



Forest Vegetation Monitoring at the St. Croix National Scenic Riverway

Natural Resource Technical Report NPS/GLKN/NRTR—2014/899



ON THE COVER

Clockwise from top: View across the St. Croix River from Riverside Landing; cardinal flower located in the forest understory; black ash forest bordering the St. Croix River.

All photographs courtesy of the Great Lakes Inventory and Monitoring Network vegetation sampling crew.

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Executive Summary

Long-term forest health monitoring programs are a valuable means of assessing the impacts of climate change, disturbance regimes, invasive species, and natural successional processes. Monitoring programs can detect subtle changes not necessarily realized otherwise, and provide scientifically valid information on which management decisions can be based. A comprehensive, long-term forest monitoring program was established at the St. Croix National Scenic Riverway (SACN) in 2007. Thirty-five plots were installed at that time; in 2013, we resampled those 35 plots and installed an additional 15, recording data on a total of 50 plots. Collectively, these plots spanned six forest types: sugar maple, upland mixed hardwood/conifer, mixed conifer/red oak, mixed oak/aspen, black ash/mixed hardwood, and silver maple lowland.

Sugar maple forests (seven plots), a climax type in the region, exhibited little change in the six-year interval between sampling periods. Substantial regeneration of *Acer saccharum* Marsh. (sugar maple) and associated species suggests little change is expected in this type in the near future. In upland mixed hardwood/conifer forests (10 plots), encroachment of *Acer rubrum* L. (red maple) and *Abies balsamea* (L.) Mill (balsam fir) in the sapling and small tree layers was indicative of fire suppression. Nine of these plots were along the Namekagon River, and the tenth was along the upper St. Croix River. Relict individuals of *Pinus banksiana* Lamb. (jack pine), *P. resinosa* Aiton (red pine), and *Quercus ellipsoidalis* E.J. Hill (northern pin oak) indicated previous exposure to fire in this forest type. This pattern of replacing fire-obligate species with *A. rubrum*, *A. balsamea*, and other species more commonly observed in mesic habitats is known as “mesophication.” Fire suppression was also evident in mixed conifer/red oak forests. These four plots were located along the lower Namekagon River and showed decreasing importance of aspen with increasing density and basal area of *Quercus rubra* L. (red oak). These forests are in more well-drained soils than those of upland mixed hardwood/conifer forests; *Q. rubra* will likely become increasingly important in the coming decades. Mixed oak/aspen forests (nine plots) were in an earlier successional sere than the other five forest types. Many of these plots experienced a high wind event in 2011; the high density of aspen observed here reflects clonal shoot growth in response to increased light availability. Both black ash/mixed hardwood forests and silver maple lowland forests supported a substantial amount of *Fraxinus nigra* Marsh. (black ash), a species tolerant of saturated conditions. Major recruitment of several species occurred in black ash/mixed hardwood forests in the previous five to ten years and is likely a result of infrequent flooding and relatively shorter durations of inundation.

The proportion of browse—defined as the ratio of the number of species showing recent white-tailed deer (*Odocoileus virginianus* Zimm.) bite marks to the number of species present—varied widely between forest types. A low of 1.6% was documented in silver maple lowland plots, and a high of 25.6% was noted in plots of upland mixed hardwood/conifer forests. The species with the highest relative incidence of browse, across all forest types, were *Amelanchier* sp. Medik (serviceberry), *Cornus racemosa* Lam. (gray dogwood), *Cornus* sp. L. (dogwood), *Corylus americana* Walter (American hazelnut), *Corylus cornuta* Marsh. (beaked hazel), *Pinus resinosa*, and *Populus grandidentata* Michx (bigtooth aspen).

Twelve taxa considered to be problem invasives were located in monitoring plots at SACN in 2013. These included *Phalaris arundinacea* L. (reed canarygrass), which was located in five plots, and *Rhamnus cathartica* L. (common buckthorn), which was located in 13 plots.

The impending arrival of the emerald ash borer (*Agrilus planipennis* Fairmaire) poses one of the greatest threats in the riverway, not only for the forests, but for the entire aquatic-terrestrial interface.

As ash trees begin to die, the loss of stems may result in reduced evapotranspiration and increased flow velocity and water yield (i.e., volume). Such changes could also drive increases in the downstream transport of nutrients and alter habitat conditions for mussels, juvenile fish, and macroinvertebrates.

Park managers face unprecedented challenges over the next few years. In addition to the problems detailed above, the threat of non-native species remains a constant pressure. This includes not only those that invade forests, such as *Rhamnus* L. (buckthorn) and *Lonicera* L. (honeysuckle), but also those impacting aquatic systems. It is possible that, over the next five years, at least one species of Asian carp will become common within the lower reaches of the St. Croix River, between Lake St. Croix and the St. Croix Falls dam. The carp's impacts to hydrology will be compounded by those from the loss of ash. Managers may wish to consider the impacts that both may have on rare and/or endangered mussel species. Options such as translocation may be desirable.

We feel that the park should develop a response plan for the arrival of emerald ash borer. Developing protocols and having them ushered through the NEPA process prior to the insect's arrival will not only save significant effort down the line, but could put the park in a better position ecologically to counter the impacts.

The 50 permanent monitoring plots sampled in 2013 will be revisited in 2022. Because it will be the third visit to these plots, an assessment of trends can be made at that time.

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Introduction

Forest health monitoring programs are a valuable means of assessing current and potential impacts such as those from invasive plant and insect species (Blossey 1999, Auclair 2005), disturbance regimes (Key and Benson 2006, Tanentzap et al. 2011), and climate change (Soldberg et al. 2009, Woodall et al. 2010). Monitoring programs can detect subtle changes not necessarily realized otherwise, and provide scientifically valid information on which management decisions can be based (Carignan and Villard 2002, Duchesne et al. 2005, Day and Puric-Mladenovic 2012). A comprehensive, long-term forest monitoring program was established at the St. Croix National Scenic Riverway (SACN or riverway) in 2007. This program, initiated by the Great Lakes Inventory and Monitoring Network (GLKN) of the National Park Service (NPS) includes goals of detecting and quantifying changes in overstory structure and composition and, ultimately, relating these changes to environmental drivers and stressors.

The St. Croix National Scenic Riverway was one of the eight river systems initially protected by the Wild and Scenic Rivers Act of 1968 (Public Law 90-542; 16 U.S.C. 1271 et seq.). It includes the St. Croix River and a major tributary—the Namekagon River—both of which have headwaters in northern Wisconsin (Figure 1). The St. Croix River forms the border between Minnesota and Wisconsin for the lower 208 km (129 mi) of its length. The riverway includes a buffer of land on either side of both rivers, averaging about 400 m wide per side. Because of the high water quality of the rivers themselves, the entire Namekagon River has been designated an Outstanding Resource Water (ORW) by the State of Wisconsin, while the entire St. Croix River has been variously designated either an ORW or Exceptional Resource Water by both Minnesota and Wisconsin.

The riverway is composed of hundreds of land tracts under nearly as many ownerships. Of the riverway's 27,596 hectares (68,191 acres) above the normal high water line, 31% is under federal ownership in fee title; 40% is owned publicly by state, county, and municipal governments; and another 21% is protected by easements with restrictive conditions.

While the forests along the riverway are largely unmanaged, harvest is permitted where key criteria are met. Typically, these criteria mandate that harvests do not occur in the immediate viewshed of the river and do not compromise the scenic nature of the tract. Our monitoring was limited to those lands owned in fee title, and did not include easements. Because the riverway is long, the drivers impacting the park's forests and successional processes are numerous, and vary over its length. The primary drivers include altered fire regimes, particularly in the lower portion of the Namekagon River, herbivory by white-tailed deer, invasive plants, insect outbreaks, and both high wind and high water events.

At the inception of the long-term forest monitoring program at SACN in 2007, 35 permanent plots were established within the park. Since that time, GLKN has also initiated this monitoring program at eight other National Park Service units. The summer of 2013 marked our first revisit to SACN. In addition to resampling the original 35 plots, 15 additional plots were established, bringing the total at the park to 50. Here, we report on the current (2013) status of SACN forests based on all 50 plots, and on select changes detected in the 35 resampled plots.

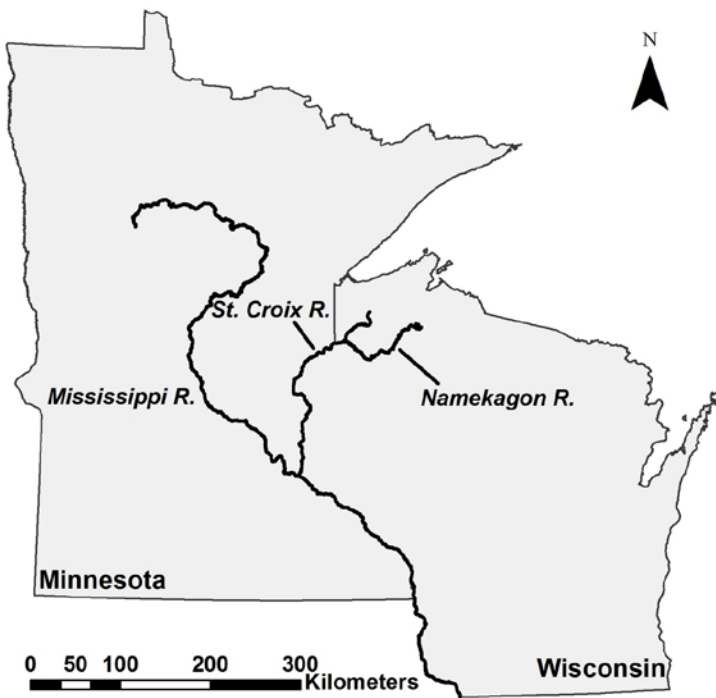


Figure 1. The location of the Namekagon and St. Croix rivers, along with the upper reaches of the Mississippi River.

Methods

Study Area and Sampling Design

The riverway commences where the Namekagon River flows out of Lake Namekagon, an impoundment in Bayfield County, Wisconsin, 159 km (99 mi) upstream from the Namekagon's confluence with the St. Croix River. It emerges from the dam as a third order stream and flows largely through alder swamps and low-lying conifer-hardwood forests. At 74 km (46 mi) from the confluence, near Earl, Wisconsin, Bean Brook discharges into the Namekagon, increasing the stream order to fourth. From here, the Namekagon flows through pine bluffs composed of coarse-textured, well-drained soils for another 64 kilometers (40 miles). The Totogatic River drains into the Namekagon, just upstream from the latter's confluence with the St. Croix River, increasing the stream order to fifth for the final six miles of its length.

Along the St. Croix River, the riverway commences at the outflow of the St. Croix Flowage near Gordon, Wisconsin, then flows 249 km (155 mi) until its confluence with the Mississippi River in Prescott, Wisconsin. The river emerges from the dam at Gordon as a fourth order stream, flows 32 km (20 mi) to its confluence with the Namekagon River (increasing the stream order to fifth), then another 62 km (39 miles) to its confluence with the Kettle River. Here, the St. Croix becomes a sixth order stream and remains so for the duration of its length. The upper St. Croix occupies a broad river valley, bordered by northern hardwood forests with pockets of *Picea A. Dietr.* (spruce), *Pinus L.* (pine), and *Thuja occidentalis L.* (white cedar), and a large component of *Fraxinus nigra*. The forests along the lower St. Croix (downstream from St. Croix Falls, Wisconsin) gradually transition into a more deciduous type with tree species typical of larger Midwest river floodplains (e.g., *Acer saccharinum L.* (silver maple), *Ulmus americana L.* (American elm), *Populus deltoides Bartram ex Marshall* (cottonwood), and *Salix sp. L.* (willow)).

Sampling was conducted at SACN from 8 June–20 August 2013. Sites were selected prior to the 2007 sampling season using a generalized random-tessellation stratified design (Stevens and Olsen 2004), ensuring that sites were both randomly located and spatially balanced throughout the park. All sites were required to have a minimum of 10% forest cover. We checked all potential new sites against an aerial photography layer in GIS prior to visiting them in the field. Potential new sites that did not initially meet the minimum 10% forest cover requirement were moved the shortest distance possible, to a maximum of 100 m, so that they fell within the desired amount of cover. If a potential site could not be moved ≤ 100 m to meet the criteria, it was not sampled. Maps of individual sites are presented in Appendix A.

