp. L.	shinleaf
<i>Pyrola elliptica</i> Nutt.	large-leaved shinleaf	<i>Pyrola</i> sp. L.	shinleaf
<i>Salix humilis</i> Marshall	prairie willow	<i>Salix</i> sp. L.	willow
<i>Solidago canadensis</i> L.	Canada goldenrod	<i>Solidago</i> sp. L.	goldenrod
<i>Solidago gigantea</i> Aiton	giant goldenrod	<i>Solidago</i> sp. L.	goldenrod

We compiled the coefficient of conservatism (CoC) for all species in our dataset. These values range from 0 to 10 and reflect the likelihood a species will be present in habitats with alterations from pre-European American settlement conditions (Swink and Wilhelm 1994), with 0 reflecting either non-native species or those species highly tolerant of disturbance, and 10 a conservative species found only in high-quality, non-degraded habitats. These values are specific to defined regions, such as a state; here we used values assigned for the state of Wisconsin (Bernthal 2003). In instances where we have identified an individual to genus, we assigned the lowest CoC value of all species within that genus that are known to be present in the park. We then calculated the site-level modified floristic quality index (mFQI) (Rooney and Rogers 2002, Sanders and Grochowski 2014a), where mFQI is simply the mean of the CoC values for all species present within that site. We then summarized mFQI by year and forest type.

Specific Metrics of Management Interest

We present metrics that are specifically of management interest to the park. For APIS, these include yew abundance, presented as a map of the change in yew frequency between years. They also include regeneration data (seedling and small sapling abundance) for key overstory species, presented in tables.

Representation of Change

We present tree densities by diameter class and species to inform successional projections. For short term change, we calculated means and standard errors and show change between the sampling periods via graphs and tables. Generally, we are interested both in how these change between years, but also how they vary within forest types and, for some metrics, within browse zones. Thus, tables are presented via multiple formats, depending on the metric. We forgo statistical tests of change for this report.

Results

All 48 sites originally sampled in 2011 were resampled in 2021, during which time two other sites were added, bringing the total number of sites to 50. Both new sites were on Outer Island (Figure 3). The taxa sampled included 25 tree species, 25 species of shrubs, 65 forb taxa, 25 graminoids, and 25 fern species (Appendix A). Collectively, this represents approximately 20% of the documented flora at the Lakeshore. The 48 original sites were classified into five broad forest types following the 2011 field season (Sanders and Grochowski 2012) (Figure 3, Table 3), while the two additional sites were categorized as hemlock-hardwood based on authors' informed knowledge. All reporting detailed here reflects only the 48 sites sampled both years.

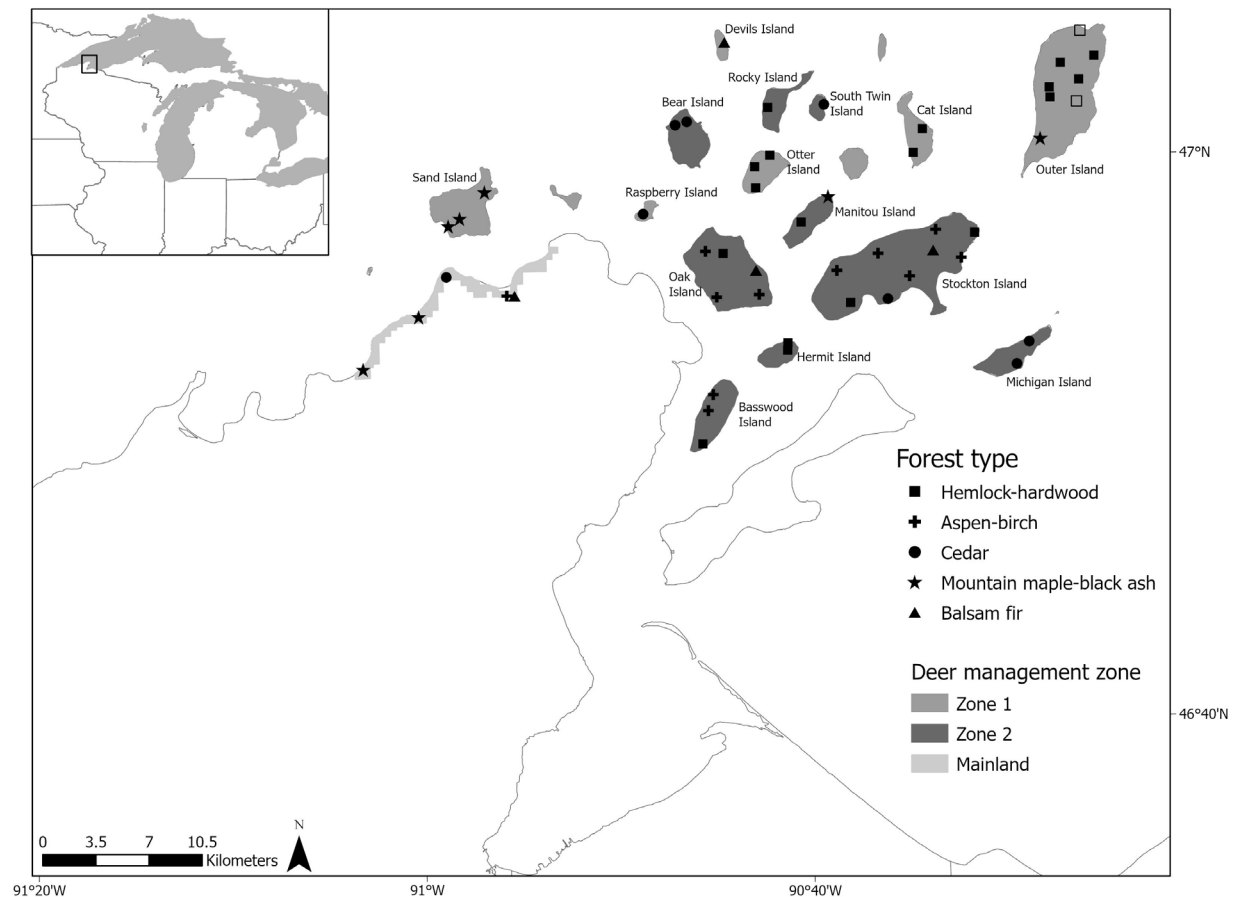


Figure 3. Locations and forest types of the 50 permanent forest monitoring sites at APIS. All sites were sampled in both 2011 and 2021 except two sites represented by the hollow symbols on Outer Island. These were added in 2021 and sampled that year only.

Table 3. Total numbers of permanent monitoring sites at APIS, by forest type and management zone.

Forest type	Zone			Total by forest type
	Zone 1	Zone 2	Mainland	
Hemlock-hardwood	12 ^A	8	–	20
Aspen-birch	–	10	1	11
Cedar	1	6	1	8
Mountain maple-black ash	4	1	2	7
Balsam fir	1	2	1	4
Total by zone	18	27	5	50

^A Ten hemlock-hardwood sites in Zone 1 were sampled in 2011, with two added in 2021, bringing the total to 12.

Successional Projections

In hemlock-hardwood forests (Figure 4A, 4B), regeneration of characteristic species (hemlock and sugar maple) is apparent, as seen by high densities in the smallest size classes. Nonetheless, hemlock declined in the 2.5–5.0-cm size class (30.9 to 25.3 saplings/ha, Figure 4B), as did yellow birch (34.6 to 24.1 saplings/ha, Figure 4A).

In aspen-birch sites (Figure 4C, 4D), forests are transitioning to sugar maple and red maple, as these dominate the smaller size classes. In all size classes below 15 cm DBH, densities are lower than 10 individuals/ha for both birch species (paper and yellow birch) and both aspen species (trembling and bigtooth). Pooled aspen density in 2021 is greater than five individuals/ha only in size classes greater than 37.5 DBH (data not shown). Other species present in this forest type include mountain maple, which declined from 60.0 to 38.3 individuals/ha.

In cedar sites, cedar continues to dominate the conifer component although balsam fir (*Abies balsamea* (L.) Mill.) is dominant in the smaller size classes (Figure 4F). The hardwood component in these sites is largely limited to small-size-class mountain maple (Figure 4E, included in other species). Within the 2.5–5.0-cm DBH size class, mountain maple increased from 187 individuals per hectare to 323 individuals/ha during the 10-year interval between sampling events.

The dominant hardwood component of mountain maple-black ash sites (Figure 4G, 4H) was mountain maple, with these limited to the smallest size classes. In the 2.5–5.0-cm DBH class, density was 602 individuals/ha in 2011 and 547 individuals/ha in 2021 (Figure 4G, other species). Similarly, black ash in the smallest size class declined slightly from 98.1 to 71.4 individuals/ha (Figure 4G, other species). At these sites, the dominant conifer was balsam fir, with some cedar present across a range of size classes.

The conifer component of sites classified as the balsam fir type were, indeed, dominated by balsam fir, largely across a range of size classes below 20 cm DBH (Figure 4J). The hardwood component at these sites was a mix, largely of sugar maple, red maple, yellow birch, paper birch, and red oak

(*Quercus rubra* L.). In the two smallest size classes, yellow birch declined 64.7% (94.4 to 33.3 saplings/ha) and 54% (66.6 to 30.6 saplings/ha), respectively (Figure 4I).