Field Methods

Basic Measurements

Sites were sampled using the Hybrid plot (Figure 2) developed specifically to meet the needs of the GLKN 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. 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 was 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 and recorded tree seedlings. Seedlings were defined as tree species <2.5 cm DBH, but at

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

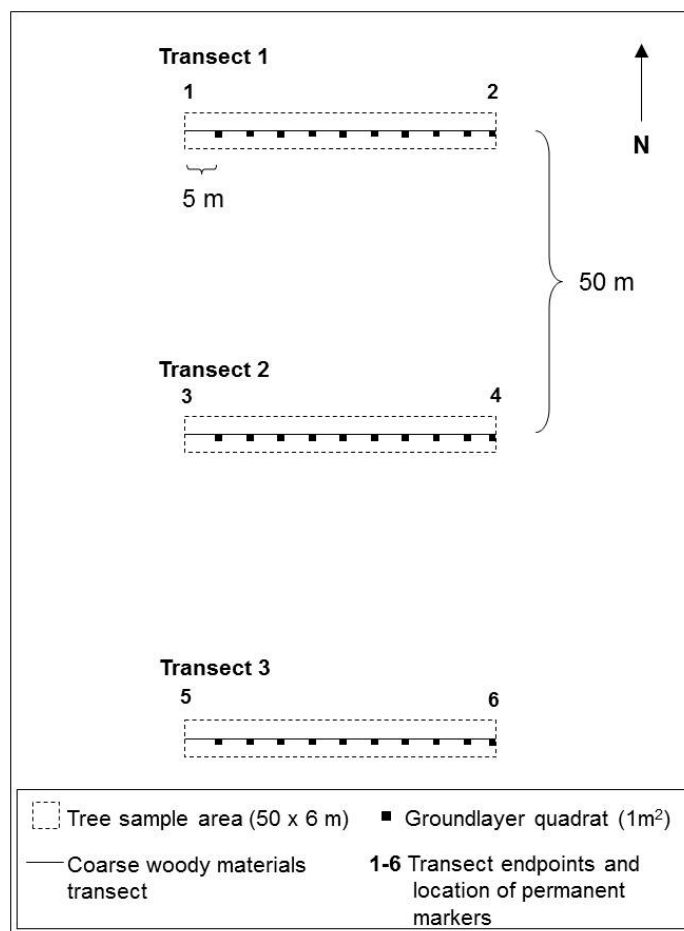


Figure 2. The Hybrid plot configuration consisted of three parallel transects, each 50 m long and oriented east-to-west.

Browse Assessments

We examined white-tailed deer (*Odocoileus virginianus* Zimm.) winter and summer browse pressure using two distinct measures. Direct browse is an assessment of visible browse (i.e., bites, directly evident on the plant) on woody species. The indirect browse assessment is conducted on herbaceous species and documents observed changes in herbaceous demography only indirectly 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.

Direct browse was measured along each of the three 50-m transects, and along four additional transects flanking the east and west sides of the plot (Figure 3). Direct browse measurements were conducted in 3.14 m² (1-m-radius) circular sampling areas. These browse sampling circles were centered every five meters along each transect, for a total of 68 per plot, equal to a total sampling area of 213 m². For each direct browse sampling circle, all woody species present in the browse zone—defined as the space between ground level and 1.8 m in height—were recorded. In addition to species presence, evidence of any deer browse on that species in the sampling circle was recorded. Typically, winter browse surveys are conducted in the spring, prior to the new season's growth. Because we were not able to sample in the spring, we only considered a plant browsed when it was apparent that the browse occurred during the current season's growth. This was evidenced by the bite marks on green and/or non-woody tissue. This was often accompanied with new growth arising from the bud immediately below the point of browse.

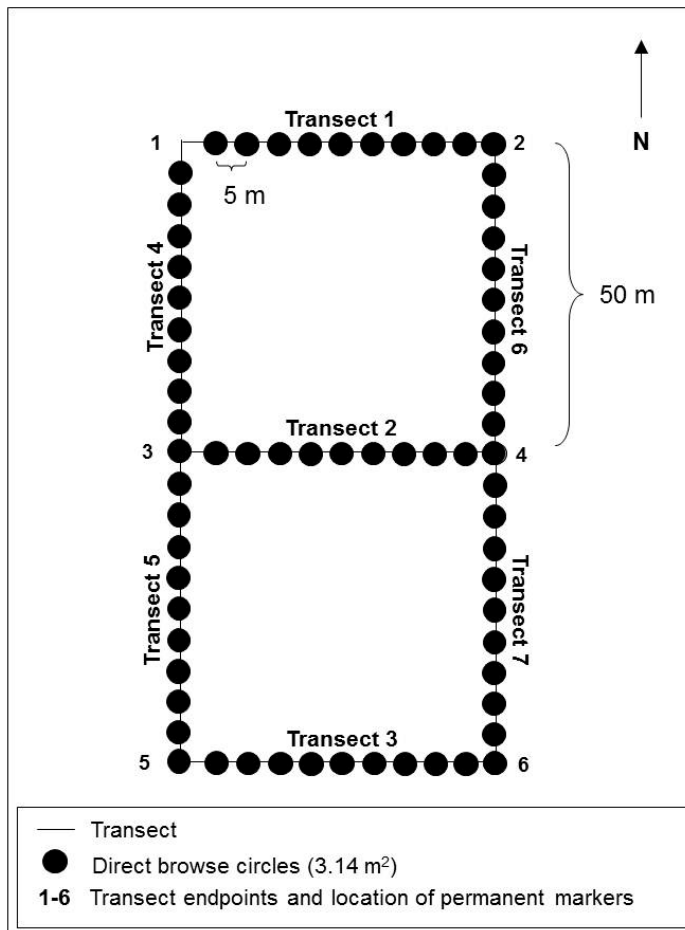


Figure 3. Location of the direct browse sampling circles in a plot.

Direct browse data were used to calculate the proportion of browse. At the 1-m-radius browse circle level, the proportion of browse is the number of species browsed to the number of species present. The proportion of browse values range from 0 to 1, where 0 represents a browse circle where no

species present are browsed, and 1 represents a browse circle where all species present are browsed (Frerker and Waller 2013). The proportion of browse calculation can then be summed across all browse circles for each plot, each forest type, and the entire park. The proportion of browse calculation can also be used to determine which species are being browsed more frequently relative to others.

The direct browse methods employed in 2013 differed considerably from those of 2007 when we simply noted the closest woody plant to each of the thirty herbaceous quadrats and recorded whether browse was present. Because of the different methodology, no comparisons between time periods can be drawn.

The data collected for the direct browse assessments were also used to calculate frequency of occurrence of shrub and woody vine species in each plot. Frequency of occurrence was calculated based on the number of browse circles in which a shrub or woody vine species was present. We then calculated the mean frequency of occurrence across all plots in a forest type.

To assess the indirect impacts of summer browse on understory species, we selected three target taxa that are known to be browsed by white-tailed deer in the region: *Maianthemum racemosum* ssp. *racemosum* (L.) Link (false Solomon's seal), *Streptopus* sp. Michx. (twistedstalk), and *Trillium* sp. L. (trillium). For each target taxa present within each 1 m² herbaceous quadrat (see Figure 2), we measured the height of the tallest individual and noted whether there was any evidence of browse within the quadrat. As with the direct browse measure, indirect browse methods of 2013 differed from those of 2007 (see Sanders (2008) for detailed methods). Because of the differing methodology, we will not make comparisons between the two time periods.

Tree Health

To assess tree health, we used an evidence-based approach whereby we examined each tree for the presence of broad classes of disease, damage, or injury (U.S. Department of Agriculture 2010). These classes included dieback, epicormic sprouting, wilted foliage, defoliation, discolored foliage, insect sign, and human induced stress. If a tree exhibited symptoms of one of these primary classes, a further classification of the damage or disease was made, based on predefined characteristics within each of the primary classes. For example, if a tree was classified as having discolored foliage, we would note whether this damage was in the form of (among other choices) marginal browning of the leaves, interveinal browning of the leaves, the leaves possessing a white coating, or a general yellowing of the leaves. This symptom-based assessment of damage and disease allows us to easily classify tree health issues, from which a diagnosis of the root cause can possibly be assigned upon further investigation. We feel that this symptom-based approach is more accurate than directly assigning a root cause to problems observed when at the field site. For some symptoms, there are dozens of possible causes and a pathologist or entomologist with specialization in the region would be needed to accurately assess the problem. Large-scale or persistent symptoms noted with this method can alert the park staff to potential disease or insect outbreaks, which would require further investigation by the park to identify the exact disease or pest. In 2007, we attempted to assign actual diseases or causal agents to diseased or injured trees, rather than focus on identification of the symptoms. Because of the differences in methods, no comparisons will be made between the two time periods.

Earthworm Assessments

Earthworm assessments were conducted at vegetation monitoring plots to determine the extent of invasive earthworm presence at SACN. 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, as well as an inspection of the A and E soil horizons, to determine their presence and thickness. 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 two evaluations, 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; no evidence of earthworm casts or middens; and the presence of an E soil horizon. A moderately invaded sample has both fresh and decayed litter, but no organic matter present; earthworm casts are present but not abundant; and earthworm middens may be present or absent. A heavily invaded sample would have fresh litter but no decayed litter and no organic matter, and earthworm casts and middens would be abundant (Loss et al. 2013). 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 2007, so comparisons in earthworm impacts between the two time periods will not be made.

Assigning Forest Types

Because of the potential to stratify by forest type during later analyses (i.e., post-sampling stratification), we used two separate classification methods to assign a forest type while we were at each plot. We first used the National Vegetation Classification System (Hop et al. 2012), which identifies the current forest type; we then used the Kotar classification (Kotar and Burger 1996, Kotar et al. 2002), which identifies the expected climax forest types, using understory species as indicators of soil moisture and fertility.

Visual Assessment/Photo Points

Documenting visual assessments of site change will be as important as statistical documentation, and potentially more informative. Therefore, we took six photographs at each plot. The six photo points were located at each of the six transect endpoints, with the photo taken facing into the plot (i.e., due east at points 1, 3, and 5, and due west at points 2, 4, and 6; see Figure 1).

Plant Identification

We attempted to identify all plants to the species level while in the field. When this was not possible, we typically collected specimens for later identification. In some instances, it was not possible to distinguish between multiple species present in a park, unless they were flowering or fruiting, which often was not the case. In these instances, we identified only to the genus or family level. Examples include *Carex* sp. L. (sedge), *Osmorhiza* sp. Raf. (sweet cicely), and Asteraceae (daisy family). For *Amelanchier* sp., another genus that presented identification challenges, we assigned individual plants to one of two groups of species complexes, with 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). (Species recognized in Group 1 were not present at SACN). Finally, if a grass was not in flower or fruit, it was typically only possible to identify to the family (Poaceae) level.

Analysis and Classification Methods

Forest Type Classification

The National Vegetation Classification Standard (NVCS) recognizes subtle nuances between forest types; hence, classifications of plots using this system tend to recognize several forest types. Indeed, our 50 plots were placed into 20 individual forest types, resulting in only one-to-a-few plots per type. We also questioned the value of our classification using the Kotar system. Rather than the current forest type, this system identifies anticipated climax forest types based on soil moisture and fertility. However, because altered disturbance regimes, such as fire suppression, will impact successional trajectories, we felt this system was of limited value for placing plots into groups of similar vegetation. For these reasons, we decided to use cluster analysis to place the 50 plots into groups with similar tree species composition. We limited inclusion in the cluster analysis to those species that were present in at least 6% (3 of 50) of the plots. Collectively, the plots supported 32 species meeting these criteria.

The cluster analysis was based on the importance value, determined by the sum of the relative density and relative basal area of each species-plot combination (Dyer 2006, Elliott and Swank 2008). We used PC-ORD software with a Sørensen distance measure and a flexible beta linkage ($\beta = -0.25$) (McCune and Grace 2002). 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, using PC-ORD software for this analysis (McCune and Grace 2002).

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. 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., *Taraxacum officinale* F.H. Wigg. (common dandelion)) 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 *Poa* sp. L. (bluegrass) and *Ranunculus* sp. L. (buttercup); 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 SACN. 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 used the values defined for the State of Wisconsin (Bernthal 2003) for all species located in 2013 sampling. We then used these COC values to calculate the modified floristic quality index (mFQI) (Rooney and Rogers 2002, Sanders and Grochowski 2014) where mFQI of a forest type is simply the mean of the

COC values for all species present within that forest type. The mFQI was calculated for each of the six forest types.

Change Calculations

For forest types where at least three plots were resampled, we calculated the mean stem density and basal area for both live and standing dead trees in both 2007 and 2013. We also calculated and graphed density and basal area of key species or groups in these forest types.