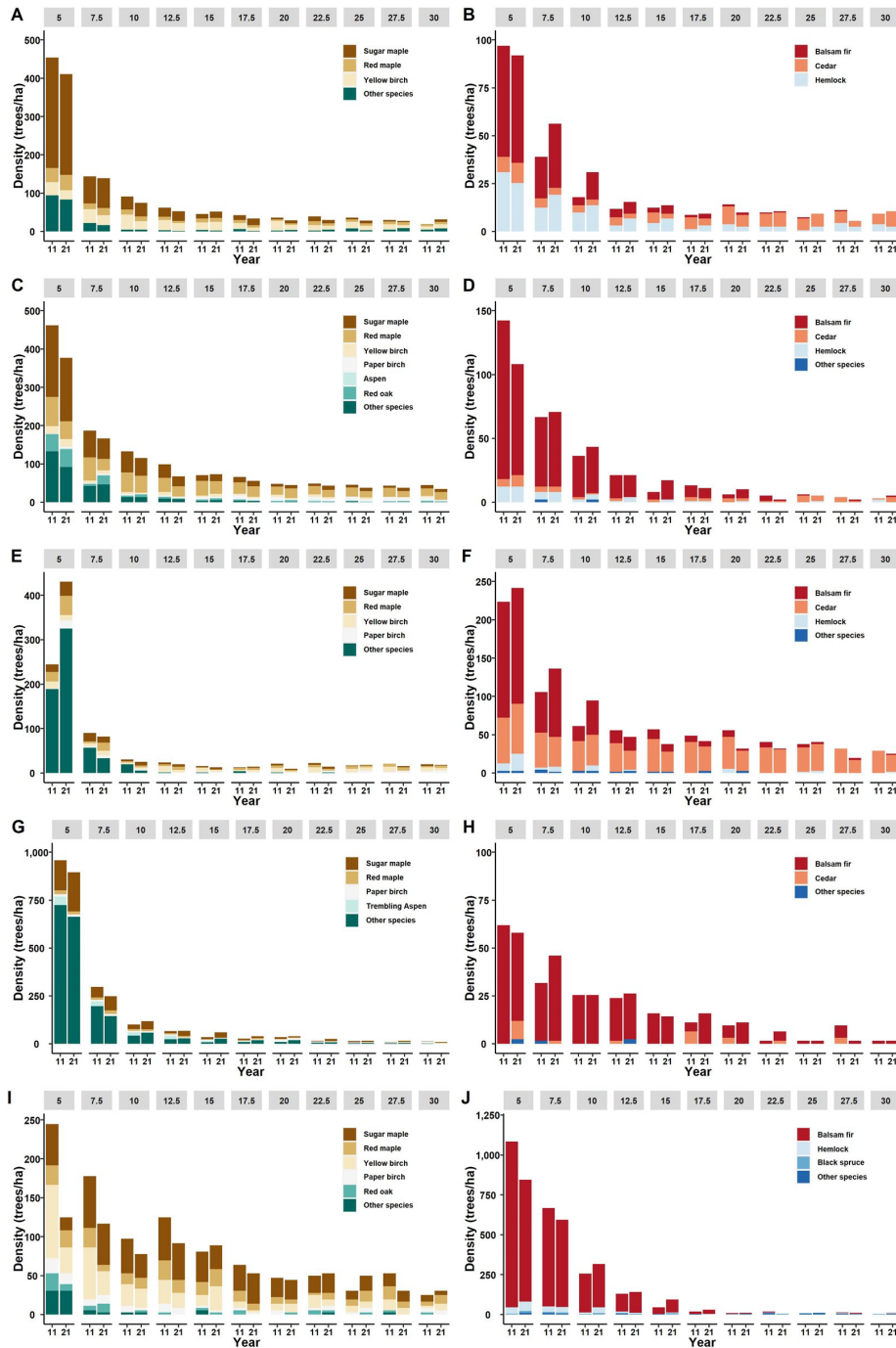


Figure 4. Diameter by size classes for hardwoods (*left column*) and conifers (*right column*) at monitoring sites in five forest types at APIS, 2011 and 2021. Forest types (from top to bottom) are hemlock-hardwood, aspen-birch, cedar, mountain maple-black ash, and balsam fir. Note the difference in scales on the y-axes. Diameter at breast height classes across the top represent the maximum value in 2.5-cm classes.

Short-Term Change

Live tree density (Figure 5, *left*) was generally similar between years for all forest types except aspen-birch, where it fell 12.6% to 1,514 trees/ha. Basal area of live trees (Figure 5, *right*) was also similar between sampling events for most forest types, although it increased 19.3% in mountain maple-black ash sites.

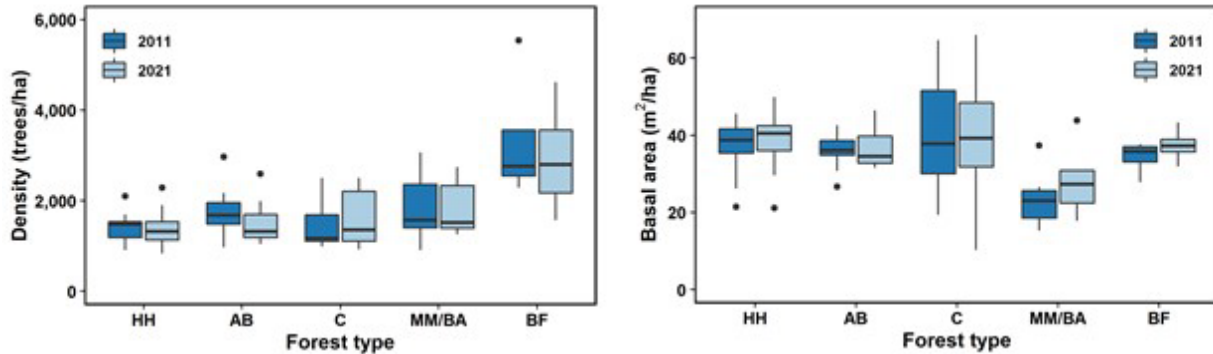


Figure 5. Live tree density (*left*) and basal area (*right*) by forest type at APIS, 2011 and 2021. This figure incorporates all live individuals ≥ 2.5 cm DBH. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Small sapling (2.5–5.0 cm DBH) density across all sites (Figure 6D) increased in cedar forests (468 to 680 saplings/ha) but declined in balsam fir sites (1,328 to 969 saplings/ha). The data from both Zone 1 sites (Figure 6A) and Zone 2 sites (Figure 6B) parallel this.

Summaries of seedling density were highly variable across species (Table 4). We have presented seedling density here solely for context; some species produce copious amounts of seed with low survival, while others have more conservative strategies. Additionally, some species largely limit seed production to occasional mast years. Values shown here may reflect these processes and not be a good indicator of long-term trends. Summaries of small (2.5–5.0 cm DBH) sapling density of individual species across all forest types show notable increases of white cedar but declines of balsam fir and yellow birch (Table 4).

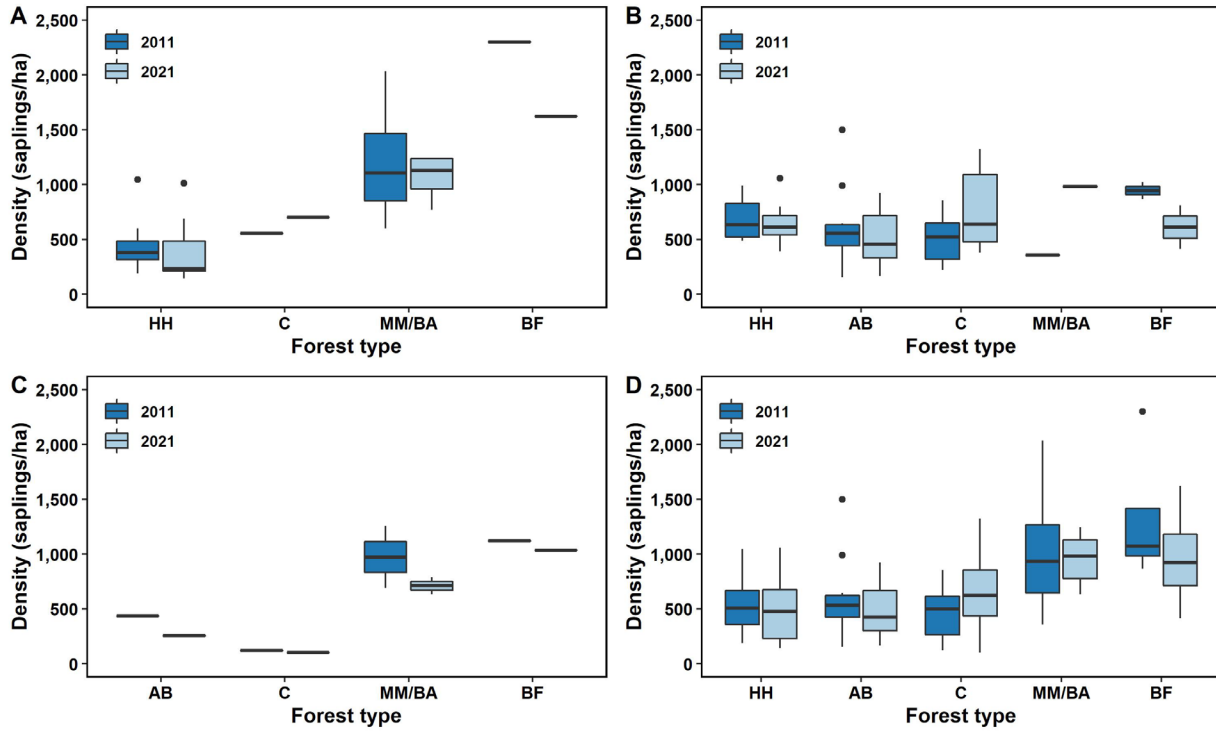


Figure 6. Sapling density by forest type and zone at APIS, 2011 and 2021. *A*: Zone 1; *B*: Zone 2; *C*: Mainland; *D*: all sites. Narrow bands indicate only one site for that forest type-zone combination. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Table 4. Seedling (<2.5 cm DBH and at least 15 cm tall) and small sapling (2.5–5.0 cm DBH) density (m²/ha) by species for both sampling years at APIS (2011 and 2021). Species are arranged by sapling density in 2011.