Spatial Extent of *Fraxinus*

In addition to describing past dynamics and the current status of the riverway's forests, we also wanted to assess the extent and location of the impending impacts of emerald ash borer (*Agrilis planipennis* Fairmaire) (EAB). We used GIS vegetation cover data developed for the riverway (National Vegetation Classification System, 2013) and identified all vegetation classes with "ash" in the name. These classes will have a large component of *Fraxinus* spp., although there can be a sizable percentage of other species as well. At SACN, the predominant species of *Fraxinus* upstream of St. Croix Falls is *F. nigra*, while *F. pennsylvanica* is more common downstream from this point. This data layer provided classified cover types for the riverway's bounded area, plus a 300 meter buffer beyond the park boundary. Because the riverway's boundary typically extends about 400 meters on either side of the river, the vegetation cover layer provided an assessment of vegetation types over a 700 m-wide swath along each side of both rivers. We divided the riverway into four segments based on landscape and hydrological characteristics: Namekagon River, St. Croix River upstream of the confluence with the Namekagon (upper St. Croix), St. Croix River from the Namekagon confluence to the St. Croix Falls hydroelectric dam (middle St. Croix), and the St. Croix from the dam to the Mississippi River confluence (lower St. Croix). For each of the four riverway segments, we used GIS (ArcMap 10.0) to calculate the percentage of area classified as an ash type within the vegetation cover layer. We also calculated the linear distance (i.e., length) of the boundary between vegetation polygons and flowing water and determined the percentage of this distance represented by ash polygons. This linear distance includes the edges of both riverbanks as well as islands. Because this calculation was derived from the vegetation cover layer, we also included the lower segments of tributaries emptying into either of the two large rivers.

Results

A total of 50 plots were sampled in 2013; 35 of these plots were initially sampled in 2007 and resampled in 2013, and 15 were newly established plots. Maps of each plot are presented in Appendix A. From among all 50 plots, we identified 39 tree species, 70 shrub and woody vine taxa, and 296 taxa of herbs. Plots were classified to one of six forest types: sugar maple, upland mixed hardwood/conifer, mixed conifer/red oak, mixed oak/aspen, black ash/mixed hardwood, and silver maple lowland (Table 1, Figure 4).

Table 1. The six forest types sampled and the plots classified in each. Plots in large, bold font are those that were sampled in 2007 as well as 2013.

Forest type	Plots
Sugar maple	7001, 7019 , 7022, 7045, 7054, 7055, 7076
Upland mixed hardwood/conifer	7012, 7015, 7020, 7025, 7028, 7036, 7048, 7052, 7064 , 7066
Mixed conifer/red oak	7005, 7017, 7021 , 7053
Mixed oak/aspen	7004, 7009 , 7010, 7014, 7018, 7037, 7049 , 7068, 7077
Black ash/mixed hardwood	7002, 7003, 7011 , 7013, 7026, 7027 , 7030, 7031, 7033, 7038 , 7039, 7042, 7043 , 7057, 7059, 7070
Silver maple lowland	7006, 7034, 7035 , 7058

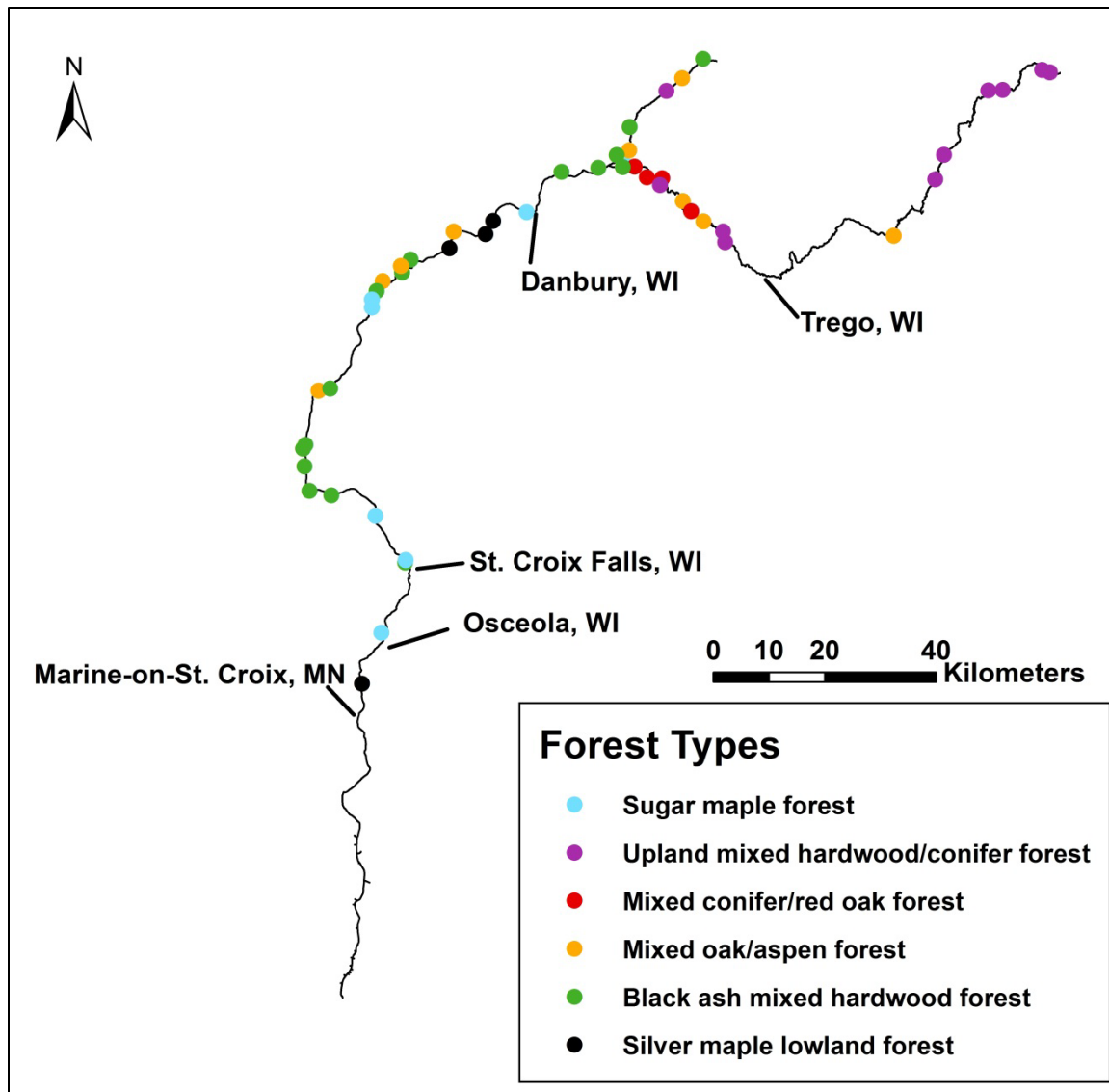


Figure 4. Distribution of plots, by forest type, at the St. Croix National Scenic Riverway, 2013.

Sugar Maple

Seven plots sampled were in sugar maple forest, a type that typically supported a large amount of both *Acer saccharum* and *Tilia americana*. These plots were fairly evenly spaced from the Namekagon River, just upstream from the confluence with the St. Croix, downstream to the Osceola area (Figure 4). A total of 21 overstory species were observed in sugar maple plots (Table 2). *Acer saccharum* density was high in small size classes (Figure 5), a pattern typically observed when a species is successfully regenerating. Densities of *Tilia americana*, a climax species in this forest type, were also highest in the smallest size classes (Figure 5).

Table 2. Basal area and density of live trees in sugar maple forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood			
<i>Acer rubrum</i>	red maple	1.36	160.32
<i>Acer saccharum</i>	sugar maple	5.52	445.24
<i>Betula alleghaniensis</i>	yellow birch	0.02	3.17
<i>Carpinus caroliniana</i>	American hornbeam	0.11	106.35
<i>Carya cordiformis</i>	bitternut hickory	0.52	33.33
<i>Fraxinus nigra</i>	black ash	2.83	68.25
<i>Fraxinus pennsylvanica</i>	green ash	0.67	15.08
<i>Juglans cinerea</i>	butternut	<0.01	1.59
<i>Ostrya virginiana</i>	ironwood	0.96	258.73
<i>Populus grandidentata</i>	bigtooth aspen	0.17	6.35
<i>Prunus serotina</i>	black cherry	<0.01	2.38
<i>Prunus virginiana</i>	chokecherry	0.01	1.59
<i>Quercus alba</i>	white oak	0.99	12.70
<i>Quercus ellipsoidalis</i>	northern pin oak	0.46	3.17
<i>Quercus macrocarpa</i>	bur oak	1.25	19.05
<i>Quercus rubra</i>	northern red oak	0.66	7.14
<i>Tilia americana</i>	basswood	6.03	106.35
<i>Ulmus americana</i>	American elm	0.40	38.10
<i>Ulmus rubra</i>	slippery elm	0.08	16.67
Conifer			
<i>Abies balsamea</i>	balsam fir	0.18	14.29
<i>Pinus strobus</i>	white pine	1.53	3.17
Total		23.74	1,323.02

Total seedling density in sugar maple forests was 17,381 seedlings/hectare, with 21 species identified (Table 3). The most abundant were *Ostrya virginiana* (Mill.) K. Koch (ironwood) and *Fraxinus nigra*, although the density was greater than 1,000 seedlings/ha for six species (Table 3).

Sugar maple forests supported 34 shrub and woody vine species, with *Corylus cornuta* being the dominant tall shrub, present in 9.1% of browse circles (Table 4). *Rubus pubescens* Raf. (dwarf red raspberry) and *Parthenocissus* sp. Planch. (Virginia creeper) were the most abundant prostrate woody species, present in 18.2% and 23.6% of the browse circles, respectively.

Characteristic herbaceous species in sugar maple forests included *Carex pensylvanica* Lam. (Pennsylvania sedge), *Eurybia macrophylla* (L.) Cass. (bigleaf aster), *Athyrium filix-femina* var. *angustum* (Willd.) C. Presl (ladyfern), *Laportea canadensis* (L.) Wedd. (woodnettle), *Geranium maculatum* L. (spotted geranium), *Viola* sp. L. (violet), *Circaea canadensis* ssp. *canadensis* (L.) Hill (enchanter's nightshade), and *Oryzopsis asperifolia* Michx. (cutleaf ricegrass).

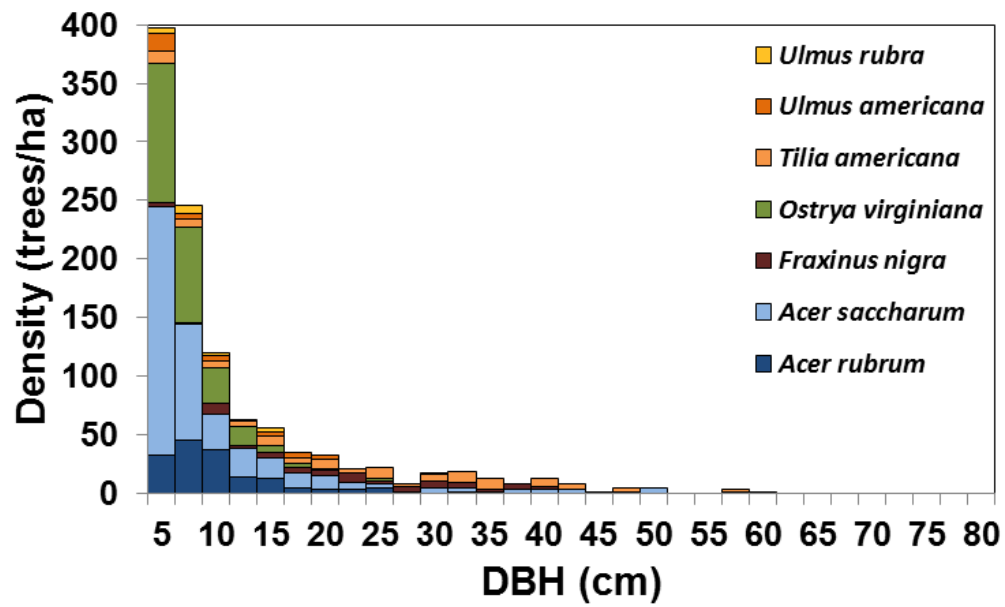


Figure 5. Density-diameter relationship for the seven most important tree species in sugar maple forests at St. Croix National Scenic Riverway, 2013.

Table 3. Seedling density in sugar maple forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Density (seedlings/ha)
Hardwood		
<i>Acer negundo</i>	boxelder	142.86
<i>Acer rubrum</i>	red maple	809.52
<i>Acer saccharum</i>	sugar maple	1,571.43
<i>Betula alleghaniensis</i>	yellow birch	47.62
<i>Betula papyrifera</i>	paper birch	47.62
<i>Carpinus caroliniana</i>	American hornbeam	2,190.48
<i>Carya cordiformis</i>	bitternut hickory	1,428.57
<i>Fraxinus nigra</i>	black ash	3,095.24
<i>Fraxinus pennsylvanica</i>	green ash	238.10
<i>Ostrya virginiana</i>	ironwood	3,428.57
<i>Populus grandidentata</i>	bigtooth aspen	47.62
<i>Populus tremuloides</i>	quaking aspen	619.05
<i>Prunus serotina</i>	black cherry	47.62
<i>Prunus virginiana</i>	chokecherry	666.67
<i>Quercus alba</i>	white oak	47.62
<i>Quercus macrocarpa</i>	bur oak	333.33
<i>Quercus rubra</i>	northern red oak	571.43
<i>Tilia americana</i>	American basswood	285.71
<i>Ulmus americana</i>	American elm	1,428.57
<i>Ulmus rubra</i>	slippery elm	238.10
Conifer		
<i>Abies balsamea</i>	balsam fir	95.24
Total		17,380.95

Table 4. Mean frequency of occurrence for shrubs and woody vines in sugar maple forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Frequency
<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder	0.002
<i>Amelanchier</i> sp. (Group 2)	serviceberry	0.019
<i>Cornus alternifolia</i>	alternate-leaf dogwood	0.026
<i>Cornus racemosa</i>	gray dogwood	0.037
<i>Cornus rugosa</i>	round-leaf dogwood	0.014
<i>Corylus americana</i>	American hazelnut	0.009
<i>Corylus cornuta</i>	beaked hazelnut	0.091
<i>Crataegus</i> sp.	hawthorn	0.012
<i>Diervilla lonicera</i>	northern bush-honeysuckle	0.002
<i>Dirca palustris</i>	eastern leatherwood	0.012
<i>Ilex verticillata</i>	common winterberry	0.026
<i>Lonicera canadensis</i>	American fly honeysuckle	0.016
<i>Lonicera dioica</i>	glaucous honeysuckle	0.005
<i>Lonicera hirsuta</i>	hairy honeysuckle	0.005
<i>Parthenocissus</i> sp.	Virginia creeper	0.236
<i>Rhamnus alnifolia</i>	alder-leaf buckthorn	0.009
<i>Rhamnus cathartica</i>	common buckthorn	0.012
<i>Rhus typhina</i>	staghorn sumac	0.002
<i>Ribes cynosbati</i>	pasture currant	0.009
<i>Ribes hirtellum</i>	hairy stem gooseberry	0.072
<i>Ribes lacustre</i>	prickly currant	0.002
<i>Rosa acicularis</i>	prickly rose	0.002
<i>Rubus pubescens</i>	dwarf red raspberry	0.182
<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	red raspberry	0.072
<i>Sambucus nigra</i> ssp. <i>canadensis</i>	elderberry	0.016
<i>Smilax tamnoides</i>	bristly greenbrier	0.026
<i>Spiraea alba</i>	white meadowsweet	0.009
<i>Symphoricarpos albus</i>	snowberry	0.009
<i>Toxicodendron rydbergii</i>	western poison ivy	0.037
<i>Vaccinium angustifolium</i>	lowbush blueberry	0.007
<i>Viburnum lentago</i>	nannyberry	0.002
<i>Viburnum rafinesqueanum</i>	downy arrowwood	0.021
<i>Vitis riparia</i>	riverbank grape	0.002
<i>Zanthoxylum americanum</i>	common prickly ash	0.063

Upland Mixed Hardwood/Conifer

We classified ten plots as the upland mixed hardwood/conifer forest type, with nine of these located on the Namekagon River and one on the upper St. Croix River. *Acer rubrum* and *Abies balsamea* were the most important species, both in terms of density and basal area (Table 5). In addition, *Pinus*

strobis L. (white pine) was also common. All three species exhibited progressively greater densities in progressively smaller size classes (Figures 6a, 6b), suggesting they are regenerating.

Table 5. Basal area and density of live trees in upland mixed hardwood/conifer forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood			
<i>Acer rubrum</i>	red maple	3.76	352.22
<i>Acer saccharum</i>	sugar maple	0.06	7.78
<i>Betula alleghaniensis</i>	yellow birch	0.21	6.67
<i>Betula papyrifera</i>	paper birch	0.40	44.44
<i>Carpinus caroliniana</i>	American hornbeam	0.01	7.78
<i>Fraxinus nigra</i>	black ash	1.36	80.00
<i>Fraxinus pennsylvanica</i>	green ash	0.01	2.22
<i>Ostrya virginiana</i>	Ironwood	0.04	21.11
<i>Populus grandidentata</i>	bigtooth aspen	2.06	46.67
<i>Populus tremuloides</i>	quaking aspen	1.84	56.67
<i>Prunus serotina</i>	black cherry	0.20	44.44
<i>Prunus virginiana</i>	chokecherry	0.01	5.56
<i>Quercus alba</i>	white oak	0.12	7.78
<i>Quercus ellipsoidalis</i>	northern pin oak	1.87	32.22
<i>Quercus rubra</i>	northern red oak	0.62	31.11
<i>Ulmus americana</i>	American elm	0.10	12.22
Conifer			
<i>Abies balsamea</i>	balsam fir	3.33	567.78
<i>Larix laricina</i>	tamarack	0.01	1.11
<i>Picea glauca</i>	white spruce	0.67	26.67
<i>Picea mariana</i>	black spruce	0.02	2.22
<i>Pinus banksiana</i>	jack pine	2.01	41.11
<i>Pinus resinosa</i>	red pine	1.65	30.00
<i>Pinus strobus</i>	white pine	4.15	180.00
<i>Thuja occidentalis</i>	northern white cedar	0.47	4.44
Total		24.96	1,612.22

Total seedling density was 18,640 seedlings/ha (Table 6) with nearly 47% of this being *Acer rubrum*. *Fraxinus nigra*, *Quercus rubra*, and *Abies balsamea* were also present with densities greater than 1,000 seedlings/ha (Table 6).

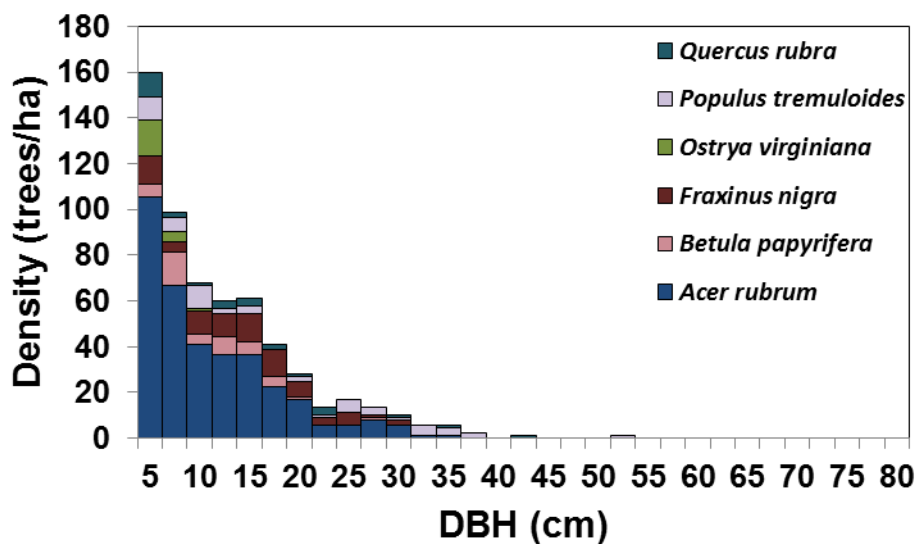


Figure 6a. Density-diameter relationship for the six most important hardwood species in upland mixed hardwood/conifer forests at St. Croix National Scenic Riverway, 2013.

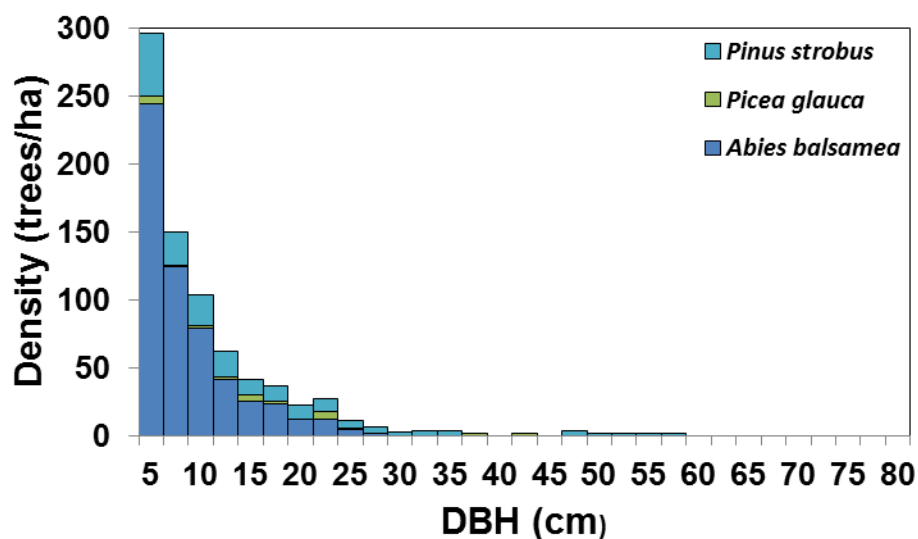


Figure 6b. Density-diameter relationship for the three most important conifer species in upland mixed hardwood/conifer forests at St. Croix National Scenic Riverway, 2013.

Table 6. Seedling density in upland mixed hardwood/conifer forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Density (seedlings/ha)
Hardwood		
<i>Acer rubrum</i>	red maple	8,713.79
<i>Acer saccharum</i>	sugar maple	66.67
<i>Acer spicatum</i>	mountain maple	33.33
<i>Betula alleghaniensis</i>	yellow birch	66.67
<i>Carpinus caroliniana</i>	American hornbeam	366.67
<i>Fraxinus nigra</i>	black ash	1,800.00
<i>Fraxinus pennsylvanica</i>	green ash	100.00
<i>Ostrya virginiana</i>	ironwood	333.33
<i>Populus grandidentata</i>	bigtooth aspen	233.33
<i>Populus tremuloides</i>	quaking aspen	633.33
<i>Prunus pensylvanica</i>	pin cherry	100.00
<i>Prunus serotina</i>	black cherry	713.79
<i>Prunus virginiana</i>	chokecherry	975.86
<i>Quercus alba</i>	white oak	200.00
<i>Quercus ellipsoidalis</i>	northern pin oak	166.67
<i>Quercus macrocarpa</i>	bur oak	200.00
<i>Quercus rubra</i>	northern red oak	1,900.00
Conifer		
<i>Abies balsamea</i>	balsam fir	1,603.45
<i>Picea glauca</i>	white spruce	33.33
<i>Pinus strobus</i>	white pine	366.67
<i>Thuja occidentalis</i>	northern white cedar	33.33
Total		18,640.23

A total of 39 shrub and woody vine species were identified in upland mixed hardwood/conifer forests (Table 7). The two native species of hazel, *Corylus cornuta* and *C. americana*, along with *Amelanchier* sp., were the most frequent tall shrubs, while *Rubus pubescens* and *Vaccinium angustifolium* Aiton (lowbush blueberry) were the most abundant prostrate woody species.

Common herbaceous species in the upland mixed hardwood/conifer forest type were *Maianthemum canadense* Desf. (Canada mayflower), *Carex pensylvanica*, *Trientalis borealis* Raf. (starflower), *Eurybia macrophylla*, *Anemone quinquefolia* L. (wood anemone), *Oryzopsis asperifolia*, and *Pteridium aquilinum* (L.) Kuhn.