Species		Seedlings		Small saplings	
Latin name	Common name	2011	2021	2011	2021
<i>Acer saccharum</i>	sugar maple	14,387	13,146	181.02	173.03
<i>Abies balsamea</i>	balsam fir	1,452	1,345	171.06	136.57
<i>Acer spicatum</i>	mountain maple	4,624	3,611	161.57	167.82
<i>Acer rubrum</i>	red maple	3,359	3,624	39.81	37.04
<i>Betula alleghaniensis</i>	yellow birch	538	367	28.24	19.21
<i>Tsuga canadensis</i>	hemlock	867	733	19.21	21.18
<i>Quercus rubra</i>	red oak	2,915	2,314	15.51	14.12
<i>Fraxinus nigra</i>	black ash	667	2,833	14.58	10.88
<i>Thuja occidentalis</i>	white cedar	2,900	3,825	14.35	18.52
<i>Ostrya virginiana</i>	hop hornbeam	533	667	11.34	6.13
<i>Populus tremuloides</i>	trembling aspen	2,452	1,778	7.64	2.78
<i>Fraxinus pennsylvanica</i>	green ash	7,000	3,000	7.41	5.56
<i>Betula papyrifera</i>	paper birch	333	417	3.94	8.56
<i>Tilia americana</i>	basswood	667	444	2.78	3.7
<i>Prunus virginiana</i>	chokecherry	6,667	4,667	2.55	2.78
<i>Picea mariana</i>	black spruce	667	500	0.93	1.39
<i>Sorbus decora</i>	mountain ash	810	750	0.46	1.85
<i>Prunus pensylvanica</i>	pin cherry	556	0	0	0
<i>Populus grandidentata</i>	bigtooth aspen	917	1,444	0	0.46
<i>Pinus strobus</i>	white pine	333	333	0	0.46
<i>Picea glauca</i>	white spruce	0	333	0	0.23
<i>Ulmus americana</i>	American elm	0	0	0	0.46

Coarse Woody Material and Standing Dead Trees

Coarse woody material density (Figure 7A) was generally higher during the second sampling event in hemlock-hardwood, aspen-birch, and balsam fir forest types, while lower at cedar sites. Large, advanced decay pieces were generally higher in all forest types except balsam fir (Figure 7D).

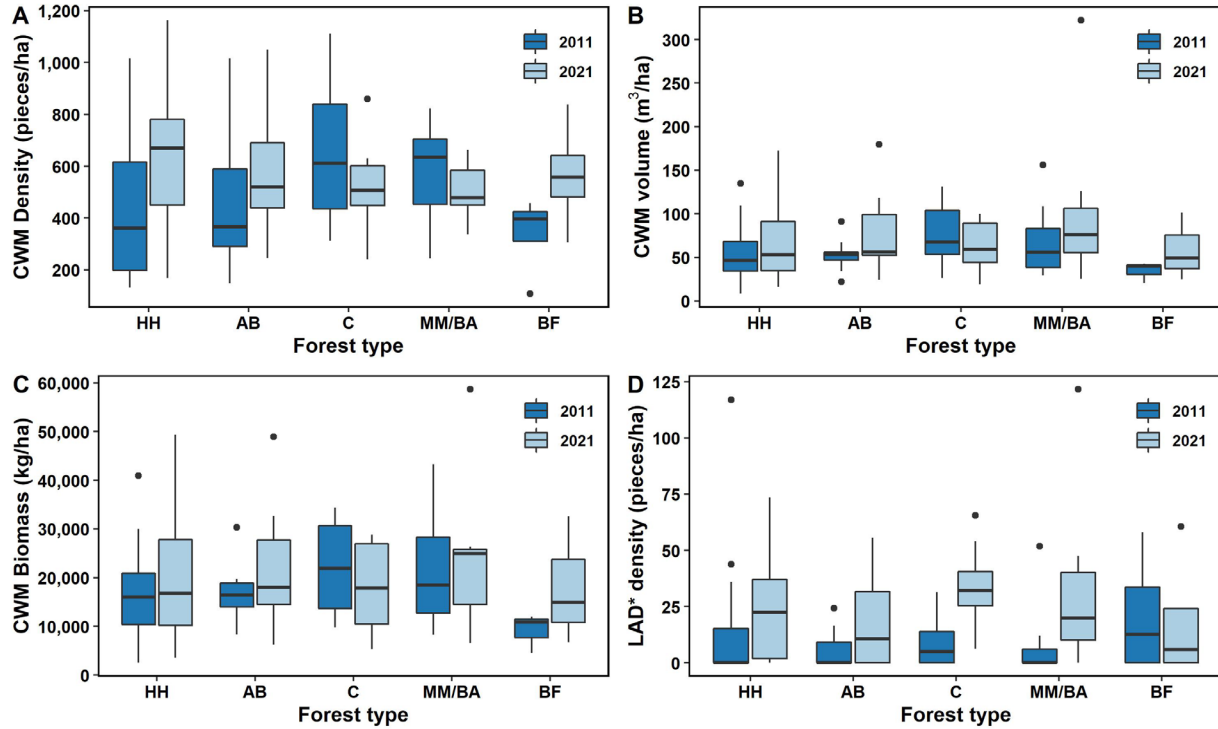


Figure 7. Coarse woody material by forest type and year at APIS, 2011 and 2021: density (A), volume (B), biomass (C), and large, advanced decay piece density (D). Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir. Sites 1026 (Stockton Island, aspen-birch forest type) and 1031 (mainland, balsam fir forest type) are not included on volume and biomass graphs because their 2021 values are an order of magnitude greater than those of other sites, making visual interpretation difficult.

Density (Figure 8, *left*) and basal area (Figure 8, *right*) of large snags followed similar patterns. These values were typically higher in aspen-birch and balsam fir forests during the second sampling event, but lower in mountain maple-black ash sites.

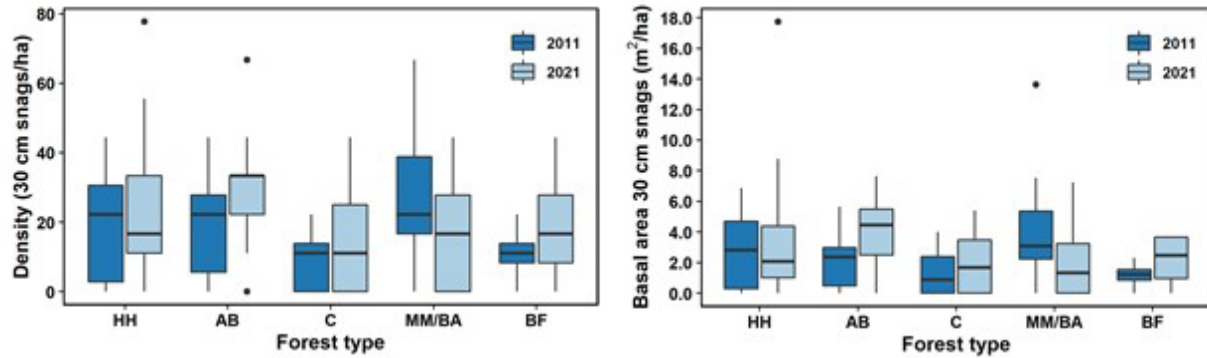


Figure 8. Density (*left*) and basal area (*right*) of snags ≥ 30 cm DBH for all forest types at APIS, 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Browse and Disease

Site-level proportion of browse (i.e., frequency of the 30 direct-browse circles in each site showing bite marks on woody individuals regardless of tree species) was low across all forest types (Figure 9, *left*) and zones (Figure 9, *right*) in 2021, compared with 2011. During this earlier sampling period, browse was high in four mountain maple-black ash sites: three on Sand Island and one on the mainland.

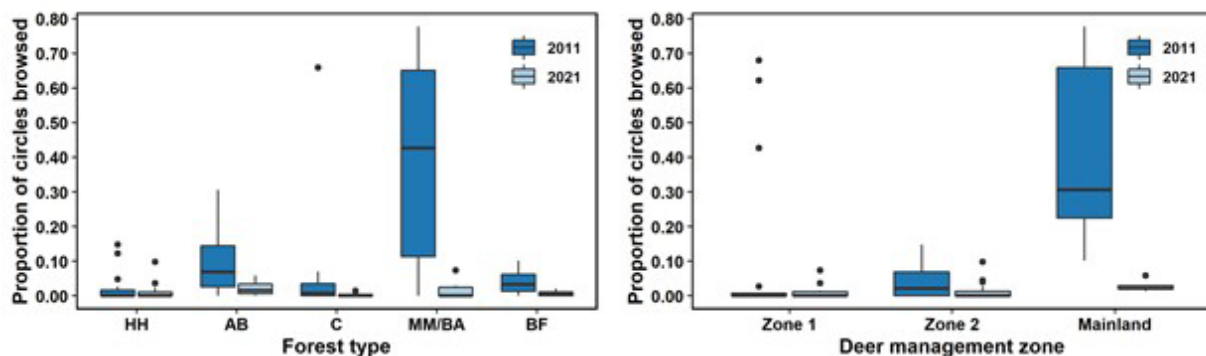


Figure 9. Proportion of browse in thirty 3.14-m² browse circles in each site at APIS, 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Parkwide, species-level assessments of browse (Table 5) on woody species were generally lower in 2021. With shrubs in 2021, only *Rubus sachalinensis* var. *sachalinensis* H. Lév. (common red raspberry) and *Cornus alternifolia* L. (alternate-leaved dogwood) showed browse in at least 20% of the circles where they were located. For trees, all but two species experienced browse in less than five percent of circles where they were located (Table 5).

Table 5. Park-wide, species-level proportion browse on shrubs and trees at APIS, 2011 and 2021. Taxa are sorted based on 2011 browse frequency. This table reflects only sites sampled in both years and does not include the two sites added on Outer Island in 2021.