Table 7. Frequency of occurrence for shrubs and woody vines in upland mixed hardwood/conifer forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Frequency
<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder	0.057
<i>Amelanchier</i> sp. (Group 2)	serviceberry	0.254
<i>Amelanchier</i> sp. (Group 3)	serviceberry	0.021
<i>Comptonia peregrina</i>	sweet fern	0.014
<i>Cornus alternifolia</i>	alternate-leaf dogwood	0.060
<i>Cornus racemosa</i>	gray dogwood	0.010
<i>Cornus rugosa</i>	round-leaf dogwood	0.005
<i>Cornus sericea</i> ssp. <i>sericea</i>	red-osier dogwood	0.005
<i>Corylus americana</i>	American hazelnut	0.223
<i>Corylus cornuta</i>	beaked hazelnut	0.407
<i>Crataegus</i> sp.	hawthorn	0.012
<i>Diervilla lonicera</i>	northern bush-honeysuckle	0.043
<i>Dirca palustris</i>	eastern leatherwood	0.002
<i>Ilex verticillata</i>	common winterberry	0.079
<i>Lonicera</i> sp. (exotic)	exotic honeysuckle	0.002
<i>Lonicera canadensis</i>	American fly honeysuckle	0.110
<i>Lonicera dioica</i>	glaucous honeysuckle	0.002
<i>Lonicera hirsuta</i>	hairy honeysuckle	0.014
<i>Parthenocissus</i> sp.	Virginia creeper	0.005
<i>Rhamnus cathartica</i>	common buckthorn	0.002
<i>Ribes americanum</i>	wild black currant	0.003
<i>Ribes cynosbati</i>	pasture currant	0.002
<i>Rosa acicularis</i>	prickly rose	0.022
<i>Rosa carolina</i>	Carolina rose	0.002
<i>Rubus allegheniensis</i>	Allegheny blackberry	0.062
<i>Rubus canadensis</i>	smooth blackberry	0.007
<i>Rubus occidentalis</i>	black raspberry	0.002
<i>Rubus pensilvanicus</i>	Pennsylvania blackberry	0.046
<i>Rubus pubescens</i>	dwarf red raspberry	0.107
<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	red raspberry	0.036
<i>Smilax tamnoides</i>	bristly greenbrier	0.007
<i>Spiraea alba</i>	white meadowsweet	0.003
<i>Symphoricarpos albus</i>	snowberry	0.002
<i>Toxicodendron rydbergii</i>	western poison ivy	0.026
<i>Vaccinium angustifolium</i>	lowbush blueberry	0.284
<i>Vaccinium myrtilloides</i>	velvetleaf huckleberry	0.003
<i>Viburnum acerifolium</i>	mapleleaf viburnum	0.003
<i>Viburnum lentago</i>	nannyberry	0.045
<i>Viburnum rafinesqueanum</i>	downy arrowwood	0.070

Mixed Conifer/Red Oak Forest

Four plots were placed in the mixed conifer/red oak forest type. All of these were located on the Namekagon River between the Namekagon Trail and Whispering Pines landings, a stretch of river ranging from 8–34 km (5–21 miles) upstream of the confluence with the St. Croix River. Three tree species had densities greater than 300 individuals/ha: *Quercus rubra* (428/ha), *Populus tremuloides* Michx. (trembling aspen) (394/ha), and *Picea mariana* (Mill.) Britton, Sterns & Poggenb. (black spruce) (314/ha) (Table 8). These three species also exhibited basal areas >2.0 m²/ha. The density-diameter graph of hardwoods in this forest type (Figure 7a) shows successive decreases in *P. tremuloides* density in size classes smaller than 10 cm; in contrast, the densities of *Quercus rubra* and *P. mariana* (Figures 7a, 7b) were high in the smallest size classes. *Pinus resinosa* had the greatest basal area of any species found in this forest type (Table 8), although the seedling density was only 83.3 seedlings/ha (Table 9). Seedling density was high for both *Quercus rubra* (4,667/ha) and *Picea mariana* (1,083/ha) as well as for *Acer rubrum* (4,167/ha) (Table 9).

Table 8. Basal area and density of live trees in mixed conifer/red oak forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood			
<i>Acer rubrum</i>	red maple	1.11	116.67
<i>Betula papyrifera</i>	paper birch	1.20	136.11
<i>Fraxinus pennsylvanica</i>	green ash	<0.01	2.78
<i>Ostrya virginiana</i>	ironwood	<0.01	5.56
<i>Populus grandidentata</i>	bigtooth aspen	0.72	27.78
<i>Populus tremuloides</i>	quaking aspen	3.16	394.44
<i>Prunus serotina</i>	black cherry	<0.01	2.78
<i>Quercus alba</i>	white oak	0.03	8.33
<i>Quercus rubra</i>	northern red oak	4.05	427.78
Conifer			
<i>Larix laricina</i>	tamarack	1.44	94.44
<i>Picea mariana</i>	black spruce	2.02	313.89
<i>Pinus banksiana</i>	jack pine	0.60	30.56
<i>Pinus resinosa</i>	red pine	8.78	133.33
<i>Pinus strobus</i>	white pine	0.43	8.33
<i>Pinus sylvestris</i> *	Scots pine	0.33	2.78
Total		23.89	1,705.56

*non-native species

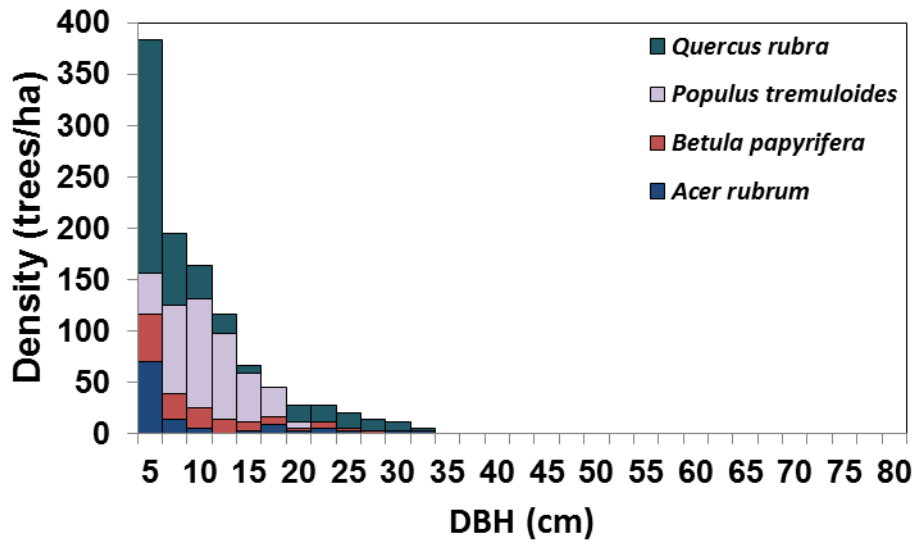


Figure 7a. Density-diameter relationship for the four most important hardwood tree species in mixed conifer/red oak forests at St. Croix National Scenic Riverway, 2013.

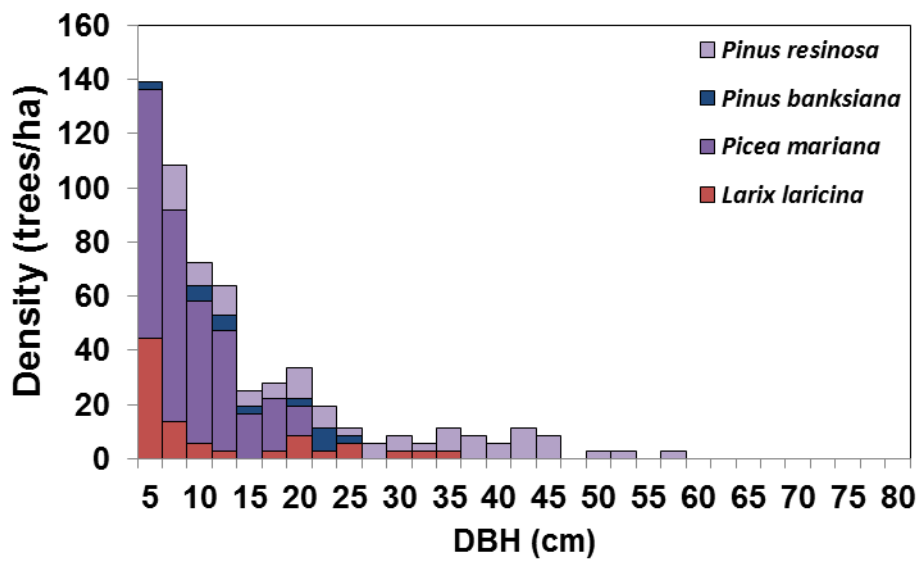


Figure 7b. Density-diameter relationship for the four most important conifer tree species in mixed conifer/red oak forests at St. Croix National Scenic Riverway, 2013.

Table 9. Seedling density in mixed conifer/red oak forests at St. Croix National Scenic Riverway.

Latin name	Common name	Density (seedlings/ha)
Hardwood		
<i>Acer rubrum</i>	red maple	4,166.67
<i>Betula papyrifera</i>	paper birch	833.33
<i>Fraxinus pennsylvanica</i>	green ash	500.00
<i>Ostrya virginiana</i>	ironwood	166.67
<i>Populus grandidentata</i>	bigtooth aspen	250.00
<i>Populus tremuloides</i>	quaking aspen	666.67
<i>Prunus serotina</i>	black cherry	500.00
<i>Prunus virginiana</i>	chokecherry	166.67
<i>Quercus alba</i>	white oak	833.33
<i>Quercus macrocarpa</i>	bur oak	166.67
<i>Quercus rubra</i>	northern red oak	4,666.67
Conifer		
<i>Abies balsamea</i>	balsam fir	83.33
<i>Picea mariana</i>	black spruce	1,083.33
<i>Pinus resinosa</i>	red pine	83.33
<i>Pinus strobus</i>	white pine	166.67
Total		14,333.33

A total of 33 species of shrubs and woody vines were identified in mixed conifer/red oak forest plots. *Corylus americana*, *Rubus allegheniensis* Porter (Allegheny blackberry), *Amelanchier* sp., and *C. cornuta* were the most frequently observed tall shrubs (Table 10), while *Vaccinium angustifolium*, a woody shrub of the groundlayer, was present in nearly three out of every four browse circles.

Common herbaceous species in the mixed conifer/red oak forest type were *Maianthemum canadense*, *Pteridium aquilinum*, *Carex pensylvanica*, *Oryzopsis asperifolia*, *Anemone quinquefolia*, *Eurybia macrophylla*, *Trientalis borealis*, *Galium boreale* L. (northern bedstraw), and *Uvularia sessilifolia* L. (bellflower).

Table 10. Mean frequency of occurrence for shrubs and woody vines in mixed conifer/oak forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Frequency
<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder	0.077
<i>Amelanchier</i> sp. (Group 2)	serviceberry	0.257
<i>Amelanchier</i> sp. (Group 3)	serviceberry	0.015
<i>Chamaedaphne calyculata</i>	leatherleaf	0.048
<i>Comptonia peregrina</i>	sweet fern	0.051
<i>Cornus racemosa</i>	gray dogwood	0.015
<i>Cornus sericea</i> ssp. <i>sericea</i>	red-osier dogwood	0.004
<i>Corylus americana</i>	American hazelnut	0.423
<i>Corylus cornuta</i>	beaked hazelnut	0.224
<i>Crataegus</i> sp.	hawthorn	0.004
<i>Diervilla lonicera</i>	northern bush-honeysuckle	0.051
<i>Ilex mucronata</i>	mountain holly	0.022
<i>Ilex verticillata</i>	common winterberry	0.066
<i>Kalmia polifolia</i>	bog laurel	0.015
<i>Lonicera dioica</i>	glaucous honeysuckle	0.018
<i>Lonicera hirsuta</i>	hairy honeysuckle	0.004
<i>Parthenocissus</i> sp.	Virginia creeper	0.007
<i>Rhamnus alnifolia</i>	alder-leaf buckthorn	0.011
<i>Rhododendron groenlandicum</i>	bog Labrador tea	0.107
<i>Rosa acicularis</i>	prickly rose	0.026
<i>Rosa blanda</i>	smooth rose	0.007
<i>Rosa carolina</i>	Carolina rose	0.037
<i>Rubus allegheniensis</i>	Allegheny blackberry	0.239
<i>Rubus pensilvanicus</i>	Pennsylvania blackberry	0.103
<i>Rubus pubescens</i>	dwarf red raspberry	0.011
<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	red raspberry	0.004
<i>Salix</i> sp.	willow	0.004
<i>Symphoricarpos albus</i>	snowberry	0.004
<i>Toxicodendron rydbergii</i>	western poison ivy	0.004
<i>Vaccinium angustifolium</i>	lowbush blueberry	0.735
<i>Vaccinium myrtilloides</i>	velvetleaf huckleberry	0.037
<i>Vaccinium oxycoccos</i>	small cranberry	0.018
<i>Viburnum rafinesqueanum</i>	downy arrowwood	0.007

Mixed Oak/Aspen

Nine plots were placed in mixed oak/aspen (*Populus* sp. L) forests which were located on the middle Namekagon and the upper St. Croix rivers, and downstream on the St. Croix River to River Mile 82, near the Old Railroad Bridge Landing. These plots supported a large number of species with *Populus tremuloides* and *P. grandidentata* collectively representing 33% of the total stems and 36% of the basal area; *Quercus alba* L. (white oak) was also an important species in mixed oak/aspen forests,

representing 15% of both the stems and basal area (Table 11). These plots supported both *Populus* species and a large number of *Quercus rubra* in the small size classes (Figure 8).

Seedling density was highest for three species in mixed oak/aspen forests: *Acer rubrum*, *Prunus virginiana* L. (chokecherry), and *Quercus rubra* (Table 12).

Table 11. Basal area and density of live trees in mixed oak/aspen forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood			
<i>Acer rubrum</i>	red maple	0.21	64.20
<i>Betula papyrifera</i>	paper birch	0.13	11.11
<i>Carpinus caroliniana</i>	American hornbeam	0.10	65.43
<i>Carya cordiformis</i>	bitternut hickory	0.01	4.94
<i>Crataegus</i> sp.	hawthorn	0.03	12.35
<i>Fraxinus nigra</i>	black ash	0.32	85.19
<i>Fraxinus pennsylvanica</i>	green ash	0.13	46.91
<i>Ostrya virginiana</i>	ironwood	0.24	133.33
<i>Populus grandidentata</i>	bigtooth aspen	2.70	200.00
<i>Populus tremuloides</i>	quaking aspen	2.66	269.75
<i>Prunus serotina</i>	black cherry	0.11	33.33
<i>Prunus virginiana</i>	chokecherry	0.02	9.26
<i>Quercus alba</i>	white oak	2.19	211.73
<i>Quercus ellipsoidalis</i>	northern pin oak	0.25	6.17
<i>Quercus macrocarpa</i>	bur oak	2.67	127.16
<i>Quercus rubra</i>	northern red oak	1.62	105.56
<i>Tilia americana</i>	American basswood	0.78	20.99
<i>Ulmus americana</i>	American elm	0.13	9.88
Conifer			
<i>Picea glauca</i>	white spruce	0.09	2.47
<i>Pinus banksiana</i>	jack pine	0.07	1.23
<i>Pinus resinosa</i>	red pine	0.29	2.47
<i>Pinus strobus</i>	white pine	0.26	2.47
Total		15.00	1,425.93

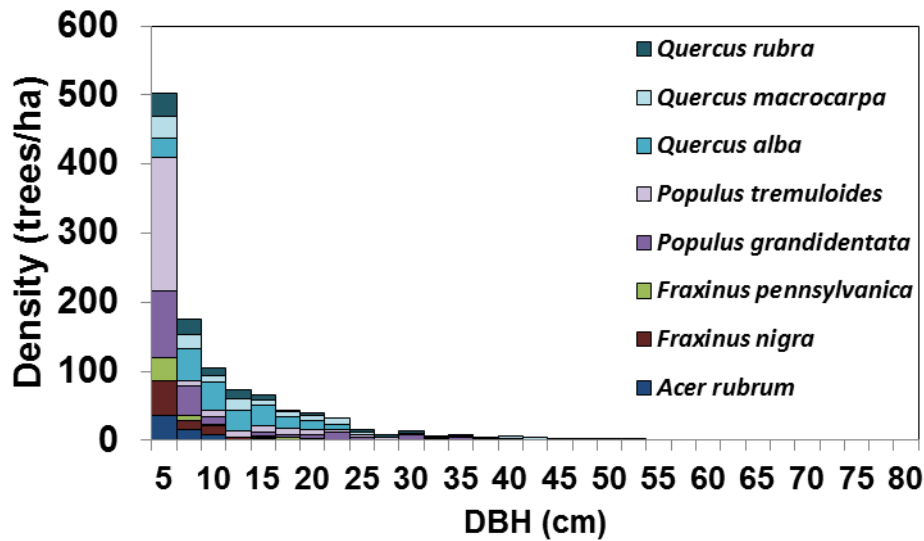


Figure 8. Density-diameter relationship for the eight most important tree species in mixed oak/aspen forests at St. Croix National Scenic Riverway, 2013.

Table 12. Seedling density in mixed oak/aspen forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Density (seedlings/ha)
Hardwood		
<i>Acer rubrum</i>	red maple	3,592.59
<i>Betula papyrifera</i>	paper birch	111.11
<i>Carpinus caroliniana</i>	American hornbeam	1,222.22
<i>Fraxinus nigra</i>	black ash	2,037.04
<i>Fraxinus pennsylvanica</i>	green ash	1,592.59
<i>Ostrya virginiana</i>	ironwood	851.85
<i>Populus grandidentata</i>	bigtooth aspen	888.89
<i>Populus tremuloides</i>	quaking aspen	1,777.78
<i>Prunus serotina</i>	black cherry	1,111.11
<i>Prunus virginiana</i>	chokecherry	3,407.41
<i>Quercus alba</i>	white oak	1,111.11
<i>Quercus macrocarpa</i>	bur oak	1,777.78
<i>Quercus rubra</i>	northern red oak	3,037.04
<i>Tilia americana</i>	American basswood	370.37
<i>Ulmus americana</i>	American elm	148.15
Conifer		
<i>Pinus strobus</i>	white pine	111.11
Total		23,148.15

A total of 44 shrub and woody vine species were recorded in plots within mixed oak/aspen forests with six present in at least 20% of browse circles (Table 13): *Corylus americana* (40.7%), *C. cornuta* (35.5%), *Cornus racemosa* (32.1%), *Viburnum rafinesqueanum* Schult. (downy arrowwood) (25.2%), *Rubus allegheniensis* (26.6%), and *Vaccinium angustifolium* (24%).

Common herbaceous species in mixed oak/aspen dominated forests were *Eurybia macrophylla*, *Carex pensylvanica*, *Oryzopsis asperifolia*, *Pteridium aquilinum*, *Maianthemum canadense*, *Geranium maculatum*, and *Thalictrum dioicum* L. (early meadowrue).

Table 13. Mean frequency of occurrence for shrubs and woody vines in mixed oak/aspen forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Frequency
<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder	0.022
<i>Amelanchier</i> sp. (Group 2)	serviceberry	0.162
<i>Amelanchier</i> sp. (Group 3)	serviceberry	0.084
<i>Comptonia peregrina</i>	sweet fern	0.002
<i>Cornus alternifolia</i>	alternate-leaf dogwood	0.017
<i>Cornus racemosa</i>	gray dogwood	0.321
<i>Cornus rugosa</i>	round-leaf dogwood	0.002
<i>Cornus sericea</i> ssp. <i>sericea</i>	red-osier dogwood	0.002
<i>Corylus americana</i>	American hazelnut	0.407
<i>Corylus cornuta</i>	beaked hazelnut	0.355
<i>Crataegus</i> sp.	hawthorn	0.034
<i>Diervilla lonicera</i>	northern bush-honeysuckle	0.074
<i>Gaylussacia baccata</i>	black huckleberry	0.002
<i>Ilex mucronata</i>	mountain holly	0.002
<i>Ilex verticillata</i>	common winterberry	0.066
<i>Lonicera canadensis</i>	American fly honeysuckle	0.021
<i>Lonicera dioica</i>	glaucous honeysuckle	0.033
<i>Lonicera hirsuta</i>	hairy honeysuckle	0.031
<i>Lonicera</i> sp. (exotic)	exotic honeysuckle	0.003
<i>Lonicera</i> sp. (native)	honeysuckle	0.002
<i>Parthenocissus</i> sp.	Virginia creeper	0.053
<i>Rhamnus cathartica</i>	common buckthorn	0.002
<i>Ribes americanum</i>	wild black currant	0.002
<i>Ribes hirtellum</i>	hairy stem gooseberry	0.033
<i>Rosa acicularis</i>	prickly rose	0.045
<i>Rosa blanda</i>	smooth rose	0.005
<i>Rosa carolina</i>	Carolina rose	0.016
<i>Rubus allegheniensis</i>	Allegheny blackberry	0.266
<i>Rubus pensilvanicus</i>	Pennsylvania blackberry	0.034
<i>Rubus pubescens</i>	dwarf red raspberry	0.128
<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	red raspberry	0.109

Table 13. Mean frequency of occurrence for shrubs and woody vines in mixed oak/aspen forests at St. Croix National Scenic Riverway, 2013 (continued).

Latin name	Common name	Frequency
<i>Salix discolor</i>	pussy willow	0.002
<i>Salix</i> sp.	willow	0.003
<i>Smilax</i> sp.	greenbrier	0.002
<i>Smilax tamnoides</i>	bristly greenbrier	0.029
<i>Spiraea alba</i>	white meadowsweet	0.009
<i>Symphoricarpos albus</i>	snowberry	0.055
<i>Toxicodendron rydbergii</i>	western poison ivy	0.138
<i>Vaccinium angustifolium</i>	lowbush blueberry	0.240
<i>Vaccinium myrtilloides</i>	velvetleaf huckleberry	0.016
<i>Viburnum lentago</i>	nannyberry	0.055
<i>Viburnum rafinesqueanum</i>	downy arrowwood	0.252
<i>Vitis riparia</i>	riverbank grape	0.002
<i>Zanthoxylum americanum</i>	common prickly ash	0.116

Black Ash/Mixed Hardwood

A total of 16 plots were classified as black ash/mixed hardwood forests. One was located on the Namekagon River just upstream from the confluence with the St. Croix, and the other 15 were evenly distributed along the St. Croix River from near the confluence at Gordon Dam, downstream to St. Croix Falls. *Fraxinus nigra* represented 48% of the total stems in the forest type and 46% of the basal area (Table 14, Figure 9a). *Tilia americana* was the next most important tree, with 9% of the total stems and 17% of the basal area. A small amount of conifers were also present in this forest type, with *Abies balsamea* representing 55% of the conifer density (Figure 9b).

Table 14. Basal area and density of live trees in black ash/mixed hardwood forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood			
<i>Acer negundo</i>	western boxelder	0.04	2.78
<i>Acer rubrum</i>	red maple	0.62	97.92
<i>Acer saccharinum</i>	silver maple	0.59	2.78
<i>Acer saccharum</i>	sugar maple	1.05	52.78
<i>Acer spicatum</i>	mountain maple	0.03	2.78
<i>Betula alleghaniensis</i>	yellow birch	0.77	70.14
<i>Betula papyrifera</i>	paper birch	0.09	7.64
<i>Carpinus caroliniana</i>	American hornbeam	0.18	147.92
<i>Carya cordiformis</i>	bitternut hickory	0.06	18.75
<i>Celtis occidentalis</i>	northern hackberry	0.01	1.39
<i>Crataegus</i> sp.	hawthorn	<0.01	2.78
<i>Fraxinus nigra</i>	black ash	12.64	1,083.33
<i>Fraxinus pennsylvanica</i>	green ash	0.01	2.78
<i>Ostrya virginiana</i>	ironwood	0.44	131.25
<i>Populus balsamifera</i>	balsam poplar	0.05	11.81
<i>Populus grandidentata</i>	bigtooth aspen	0.01	0.69
<i>Populus tremuloides</i>	quaking aspen	0.43	13.19
<i>Prunus serotina</i>	black cherry	<0.00	1.39
<i>Prunus virginiana</i>	chokecherry	0.01	7.64
<i>Quercus alba</i>	white oak	0.72	18.06
<i>Quercus ellipsoidalis</i>	northern pin oak	0.13	1.39
<i>Quercus macrocarpa</i>	bur oak	1.30	36.11
<i>Quercus rubra</i>	northern red oak	0.17	18.75
<i>Tilia americana</i>	American basswood	4.53	209.72
<i>Ulmus americana</i>	American elm	0.64	95.14
<i>Ulmus rubra</i>	slippery elm	0.08	15.97
Conifer			
<i>Abies balsamea</i>	balsam fir	0.42	122.92
<i>Picea glauca</i>	white spruce	0.61	18.75
<i>Picea mariana</i>	black spruce	0.37	32.64
<i>Thuja occidentalis</i>	northern white cedar	1.38	50.00
Total		27.38	2,279.17

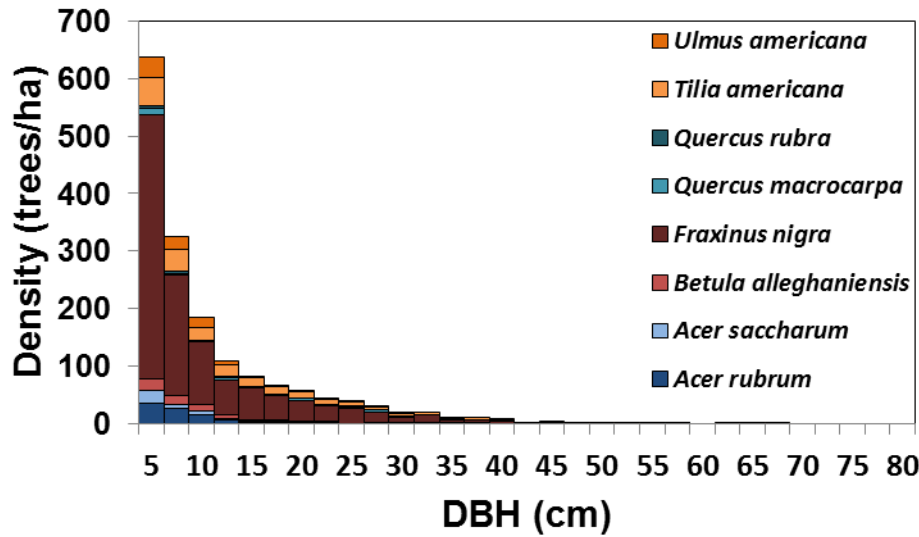


Figure 9a. Density-diameter relationship for the eight most important hardwood species in black ash/mixed hardwood forests at St. Croix National Scenic Riverway, 2013.