Category	Species ^A	2011	2021
Shrubs	<i>Cornus sericea</i>	0.52	0.08
	<i>Alnus incana</i> ssp. <i>rugosa</i>	0.27	0.03
	<i>Rubus parviflorus</i>	0.21	0.03
	<i>Corylus cornuta</i>	0.17	0.01
	<i>Lonicera canadensis</i>	0.16	0.01
	<i>Taxus canadensis</i>	0.13	0.01
	<i>Ribes triste</i>	0.10	0.03
	<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	0.09	0.21
	<i>Amelanchier</i> sp.	0.08	0.00
	<i>Cornus alternifolia</i>	0.00	0.20
Trees	<i>Populus grandidentata</i>	0.77	0.04
	<i>Populus tremuloides</i>	0.51	0.04
	<i>Fraxinus nigra</i>	0.33	0.03
	<i>Prunus virginiana</i>	0.33	0.00
	<i>Prunus pensylvanica</i>	0.25	0.25
	<i>Acer spicatum</i>	0.18	0.02
	<i>Fraxinus pennsylvanica</i>	0.13	0.10
	<i>Betula papyrifera</i>	0.12	0.00
	<i>Sorbus decora</i>	0.06	0.02
	<i>Acer saccharum</i>	0.05	0.02
	<i>Acer rubrum</i>	0.04	0.01
	<i>Betula alleghaniensis</i>	0.03	0.00
	<i>Tsuga canadensis</i>	0.02	0.01
	<i>Abies balsamea</i>	0.02	0.01
	<i>Quercus rubra</i>	0.01	0.02
	<i>Tilia americana</i>	0.00	0.03

^A There was no recorded browse in either year on 15 shrub taxa: *Diervilla lonicera*, *Ilex mucronata*, *Ilex verticillata*, *Rhododendron groenlandicum*, *Ribes glandulosum*, *Ribes hirtellum*, *Rubus allegheniensis*, *Rubus canadensis*, *Rubus glagellaris*, *Rubus pubescens*, *Salix* sp., *Sambucus racemosa* var. *racemosa*, *Vaccinium angustifolium*, *Vaccinium myrtilloides*, *Vaccinium oxycoccos*. There was no recorded browse on five tree species in either year: *Ostrya virginiana*, *Picea glauca*, *Picea mariana*, *Pinus banksiana*, *Pinus strobus*.

Of the 11 herbaceous species identified as preferred by deer (Table 1), the number present in sites was generally similar between years for forest types except mountain maple-black ash (where it fell from 2.4 to 1.7 species/site) and balsam fir (where it fell from 4.0 to 3.0 species/site) (Figure 10, *left*). The abundance of preferred herbaceous species, measured as the number of preferred species-quadrat combinations, was also generally lower in these two forest types (declines of 32% and 26%, respectively), as well as at cedar sites (30% decline) (Figure 10, *right*).

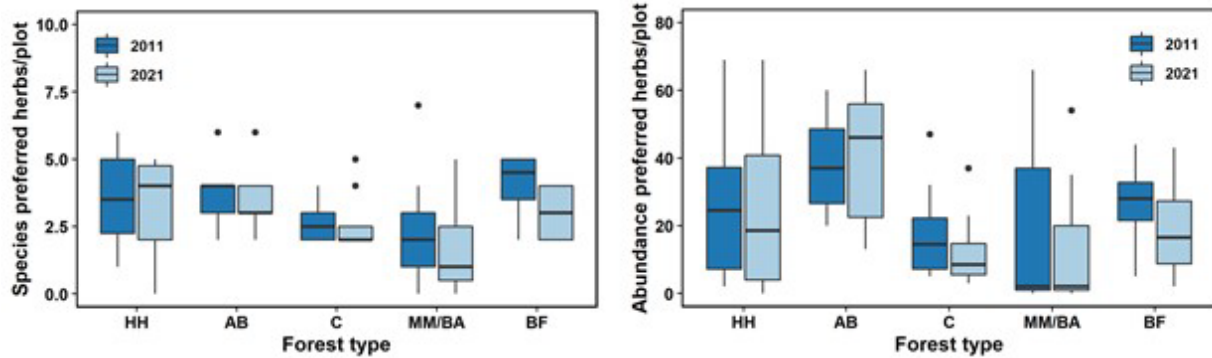


Figure 10. Number of preferred browse species in sites (*left*) and abundance of preferred browse species in sites (*right*) for all forest types at APIS, 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Our three target understory taxa for additional measurements were *Aralia nudicaulis*, *Streptopus* spp., and *Clintonia borealis*. *Aralia nudicaulis* was present in groundlayer quadrats in 32 sites in 2011 and 30 in 2021. At sites where present, frequency was similar between years for all forest types except balsam-fir where it declined from 18% to 9% of quadrats per site (Figure 11, *left*); maximum height was similar between years for three forest types but was taller in cedar (27.7 cm in 2011, 35.5 cm in 2021) and mountain maple-black ash forests (30.2 cm in 2011, 35.2 cm in 2021) (Figure 11, *right*).

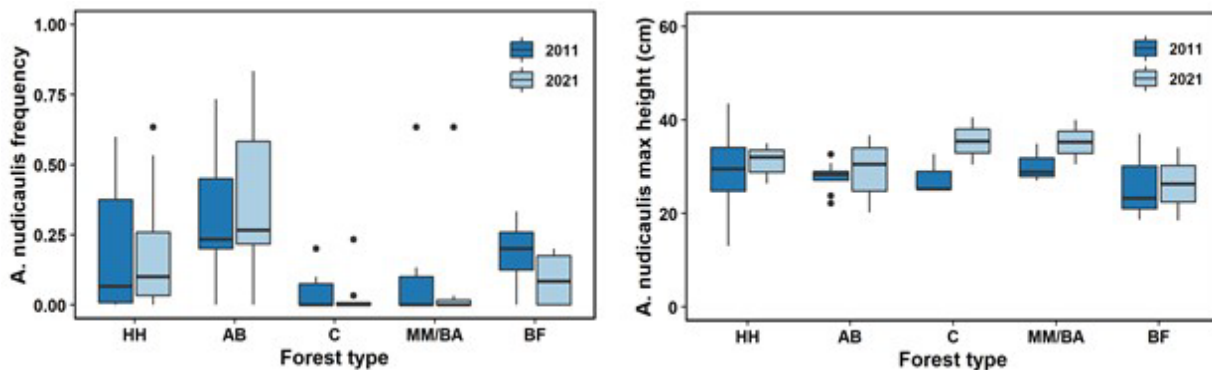


Figure 11. Frequency (*left*) and maximum height (*right*) of *Aralia nudicaulis* within the 30 groundlayer quadrats in each site where present at APIS, 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Streptopus spp. were present in groundlayer quadrats in only 20 of the 48 sites in 2011 and in 17 sites in 2021. Where present, frequency was generally equal between years for all forest types except aspen-birch where it fell from 5.4% of quadrats per site in 2011 to 3.9% of quadrats in 2021 and balsam fir where it fell from 3% to under 1% (Figure 12, left). *Streptopus* sp. maximum height varied between years and forest types but due to the small sample size, we are not making generalizations on change here.

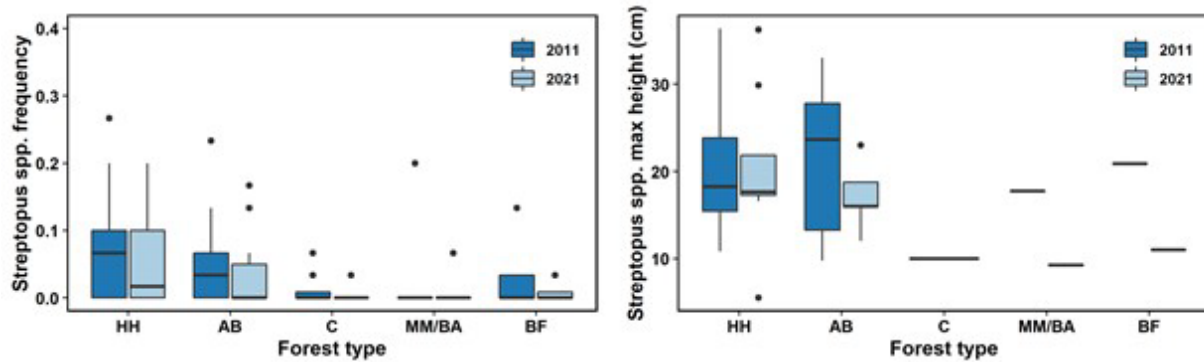


Figure 12. Frequency (left) and maximum height (right) of *Streptopus* spp. within the 30 groundlayer quadrats in sites where present at APIS, 2011 and 2021. *Streptopus* spp. was located in only a limited number of sites in both 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Clintonia borealis was present in quadrats at 39 sites in 2011 and in five fewer sites (34) in 2021. Where present, frequency was generally lower in all forest types, but this was most notable in cedar sites where it fell from 25% to 18% of quadrats where it was present (Figure 13, left). Maximum height dropped markedly in both hemlock-hardwood sites (17.7 cm to 15.2 cm) and cedar (17.6 cm to 15.9 cm) (Figure 13, right).

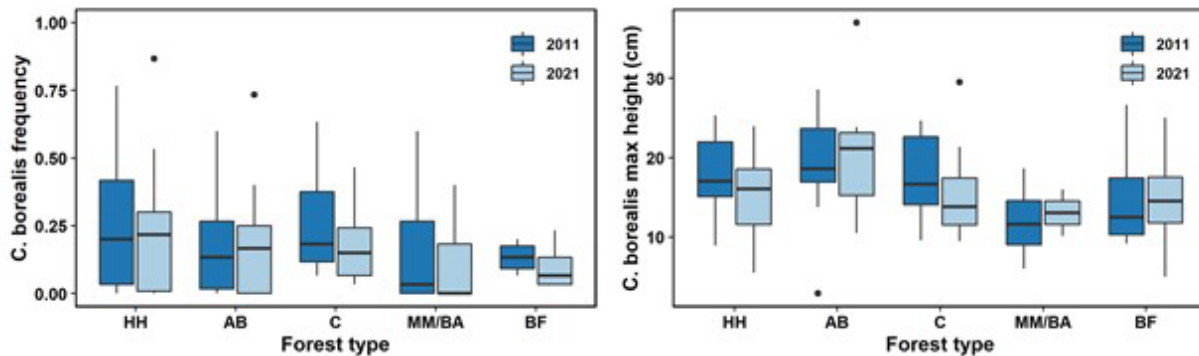


Figure 13. Frequency (left) and maximum height (right) of *Clintonia borealis* within the 30 groundlayer quadrats in each site where present at APIS, 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Comparisons of site-level yew frequency (Figure 14) showed this metric did not substantially vary between sampling events in any forest type or zone with the exception of cedar forests in Zone 2 (Figure 14B). In these eight sites, yew frequency increased from 29% to 33% of browse circles.

No consistent damage or disease was noted in any one forest type or tree species.

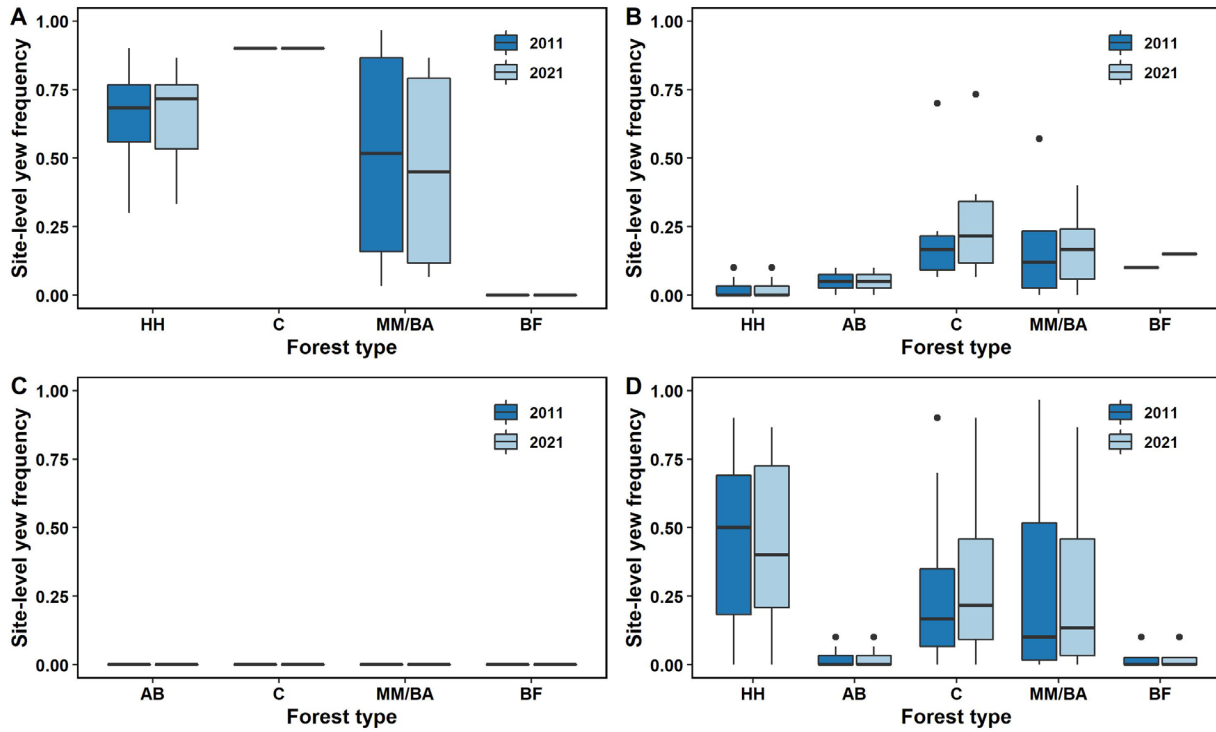


Figure 14. Canada yew frequency by forest type for Zone 1 (A), Zone 2 (B), Mainland (C), and all sites (D) at APIS, 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Community Indices

Taxa richness was similar between years for three forest types but fell in hemlock-hardwood from 29.1 to 27.3 taxa/site and balsam fir, dropping from 43.0 to 35.5 taxa/site (Figure 15D). Taxa richness also fell in Zone 1 sites, dropping 3.6 taxa/site in hemlock-hardwood sites and 7.0 taxa/site in mountain maple-black ash sites (Figure 15A).

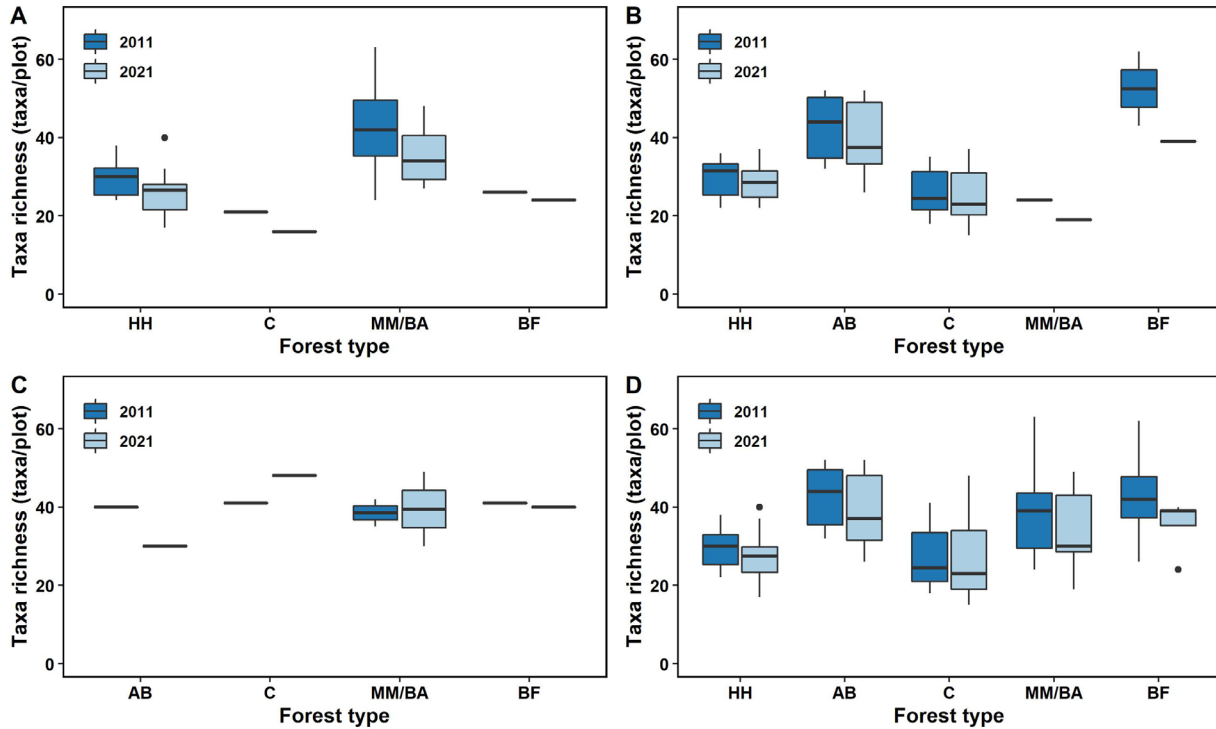


Figure 15. Taxa richness by forest type for Zone 1 (A), Zone 2 (B), Mainland (C), and all sites (D) at APIS, 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Mean coefficient of conservatism was generally similar between years for all forest types across all sites (Figure 16D), regardless of zone (Figure 16A–C).

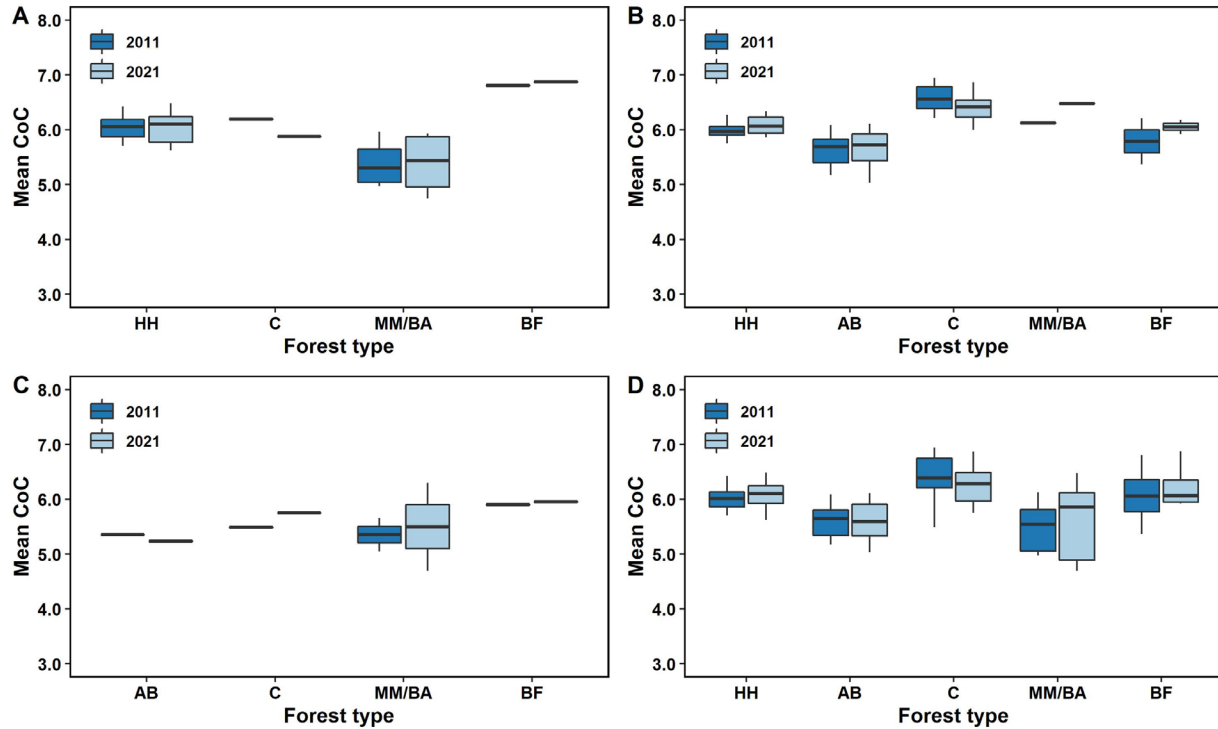


Figure 16. Mean Coefficient of Conservatism (CoC) by forest type for Zone 1 (A), Zone 2 (B), Mainland (C), and all sites (D) at APIS, 2011 and 2021. Forest type abbreviations are: HH: hemlock-hardwood; AB: aspen-birch; C: cedar; MM/BA: mountain maple-black ash; BF: balsam fir.

Specific Metrics of Management Interest

Canada yew frequency per site was generally the same between years or changed by one quadrat/site (-0.033 , 0.033 , or, in the case of Manitou Island, 0.05). Yew frequency declined by more than this at all three sites on Sand, one site on Cat, and one site on Stockton Island (Figure 17). Yew frequency increased most on South Twin and at one site each on Otter, Stockton, and Outer (Figure 17).