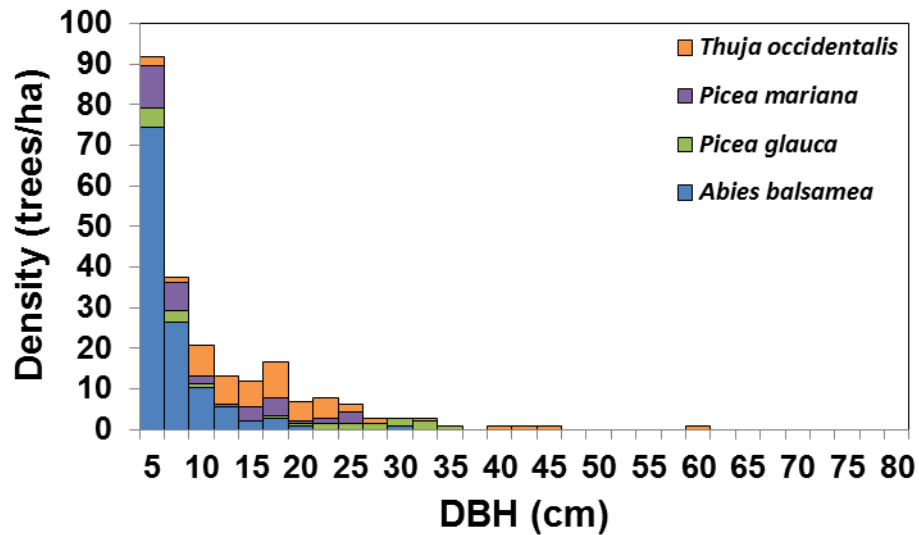


Figure 9b. Density-diameter relationship for the four most important conifer species in black ash/mixed hardwood forests at St. Croix National Scenic Riverway, 2013.

Fraxinus nigra was the most abundant species among seedlings with 46% of the total; *Carpinus caroliniana* Walter (American hornbeam) was the second most abundant with 9% of the total (Table 15).

Table 15. Seedling density in black ash/mixed hardwood forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Density (seedlings/ha)
Hardwood		
<i>Acer rubrum</i>	red maple	1,637.82
<i>Acer saccharinum</i>	silver maple	62.50
<i>Acer saccharum</i>	sugar maple	270.83
<i>Acer spicatum</i>	mountain maple	375.00
<i>Betula alleghaniensis</i>	yellow birch	208.33
<i>Betula papyrifera</i>	paper birch	41.67
<i>Carpinus caroliniana</i>	American hornbeam	2,145.83
<i>Carya cordiformis</i>	bitternut hickory	104.17
<i>Fraxinus nigra</i>	black ash	10,652.24
<i>Fraxinus pennsylvanica</i>	green ash	854.17
<i>Ostrya virginiana</i>	ironwood	1,208.33
<i>Populus balsamifera</i>	balsam poplar	41.67
<i>Populus tremuloides</i>	quaking aspen	187.50
<i>Prunus serotina</i>	black cherry	104.17
<i>Prunus virginiana</i>	chokecherry	1,383.01
<i>Quercus alba</i>	white oak	166.67
<i>Quercus macrocarpa</i>	bur oak	556.09
<i>Quercus rubra</i>	northern red oak	395.83
<i>Tilia americana</i>	American basswood	464.74
<i>Ulmus americana</i>	American elm	1,833.33
<i>Ulmus rubra</i>	slippery elm	83.33
Conifer		
<i>Abies balsamea</i>	balsam fir	274.04
<i>Picea glauca</i>	white spruce	62.50
<i>Picea mariana</i>	black spruce	20.83
<i>Thuja occidentalis</i>	northern white cedar	41.67
Total		23,176.28

Black ash/mixed hardwood forests supported the most shrub and woody vine species, with 50 species recorded in plots within this forest type. *Corylus cornuta*, *Alnus incana* ssp. *rugosa* (Du Roi) R.T. Clausen (speckled alder), and *Ilex verticillata* (L.) A. Gray (winterberry) were all present in at least 14% of browse circles. Other common tall shrubs included *Zanthoxylum americanum* Mill. (prickly ash) (11.9%) and *Rubus sachalinensis* var. *sachalinensis* H. Lév. (10.3%) (Table 16). Common prostrate shrubs included *Toxicodendron rydbergii* (Small ex Rydb.) Greene, *Rubus pubescens*, and *Parthenocissus* sp. (Table 16).

Table 16. Mean frequency of occurrence for shrubs and woody vines in black ash/mixed hardwood forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Frequency
<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder	0.142
<i>Amelanchier</i> sp. (Group 2)	serviceberry	0.043
<i>Amelanchier</i> sp. (Group 3)	serviceberry	0.001
<i>Aronia X prunifolia</i>	purple chokeberry	0.001
<i>Celastrus</i> sp.	bittersweet	0.002
<i>Cornus alternifolia</i>	alternate-leaf dogwood	0.005
<i>Cornus racemosa</i>	gray dogwood	0.102
<i>Cornus rugosa</i>	round-leaf dogwood	0.001
<i>Cornus sericea</i> ssp. <i>sericea</i>	red-osier dogwood	0.031
<i>Cornus</i> sp.	dogwood	0.001
<i>Corylus americana</i>	American hazelnut	0.042
<i>Corylus cornuta</i>	beaked hazelnut	0.146
<i>Crataegus</i> sp.	hawthorn	0.016
<i>Diervilla lonicera</i>	northern bush-honeysuckle	0.002
<i>Dirca palustris</i>	eastern leatherwood	0.001
<i>Euonymus atropurpureus</i>	burning bush	0.001
<i>Humulus lupulus</i>	hops	0.001
<i>Ilex verticillata</i>	common winterberry	0.151
<i>Lonicera canadensis</i>	American fly honeysuckle	0.004
<i>Lonicera dioica</i>	glaucous honeysuckle	0.004
<i>Lonicera hirsuta</i>	hairy honeysuckle	0.004
<i>Lonicera oblongifolia</i>	swamp fly honeysuckle	0.007
<i>Parthenocissus quinquefolia</i>	Virginia creeper	0.001
<i>Parthenocissus</i> sp.	Virginia creeper	0.217
<i>Rhamnus alnifolia</i>	alder-leaf buckthorn	0.041
<i>Rhamnus cathartica</i>	common buckthorn	0.064
<i>Rhus typhina</i>	staghorn sumac	0.002
<i>Ribes americanum</i>	wild black currant	0.022
<i>Ribes cynosbati</i>	pasture currant	0.037
<i>Ribes hirtellum</i>	hairy stem gooseberry	0.081
<i>Ribes hudsonianum</i>	northern black currant	0.007
<i>Ribes triste</i>	swamp red currant	0.016
<i>Rosa acicularis</i>	prickly rose	0.003
<i>Rosa</i> sp.	rose	0.001
<i>Rubus allegheniensis</i>	Allegheny blackberry	0.004
<i>Rubus occidentalis</i>	black raspberry	0.024
<i>Rubus pubescens</i>	dwarf red raspberry	0.431
<i>Rubus sachalinensis</i> var. <i>sachalinensis</i>	red raspberry	0.103

Table 16. Mean frequency of occurrence for shrubs and woody vines in black ash/mixed hardwood forests at St. Croix National Scenic Riverway, 2013 (continued).

Latin name	Common name	Frequency
<i>Salix</i> sp.	willow	0.011
<i>Smilax tamnoides</i>	bristly greenbrier	0.044
<i>Solanum dulcamara</i>	woody nightshade	0.003
<i>Spiraea alba</i>	white meadowsweet	0.006
<i>Toxicodendron rydbergii</i>	western poison ivy	0.117
<i>Vaccinium angustifolium</i>	lowbush blueberry	0.023
<i>Vaccinium myrtilloides</i>	velvetleaf huckleberry	0.001
<i>Viburnum acerifolium</i>	mapleleaf viburnum	0.004
<i>Viburnum lentago</i>	nannyberry	0.046
<i>Viburnum opulus</i> var. <i>americanum</i>	American cranberrybush	0.001
<i>Viburnum rafinesqueanum</i>	downy arrowwood	0.037
<i>Vitis riparia</i>	riverbank grape	0.005
<i>Zanthoxylum americanum</i>	common prickly ash	0.119

Common herbaceous taxa in the black ash dominated mixed hardwood forests were *Viola* sp., *Maianthemum canadense*, *Carex* sp., *Athyrium filix-femina* var. *angustum*, *Geranium maculatum*, and *Mitella diphylla* L. (twoleaf miterwort).

Silver Maple Lowland

Four plots were classified as silver maple lowland. All were along the St. Croix River, with three located within 23 km (14 mi) downstream from Danbury, Wisconsin, and one located 8 km (5 mi) upstream from Marine-on-St. Croix, Minnesota. This forest type had the lowest tree density of all six forest types. The three most abundant tree taxa were *Fraxinus nigra* (402.78 trees/ha), *Acer saccharinum* (355.56 trees/ha), and *Ulmus* sp. L. (52.78 trees/ha), representing 96% of the total of 847.22 trees/ha (Table 17). Both *F. nigra* and *A. saccharinum* displayed the highest densities in the smallest size classes, indicating that regeneration is occurring (Figure 10).

Seedlings of only five tree species were located in silver maple lowland plots (Table 18). Of these five species, seedlings of *Fraxinus nigra*, *Acer saccharinum*, and *Ulmus americana* represented 94% of the total density of 4,166.67 seedlings/ha.

Table 17. Basal area and density of live trees in silver maple lowland forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Basal area (m ² /ha)	Density (trees/ha)
Hardwood			
<i>Acer saccharinum</i>	silver maple	20.82	355.56
<i>Carpinus caroliniana</i>	American hornbeam	0.01	2.78
<i>Celtis occidentalis</i>	northern hackberry	0.46	16.67
<i>Fraxinus americana</i>	white ash	0.05	2.78
<i>Fraxinus nigra</i>	black ash	5.07	402.78
<i>Quercus macrocarpa</i>	bur oak	2.01	11.11
<i>Tilia americana</i>	American basswood	0.06	2.78
<i>Ulmus americana</i>	American elm	0.38	47.22
<i>Ulmus rubra</i>	slippery elm	0.02	5.56
Total		28.88	847.22

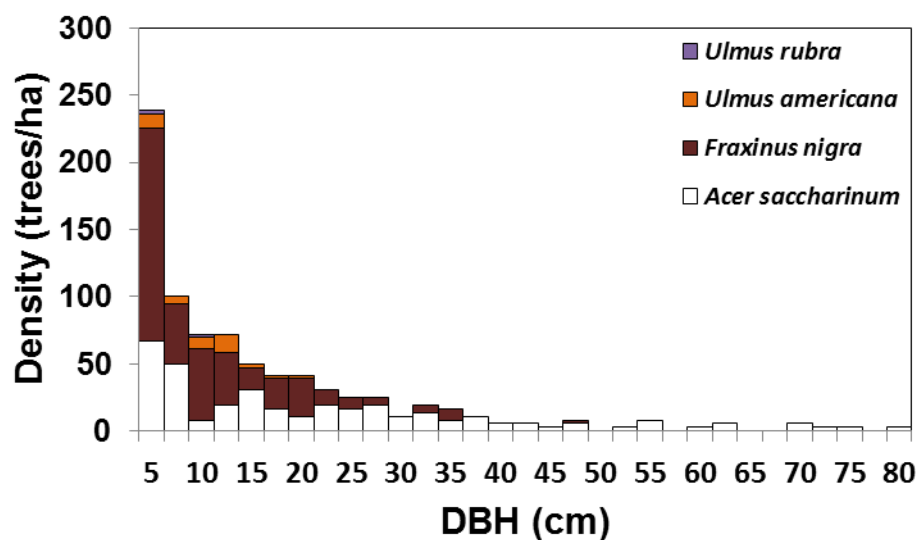


Figure 10. Density-diameter relationship for the four most important tree species in silver maple lowland forests at St. Croix National Scenic Riverway, 2013.