Regeneration of overstory species, measured as both seedlings/ha (Table 6) and small saplings/ha (Table 7), varied greatly by species. Notably, sapling density of *Betula alleghaniensis*, *Quercus rubra*, and *Thuja occidentalis* declined in Zone 1 sites.

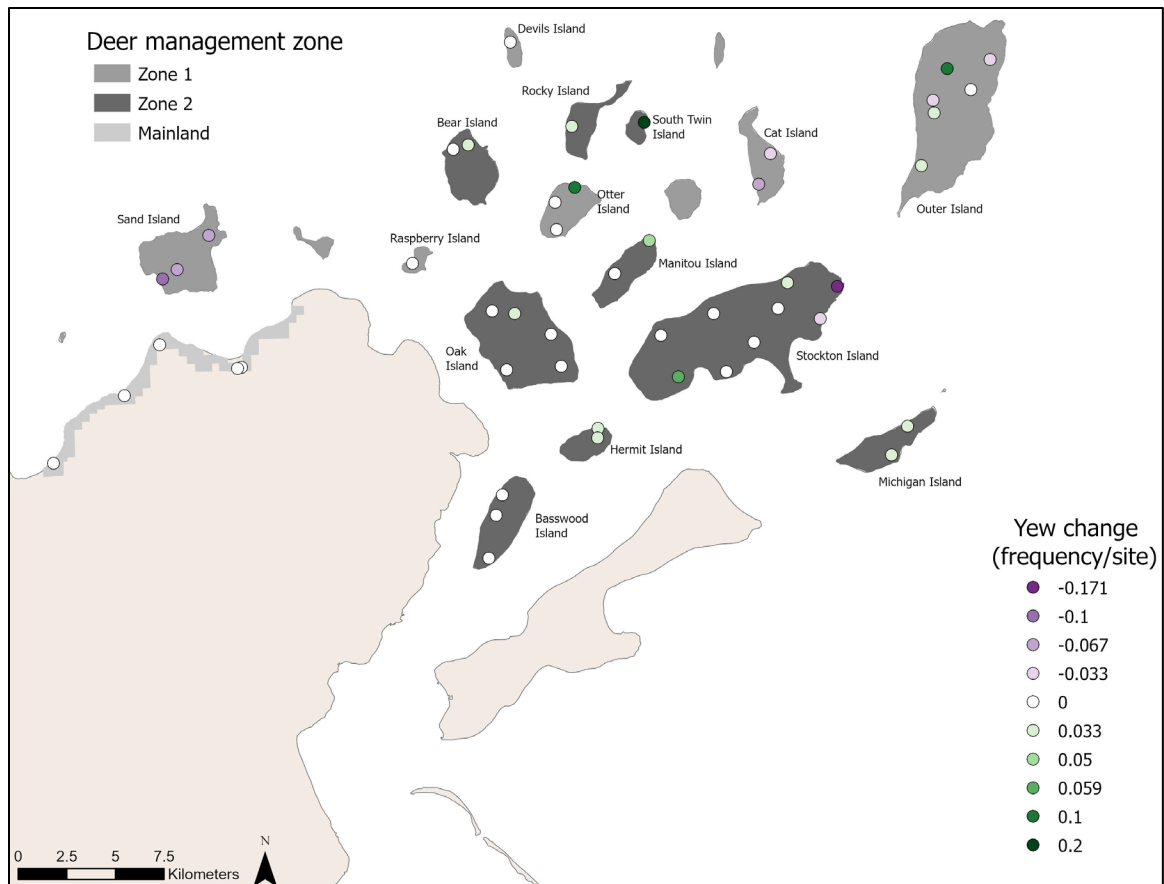


Figure 17. Site-level change in frequency of Canada yew at APIS between 2011 and 2021. Values of -0.033, 0.033, and 0.05 (Manitou Island only) represent changes in occurrence of one quadrat per site.

Table 6. Seedling density (seedlings/ha) of key trees at APIS by zone and year, 2011 and 2021. Zone 1 sites are managed for few-to-no deer, while Zone 2 sites are managed for deer density <3.86 deer/km². ND=not detected.

Tree type	Species	Zone 1		Zone 2	
		2011	2021	2011	2021
Hardwoods	<i>Acer rubrum</i>	1,533	1,750	4,173	4,000
	<i>Acer saccharum</i>	10,359	8,333	14,862	13,486
	<i>Betula alleghaniensis</i>	583	444	519	333
	<i>Betula papyrifera</i>	333	333	333	333
	<i>Populus grandidentata</i>	667	ND	667	1,444
	<i>Populus tremuloides</i>	1,222	1,333	3,397	2,074
	<i>Quercus rubra</i>	3,967	2,733	2,377	2,136
Conifers	<i>Abies balsamea</i>	1,000	722	1,596	1,596
	<i>Thuja occidentalis</i>	2,600	2,667	3,000	4,404
	<i>Tsuga canadensis</i>	ND	ND	1,000	733

Table 7. Small sapling (≥ 2.5 cm, ≤ 5.0 cm DBH) density (saplings/ha) of key trees by zone and year at APIS, 2011 and 2021. Zone 1 sites are managed for few-to-no deer, while Zone 2 sites are managed for deer density <3.86 deer/km². ND=not detected.

Tree type	Species	Zone 1		Zone 2	
		2011	2021	2011	2021
Hardwoods	<i>Acer rubrum</i>	27	29	79	70
	<i>Acer saccharum</i>	311	275	186	194
	<i>Betula alleghaniensis</i>	48	26	48	37
	<i>Betula papyrifera</i>	44	24	11	36
	<i>Populus grandidentata</i>	ND	11	ND	11
	<i>Populus tremuloides</i>	72	56	27	33
	<i>Quercus rubra</i>	31	18	69	64
Conifers	<i>Abies balsamea</i>	237	181	179	155
	<i>Thuja occidentalis</i>	31	20	59	70
	<i>Tsuga canadensis</i>	33	33	65	57

Discussion

Several metrics presented here point to long-term shifts. The successional projections here most notably indicate the aspen-birch forests transitioning away from this early successional type to one dominated by maples (both sugar and red), but also supporting red oak and yellow birch, as well as balsam fir. Ten of the 11 sites designated as aspen-birch are located on either Basswood, Oak, or Stockton Islands, with one on the mainland. Pre-European American settlement forests on all three of these islands were largely dominated by hemlock, with paper birch, yellow birch, white pine, red oak, and cedar locally common (Judziewicz and Koch 1993). Fires following logging operations on Oak and Stockton Islands from the mid-1930s through the mid-1950s returned forests there to early successional states (Wisconsin Conservation Department 1956, Brander and Bailey 1983). Although we are unaware of any logging-era fires on Basswood, browsing pressure from resident deer was possibly greater due to the island's proximity to the mainland and its small size, effectively limiting carrying capacity. Stands on Oak and Stockton today are approximately 65–85 years post-fire, and aspen and paper birch are senescing. This process was hastened by a severe windstorm in July 2020 that affected forests on several islands but was particularly impactful on Oak Island. Figure 8A shows the density of large snags (≥ 30 cm DBH) increased 53%, from 19.1 to 29.2 snags/ha in aspen-birch forests.

Taxa richness remained relatively low, compared with similar protected areas regionally (Sanders and Grochowski 2014a), even dropping somewhat in hemlock-hardwood and balsam fir sites (see Figure 15). Lower richness (Judziewicz and Koch 1993) and herb layer simplification (Mudrak et al. 2009) at APIS has been addressed by others, with explanations focusing on the roles played by deer browse, fire, and the dense yew layer. Island size and location within the archipelago, relative to the mainland have also come into play. We agree that these factors are collectively acting upon the ecosystem and contributing to the paucity, although additional impacts may be contributing as well.

Snowshoe hare are likely shaping richness on the islands via browse. Work by Reibel (2019) found hare present on many of the islands, with their densities influenced by food availability, visual cover, and carnivore abundance. He assessed hare populations at 18 sites on eight of the Apostle Islands, estimating hare densities on Devils Island at 0.977 hares/ha, a value 7.1 times greater than the location with the next highest density (South Twin at 0.137 hares/ha). We have one sampling site on Devils Island where hare overbrowsing has been noted (Reibel 2019), which is classified as balsam fir forest. He also assessed hare abundance near our other three sampling locations in balsam fir forest, finding few-to-no hare (Reibel 2019). With only four sites in this type, declines at one site (that on Devils) will have a large impact on the forest-type mean.

Canopy closure could also be affecting richness, particularly in sites with no deer history. Notably, richness in the site on the southern end of Outer Island declined by 25 taxa from 63 to 38 (Figure 18). This site is adjacent to a historic landing strip and appears to be transitioning away from dominance by *Rubus* spp. to a more open understory. For other sites, particularly those in the aspen-birch forest type, similar processes, with an understory transition away from ruderals, may be playing out. Finally, as noted above, ongoing growth of Canada yew (see Figure 17) may also contribute to

declines in taxa richness by limiting light and resources on the forest floor. This is in line with Mudrak et al. (2009), who found a decline in species richness after 47 years at sites on islands where there is no historic documentation of deer.

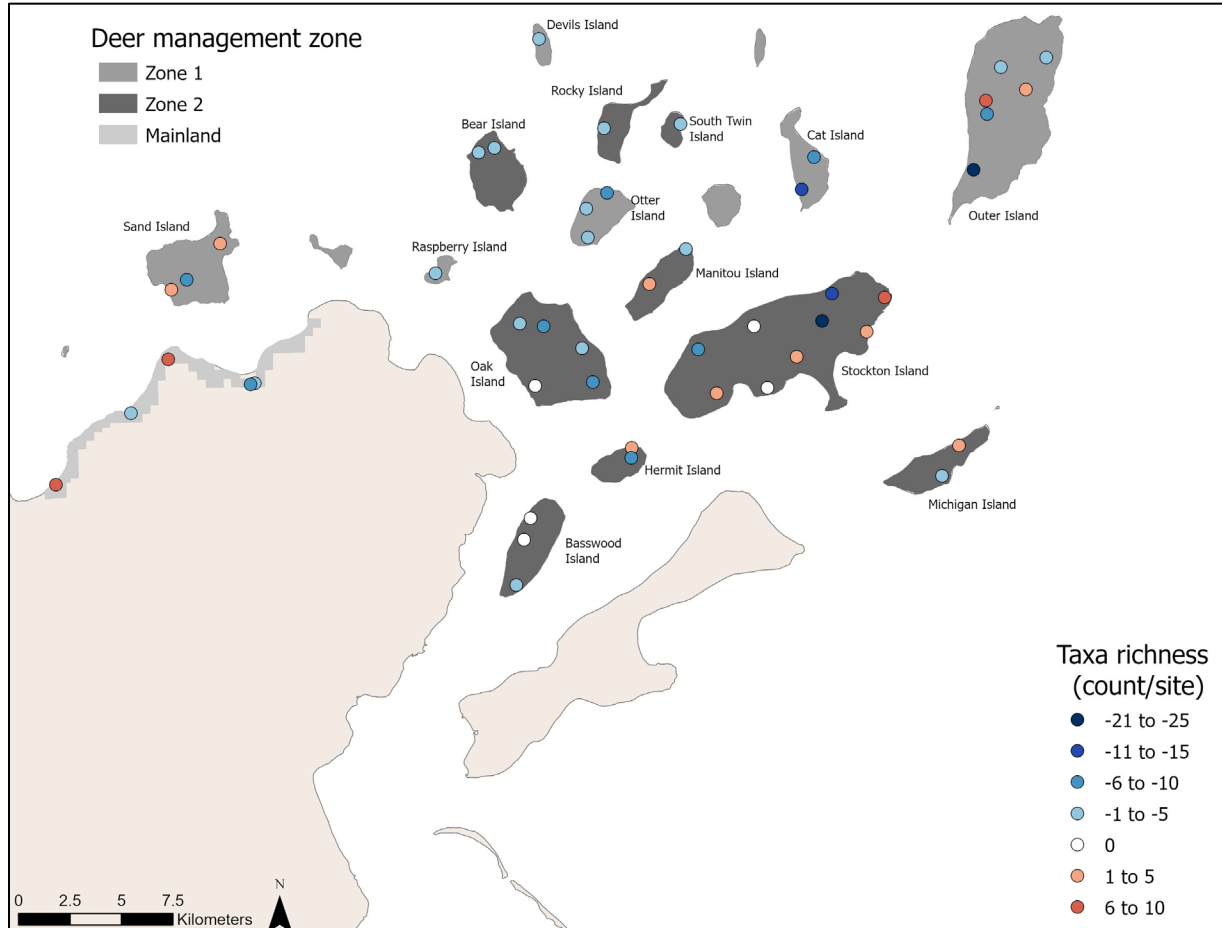


Figure 18. Site-level change in taxa richness at Apostle Islands National Lakeshore, 2011–2021. To promote comparisons among sites sampled throughout the growing season, this metric does not include grasses or sedges and, in some instances, condenses species to the genus level (e.g., *Actaea*, *Pyrola*, *Amelanchier*).

Large, advanced-decay pieces of coarse woody material increased in all forest types except balsam fir (see Figure 7D). This metric, defined by coarse woody material pieces ≥ 30 cm in diameter, ≥ 2.0 meters in length, and of decay class 3 or 4, is one measure of habitat availability for wildlife. This is particularly notable due to the marten population present within the archipelago. Marten (*Martes martes* Turton) favor the use of softwoods, with females shown to preferentially select denning sites in large logs or cedar trees 40 cm to 70 cm in diameter (Wynne and Sherburne 1984). In our eight sites in cedar forests at APIS, we found 38.9 trees/ha (2011) and 34.7 trees/ha (2021) in the 40- to 70-cm DBH size class, although 50% and 60%, respectively, fell within the 40- to 45-cm DBH size class (data not shown).

Park-wide declines in richness make it difficult to tease out the impacts of browse. While we should be able to use height data from target taxa to provide insight, the patterns we observed were not clear. *Aralia nudicaulis* was appreciably taller in cedar and mountain maple-black ash forests, while *Clintonia borealis* was notably shorter in hemlock-hardwood and cedar sites. A better understanding of broadscale species decline is needed before we can truly interpret browse impacts, both to herbaceous and woody species.

Management Recommendations

As the marten population at APIS is of management interest, further studies on woody structure on islands with known marten presence may be warranted. This could include targeted assessments of large diameter trees, snags, hollow trees, and large down logs. Further, examinations of similar habitat on other islands could also be informative.

Additionally, continued monitoring for invasive plant species is critical. We did not find any invasive species in sampling sites, although we did find four non-native species along with one non-native genus (Table 8).

Table 8. Non-native species located in sampling plots at APIS in both years (2011 and 2021).

Species	Common name	Total sites where present	
		2011	2021
<i>Galeopsis tetrahit</i> L.	hempnettle	1	1
<i>Hieraceum</i> sp. L.	hawkweed	3	3
<i>Poa compressa</i> L.	flat-stem bluegrass	2	3
<i>Ranunculus acris</i> L.	meadow buttercup	4	5
<i>Taraxicum officinale</i> F.H. Wigg.	dandelion	2	2

Finally, we did note a couple of surprises in our regeneration data. Yellow birch small saplings fell from 28.2 to 19.2 trees/ha, with this drop most pronounced in both hemlock-hardwood and balsam fir forests. Additionally, small sapling density, in general, in the four balsam fir sites was notably lower in 2021. This was the case for both hardwoods and conifers. While it is not practical for park managers to establish comprehensive monitoring protocols for these, it is advisable that they be alert to possible contributing factors, be they deer, climate, or any other natural or anthropogenic driver.

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Appendix A. All species located during 2021 sampling.

Table A-1. Ferns and fern allies located in GLKN sampling sites at Apostle Islands National Lakeshore, 2021.

Family	Species	Common name
Dennstaedtiaceae	<i>Pteridium aquilinum</i> ssp. <i>latiusculum</i>	western brackenfern
Dryopteridaceae	<i>Dryopteris carthusiana</i>	spinulose woodfern
Dryopteridaceae	<i>Dryopteris cristata</i>	crested woodfern
Dryopteridaceae	<i>Dryopteris expansa</i>	spreading woodfern
Dryopteridaceae	<i>Dryopteris intermedia</i>	intermediate woodfern
Equisetaceae	<i>Equisetum arvense</i>	western horsetail
Equisetaceae	<i>Equisetum palustre</i>	marsh horsetail
Equisetaceae	<i>Equisetum pratense</i>	meadow horsetail
Equisetaceae	<i>Equisetum sylvaticum</i>	woodland horsetail
Lycopodiaceae	<i>Huperzia lucidula</i>	shining clubmoss
Lycopodiaceae	<i>Lycopodium annotinum</i>	stiff clubmoss
Lycopodiaceae	<i>Lycopodium clavatum</i>	running clubmoss
Lycopodiaceae	<i>Lycopodium complanatum</i>	groundcedar
Lycopodiaceae	<i>Lycopodium dendroideum</i>	tree groundpine
Lycopodiaceae	<i>Lycopodium digitatum</i>	fan clubmoss
Lycopodiaceae	<i>Lycopodium obscurum</i>	tree club moss
Onocleaceae	<i>Matteuccia struthiopteris</i>	ostrich fern
Onocleaceae	<i>Onoclea sensibilis</i>	sensitive fern
Osmundaceae	<i>Osmunda claytoniana</i>	interrupted fern
Osmundaceae	<i>Osmundastrum cinnamomeum</i>	cinnamon fern
Polypodiaceae	<i>Polypodium virginianum</i>	rock polypody
Thelypteridaceae	<i>Phegopteris connectilis</i>	long beechfern
Thelypteridaceae	<i>Thelypteris palustris</i>	meadow fern
Woodsiaceae	<i>Athyrium filix-femina</i> var. <i>angustum</i>	subarctic ladyfern
Woodsiaceae	<i>Gymnocarpium dryopteris</i>	western oakfern

Table A-2. Herbaceous (forb) species located in GLKN sampling sites at Apostle Islands National Lakeshore, 2021.

Family	Species	Common name
Apocynaceae	<i>Apocynum androsaemifolium</i>	spreading dogbane
Araceae	<i>Arisaema triphyllum</i>	Jack-in-the-pulpit
Araliaceae	<i>Aralia nudicaulis</i>	wild sarsaparilla
Asparagaceae	<i>Maianthemum canadense</i>	Canada mayflower
Asparagaceae	<i>Maianthemum racemosum</i>	feathery false Solomon's-seal
Asparagaceae	<i>Maianthemum trifolium</i>	threeleaf false lily of the vally
Asparagaceae	<i>Polygonatum pubescens</i>	hairy Solomon's seal
Asteraceae	<i>Eurybia macrophylla</i>	bigleaf aster
Asteraceae	<i>Hieracium</i> sp.	hawkweed
Asteraceae	<i>Lactuca biennis</i>	wild blue lettuce
Asteraceae	<i>Solidago</i> sp.	goldenrod
Asteraceae	<i>Symphyotrichum lateriflorum</i>	calico aster
Asteraceae	<i>Symphyotrichum puniceum</i>	purplestem aster
Asteraceae	<i>Symphyotrichum</i> sp.	aster
Asteraceae	<i>Taraxacum officinale</i>	common dandelion
Balsaminaceae	<i>Impatiens capensis</i>	spotted touch-me-not
Colchicaceae	<i>Uvularia sessilifolia</i>	sessile-leaf bellwort
Cornaceae	<i>Cornus canadensis</i>	Canadian bunchberry
Ericaceae	<i>Chimaphila umbellata</i>	pipsissewa
Ericaceae	<i>Gaultheria hispidula</i>	creeping snowberry
Ericaceae	<i>Gaultheria procumbens</i>	wintergreen
Ericaceae	<i>Hypopitys monotropa</i>	yellow pinesap
Ericaceae	<i>Monotropa uniflora</i>	one-flower Indian-pipe
Ericaceae	<i>Pyrola elliptica</i>	large-leaved shinleaf
Ericaceae	<i>Pyrola</i> sp.	shinleaf
Iridaceae	<i>Iris versicolor</i>	harlequin blueflag
Lamiaceae	<i>Clinopodium vulgare</i>	wild basil
Lamiaceae	<i>Galeopsis tetrahit</i>	brittle-stem hemp-nettle
Lamiaceae	<i>Lycopus uniflorus</i>	oneflower bugleweed
Lamiaceae	<i>Prunella vulgaris</i>	selfheal

Table A-2 (continued). Herbaceous (forb) species located in GLKN sampling sites at Apostle Islands National Lakeshore, 2021.

Family	Species	Common name
Lamiaceae	<i>Scutellaria lateriflora</i>	mad dog skullcap
Liliaceae	<i>Clintonia borealis</i>	bluebead lily
Liliaceae	<i>Streptopus amplexifolius</i>	clasping twistedstalk
Liliaceae	<i>Streptopus lanceolatus</i> var. <i>roseus</i>	twistedstalk
Melanthiaceae	<i>Trillium cernuum</i>	whip-poor-will-flower
Onagraceae	<i>Chamerion angustifolium</i>	fireweed
Onagraceae	<i>Circaea alpina</i>	small enchanter's nightshade
Onagraceae	<i>Circaea canadensis</i> ssp. <i>canadensis</i>	broadleaf enchanter's nightshade
Onagraceae	<i>Epilobium coloratum</i>	willowweed
Onagraceae	<i>Epilobium</i> sp.	willow weed
Orchidaceae	<i>Corallorhiza maculata</i>	spotted coralroot
Orchidaceae	<i>Corallorhiza striata</i>	striped coralroot
Orchidaceae	<i>Cypripedium acaule</i>	pink moccasin flower
Orchidaceae	<i>Goodyera oblongifolia</i>	western rattlesnake plantain
Orobanchaceae	<i>Conopholis americana</i>	squaw-root
Orobanchaceae	<i>Melampyrum lineare</i>	narrowleaf cowwheat
Oxalidaceae	<i>Oxalis montana</i>	mountain woodsorrel
Oxalidaceae	<i>Oxalis stricta</i>	yellow woodsorrel
Plantaginaceae	<i>Veronica serpyllifolia</i>	thyme-leaf speedwell
Polygonaceae	<i>Fallopia cilinodis</i>	fringed black bindweed
Primulaceae	<i>Trientalis borealis</i>	starflower
Ranunculaceae	<i>Actaea pachypoda</i>	white baneberry
Ranunculaceae	<i>Actaea</i> sp.	baneberry
Ranunculaceae	<i>Anemone canadensis</i>	Canadian anemone
Ranunculaceae	<i>Anemone quinquefolia</i>	wood anemone
Ranunculaceae	<i>Coptis trifolia</i>	threeleaf goldthread
Ranunculaceae	<i>Ranunculus abortivus</i>	smallflower crowfoot
Ranunculaceae	<i>Ranunculus acris</i>	tall buttercup
Ranunculaceae	<i>Ranunculus hispidus</i>	bristly buttercup
Ranunculaceae	<i>Ranunculus pensylvanicus</i>	Pennsylvania buttercup

Table A-2 (continued). Herbaceous (forb) species located in GLKN sampling sites at Apostle Islands National Lakeshore, 2021.

Family	Species	Common name
Ranunculaceae	<i>Ranunculus recurvatus</i>	littleleaf buttercup
Ranunculaceae	<i>Thalictrum dasycarpum</i>	purple meadow-rue
Rosaceae	<i>Agrimonia striata</i>	roadside agrimony
Rosaceae	<i>Fragaria virginiana</i>	wild strawberry
Rosaceae	<i>Geum aleppicum</i>	yellow avens
Rubiaceae	<i>Galium triflorum</i>	sweetscented bedstraw
Rubiaceae	<i>Mitchella repens</i>	partridgeberry
Violaceae	<i>Viola</i> sp.	violet

Table A-3. Graminoid species located in GLKN sampling sites at Apostle Islands National Lakeshore, 2021.

Family	Species	Common name
Cyperaceae	<i>Carex arctata</i>	drooping woodland sedge
Cyperaceae	<i>Carex brunnescens</i>	brownish sedge
Cyperaceae	<i>Carex canescens</i>	silvery sedge
Cyperaceae	<i>Carex communis</i>	fibrousroot sedge
Cyperaceae	<i>Carex deweyana</i>	round-fruit short-scale sedge
Cyperaceae	<i>Carex gracillima</i>	graceful sedge
Cyperaceae	<i>Carex gynandra</i>	nodding sedge
Cyperaceae	<i>Carex intumescens</i>	greater bladder sedge
Cyperaceae	<i>Carex lacustris</i>	lakebank sedge
Cyperaceae	<i>Carex leptalea</i>	bristlystalked sedge
Cyperaceae	<i>Carex leptonevia</i>	nerveless woodland sedge
Cyperaceae	<i>Carex pedunculata</i>	long-stalk sedge
Cyperaceae	<i>Carex projecta</i>	necklace sedge
Cyperaceae	<i>Carex</i> sp.	sedge
Cyperaceae	<i>Carex stipata</i>	stalk-grain sedge
Cyperaceae	<i>Carex trisperma</i>	threeseeded sedge
Cyperaceae	<i>Scirpus cyperinus</i>	woolgrass
Cyperaceae	<i>Scirpus</i> sp.	bulrush
Poaceae	<i>Brachyelytrum erectum</i>	bearded shorthusk
Poaceae	<i>Calamagrostis canadensis</i>	bluejoint reedgrass
Poaceae	<i>Cinna latifolia</i>	slender wood-reed
Poaceae	<i>Glyceria canadensis</i>	rattlesnake mannagrass
Poaceae	<i>Glyceria striata</i>	fowl mannagrass
Poaceae	<i>Milium effusum</i>	American milletgrass
Poaceae	<i>Oryzopsis asperifolia</i>	white-grain mountain-rice gras
Poaceae	<i>Poa compressa</i>	flat-stem blue grass
Poaceae	<i>Poa</i> sp.	bluegrass
Poaceae	Poaceae	grass family
Poaceae	<i>Schizachne purpurascens</i>	false melic grass

Table A-4. Shrub species located in GLKN sampling sites at Apostle Islands National Lakeshore, 2021.

Family	Species	Common name
Adoxaceae	<i>Sambucus racemosa</i> var. <i>racemosa</i>	red elderberry
Adoxaceae	<i>Viburnum opulus</i> var. <i>americanum</i>	American cranberrybush
Aquifoliaceae	<i>Ilex mucronata</i>	mountain holly
Aquifoliaceae	<i>Ilex verticillata</i>	common winterberry
Betulaceae	<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder
Betulaceae	<i>Corylus cornuta</i>	beaked hazelnut
Caprifoliaceae	<i>Lonicera canadensis</i>	American fly honeysuckle
Cornaceae	<i>Cornus alternifolia</i>	alternate-leaf dogwood
Cornaceae	<i>Cornus sericea</i>	red-osier dogwood
Diervillaceae	<i>Diervilla lonicera</i>	northern bush-honeysuckle
Ericaceae	<i>Rhododendron groenlandicum</i>	bog Labrador tea
Ericaceae	<i>Vaccinium angustifolium</i>	lowbush blueberry
Ericaceae	<i>Vaccinium myrtilloides</i>	velvetleaf huckleberry
Ericaceae	<i>Vaccinium oxycoccos</i>	small cranberry
Grossulariaceae	<i>Ribes glandulosum</i>	skunk currant
Grossulariaceae	<i>Ribes hirtellum</i>	hairy stem gooseberry
Grossulariaceae	<i>Ribes triste</i>	swamp red currant
Rosaceae	<i>Amelanchier</i> sp.	serviceberry
Rosaceae	<i>Rubus allegheniensis</i>	Allegheny blackberry
Rosaceae	<i>Rubus canadensis</i>	smooth blackberry
Rosaceae	<i>Rubus parviflorus</i>	western thimbleberry
Rosaceae	<i>Rubus pubescens</i>	dwarf red raspberry
Rosaceae	<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	red raspberry
Salicaceae	<i>Salix</i> sp.	willow
Taxaceae	<i>Taxus canadensis</i>	Canada yew

Table A-5. Tree species located in GLKN sampling sites at Apostle Islands National Lakeshore, 2021.

Family	Species	Common name
Betulaceae	<i>Betula alleghaniensis</i>	yellow birch
Betulaceae	<i>Betula papyrifera</i>	paper birch
Betulaceae	<i>Betula</i> sp.	birch
Betulaceae	<i>Ostrya virginiana</i>	ironwood
Cupressaceae	<i>Thuja occidentalis</i>	northern white cedar
Fagaceae	<i>Quercus rubra</i>	northern red oak
Fagaceae	<i>Quercus</i> sp.	oak
Malvaceae	<i>Tilia americana</i>	American basswood
Oleaceae	<i>Fraxinus nigra</i>	black ash
Oleaceae	<i>Fraxinus pennsylvanica</i>	green ash
Oleaceae	<i>Fraxinus</i> sp.	ash
Pinaceae	<i>Abies balsamea</i>	balsam fir
Pinaceae	<i>Picea glauca</i>	white spruce
Pinaceae	<i>Picea mariana</i>	black spruce
Pinaceae	<i>Picea</i> sp.	spruce
Pinaceae	<i>Pinus strobus</i>	white pine
Pinaceae	<i>Tsuga canadensis</i>	hemlock
Rosaceae	<i>Amelanchier arborea</i>	downy serviceberry
Rosaceae	<i>Prunus pensylvanica</i>	pin cherry
Rosaceae	<i>Prunus virginiana</i>	chokecherry
Rosaceae	<i>Sorbus americana</i>	American mountain ash
Rosaceae	<i>Sorbus decora</i>	northern mountain ash
Salicaceae	<i>Populus grandidentata</i>	bigtooth aspen
Salicaceae	<i>Populus</i> sp.	poplar
Salicaceae	<i>Populus tremuloides</i>	quaking aspen
Sapindaceae	<i>Acer rubrum</i>	red maple
Sapindaceae	<i>Acer saccharum</i>	sugar maple
Sapindaceae	<i>Acer</i> sp.	maples
Sapindaceae	<i>Acer spicatum</i>	mountain maple
Ulmaceae	<i>Ulmus americana</i>	American elm

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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