Table 18. Seedling density in silver maple lowland forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Density (seedlings/ha)
Hardwood		
<i>Acer saccharinum</i>	silver maple	1,666.67
<i>Fraxinus americana</i>	white ash	166.67
<i>Fraxinus nigra</i>	black ash	1,833.33
<i>Quercus macrocarpa</i>	bur oak	83.33
<i>Ulmus americana</i>	American elm	416.67
Total		4,166.67

Only 16 shrub and woody vine species were located in silver maple lowland forests, with *Ilex verticillata* being the most frequently observed (Table 19).

Common herbaceous taxa in the silver maple dominated lowland forests were *Laportea canadensis*, *Carex lacustris* L. (lakebank sedge), *Elymus virginicus* L. (Virginia wildrye), *Calamagrostis canadensis* (Michx.) P. Beauv. (bluejoint), *Onoclea sensibilis* L. (sensitive fern), and *Symphytotrichum lateriflorum* (L.) Á. Löve & D. Löve (calico aster).

Table 19. Mean frequency of occurrence for shrubs and woody vines in silver maple lowland forests at St. Croix National Scenic Riverway, 2013.

Latin name	Common name	Frequency
<i>Alnus incana</i> ssp. <i>rugosa</i>	speckled alder	0.022
<i>Cornus sericea</i> ssp. <i>sericea</i>	red-osier dogwood	0.004
<i>Corylus americana</i>	American hazelnut	0.037
<i>Crataegus</i> sp.	hawthorn	0.004
<i>Ilex verticillata</i>	common winterberry	0.107
<i>Menispermum canadense</i>	common moonseed	0.037
<i>Parthenocissus</i> sp.	Virginia creeper	0.037
<i>Rhamnus cathartica</i>	common buckthorn	0.004
<i>Ribes americanum</i>	wild black currant	0.019
<i>Rubus pensilvanicus</i>	Pennsylvania blackberry	0.007
<i>Rubus pubescens</i>	dwarf red raspberry	0.074
<i>Smilax tamnoides</i>	bristly greenbrier	0.063
<i>Spiraea alba</i>	white meadowsweet	0.019
<i>Staphylea trifolia</i>	American bladdernut	0.019
<i>Viburnum lentago</i>	nannyberry	0.004
<i>Zanthoxylum americanum</i>	common prickly ash	0.033

Coarse Woody Material and Standing Dead Trees

The amount of coarse woody material varied greatly between forest types, with sugar maple forests having the greatest volume (63.03 m³/ha) and biomass (20,884.78) (Table 20). Mixed conifer/red oak forests had the least volume (12.37 m³/ha) and biomass (3,401.44 kg/ha). Sugar maple forests also had the greatest number of large (≥ 33 cm diameter) pieces, with 23.70 pieces/ha (Table 21). Silver maple lowland forests supported the highest total density (685 pieces/ha), with most of those downed logs being in the smallest size class (Table 21). Two forest types—sugar maple and mixed oak/aspen—supported at least 10 snags/ha that were ≥ 30 cm DBH (Table 22). There were no large snags located in mixed conifer/red oak forests.

Table 20. Coarse woody material volume and biomass for each forest type at St. Croix National Scenic Riverway, 2013.

Forest type	Number of plots in forest type	Volume (m ³ /ha)	Biomass (kg/ha)	Biomass (tons/ac)
Sugar maple	7	63.03	20,884.78	9.32
Upland mixed hardwood/conifer	10	34.64	9,953.29	4.44
Mixed conifer/red oak	4	12.37	3,401.44	5.43
Mixed oak/aspen	9	31.77	9,967.02	4.45
Black ash/mixed hardwood	16	41.20	12,161.57	1.52
Silver maple lowland	4	47.11	13,274.93	5.92
Mean		38.02	11,498.75	5.13

Table 21. Density of coarse woody material by diameter class in each forest type at St. Croix National Scenic Riverway, 2013.

Forest type	Density (pieces/ha) for each diameter class (cm)				Total pieces/ha
	7.5-19.9	20.0-32.9	33.0-45.9	>46.0	
Sugar maple	261	74	20	3	358
Upland mixed hardwood/conifer	266	75	2	0	343
Mixed conifer/red oak	136	20	0	0	156
Mixed oak/aspen	414	77	14	0	505
Black ash/mixed hardwood	316	71	15	1	403
Silver maple lowland	569	109	3	4	685
Mean	311	70	10	1	392

Table 22. Density of standing dead trees ≥ 30 cm DBH in each forest type at St. Croix National Scenic Riverway, 2013.

Forest type	Density (trees/ha)
Sugar maple	14.30
Upland mixed hardwood/conifer	8.88
Mixed conifer/red oak	0
Mixed oak/aspen	18.48
Black ash/mixed hardwood	6.21
Silver maple lowland	2.78
Mean	8.89

Browse and Disease

Browse pressure was observed in all forest types at SACN in 2013. Across the whole park, the proportion of browse was moderate, with 13.8% of the woody species assessed for bite marks in the direct browse circles showing recent browse by deer (Table 23). This varied widely between forest types from a low of 1.6% in silver maple lowland plots to a high of 25.6% in plots in upland mixed hardwood/conifer forests.

The species with the highest relative incidence of browse, across all forest types, were *Amelanchier* sp., *Cornus racemosa*, *Cornus* sp., *Corylus americana*, *Corylus cornuta*, *Pinus resinosa*, and *Populus grandidentata*.

Table 23. Proportion of species browsed in the 3.14 m² (1 m radius) circles.

Forest type	Number of plots	Proportion of browse
Sugar maple	7	0.1073
Upland mixed hardwood/conifer	10	0.2556
Mixed conifer/red oak	4	0.1793
Mixed oak/aspen	9	0.2091
Black ash/mixed hardwood	16	0.0375
Silver maple lowland	4	0.0163
Whole park	50	0.1381

Deer browse was not regularly observed on our three target herbaceous taxa in 2013, although these taxa were not commonly located in plots and quadrats. Of the 133 taxa-quadrat combinations where indicator species were present, browse was only observed 19 times (Table 24).

Although direct evidence of browse on herbaceous species was only infrequently observed, our primary concern with browse impacts on herbs is how it affects their size and abundance. Over time,

we will use the indirect browse data to assess long-term impacts on herbs by testing for changes in both frequency and height.

Table 24. Summary of indirect browse (plant presence and height) on three target herbaceous taxa at St. Croix National Scenic Riverway, 2013. No indirect browse indicators were observed in silver maple lowland plots.

Forest type	Taxon	Number of quadrats where present	Mean maximum height per quadrat (cm)	Number of quadrats with browse
Sugar maple	<i>Streptopus</i> sp.	2	8.0	0
	<i>Trillium</i> sp.	3	23.0	0
Upland mixed hardwood/conifer	<i>Maianthemum racemosum</i>	5	32.6	1
	<i>Streptopus</i> sp.	10	17.2	0
	<i>Trillium</i> sp.	6	27.1	0
Mixed conifer/red oak	<i>Maianthemum racemosum</i>	14	24.2	2
	<i>Streptopus</i> sp.	4	12.5	0
Mixed oak/aspen	<i>Maianthemum racemosum</i>	5	29.8	3
	<i>Streptopus</i> sp.	10	15.7	1
	<i>Trillium</i> sp.	5	11.5	1
Black ash/mixed hardwood	<i>Maianthemum racemosum</i>	6	19.0	1
	<i>Streptopus</i> sp.	44	16.3	4
	<i>Trillium</i> sp.	19	17.5	6

A number of trees measured in our plots presented evidence of a pest, pathogen, or damage (Table 25). The most common indicators noted at SACN were discolored foliage, epicormic sprouts, and dieback; a total of 6.49% of all trees sampled along our transects had at least one indicator present. In general, with the exception of *Fraxinus nigra*, only a few trees of each species in each forest type displayed any evidence of a pest, pathogen, or damage; thus, it is probable that this low level of damage was caused by native pests and pathogens and/or expected physical stressors such as wind and localized tree fall.

Ash trees (*Fraxinus* sp.) are of special concern due to the outbreak of emerald ash borer (EAB). Across all forest types, 145 of 1,885 (7.69%) *F. nigra* trees measured and 4 of the 47 (8.51%) *F. pennsylvanica* Marsh. (green ash) trees showed signs of damage or disease (Tables 26a, 26b). No D-shaped exit holes, the diagnostic indicator for EAB, were observed; other symptoms observed affecting ash trees were dieback, discolored and/or wilted foliage, and epicormic sprouting. These other indicators, while characteristic of EAB presence, are also indicative of a number of other diseases and disease complexes (for example, ash yellows; see Palik et al. 2011 for more examples) impacting ash.

Table 25. The number of trees in each of the five forest types at SACN with any sign or symptom of a pest, pathogen, or damage in 2013.

Forest type	Total number of live trees	Total number of trees with indicator	Percentage of trees with indicator
Sugar maple	674	47	6.97
Upland mixed hardwood/conifer	1153	87	7.54
Mixed conifer/red oak	419	21	5.01
Mixed oak/aspen	1,074	69	6.42
Black ash/mixed hardwood	3,147	177	5.62
Silver maple lowland	293	38	12.97
Whole park	6,760	439	6.49

Table 26a. Pest/pathogen signs and symptoms observed on living *Fraxinus nigra* in five forest types at St. Croix National Scenic Riverway, 2013. No *F. nigra* were recorded in mixed conifer/red oak plots.

Forest type	Number of black ash trees in forest type	Indicator on ash trees	Number of ash trees with indicator
Sugar maple	43	Abnormal foliage (foliage/twigs distorted or with galls)	1
		Dieback (>10% but not pervasive)	1
		Disease signs (cankers)	1
		Epicormic sprouts	5
Upland mixed hardwood/conifer	72	Dieback (>10% but not pervasive)	7
		Dieback (pervasive throughout crown)	5
Mixed oak/aspen	65	Epicormic sprouts	3
Black ash/mixed hardwood	1,560	Dieback (>10% but not pervasive)	25
		Dieback (pervasive throughout crown)	12
		Discolored foliage (black coating)	2
		Discolored foliage (mottling, spots, or blotches)	9
		Disease signs (cankers)	2
		Disease signs (woody galls or burls)	1
		Broken branches	8
		Epicormic sprouts	32
		Foliage affected (>10% but less than 30%)	1
		Insect signs, branches and bole (shot holes (<2mm))	1
		Loose bark	1
Silver maple lowland forest	145	Defoliation (>10% but not pervasive)	2
		Dieback (>10% but not pervasive)	17
		Dieback (pervasive throughout crown)	2
		Discolored foliage (interveinal scorching of leaves)	1
		Discolored foliage (mottling, spots, or blotches)	3
		Foliage affected, general (>10% but less than 30%)	1
		Foliage affected, general (>30% but not the whole crown)	2

Table 26b. Pest/pathogen signs and symptoms observed on living *Fraxinus pennsylvanica* at St. Croix National Scenic Riverway, 2013. *Fraxinus pennsylvanica* were only recorded in the two forest types shown here.

Forest type	Number of green ash trees in forest type	Indicator on ash trees	Number of ash trees with indicator
Sugar maple	9	Dieback (pervasive throughout crown)	1
Mixed oak/aspen	38	Discolored foliage (mottling, spots, or blotches)	2
		Epicormic sprouts	1

Community Indices

A total of 405 species were located in the 50 plots, with a park-wide mean of 77.12 taxa per plot. Across all forest types, the majority of taxa were perennial and native (Table 27). Park-wide, herbaceous species (forbs and graminoids) represented 61% of the total and, within the pollination group, 64% of species were biotically pollinated.

Table 27. Mean plot species richness within classes of each functional group for all six forest types at St. Croix National Scenic Riverway, 2013.

Functional group	Class	Forest type					
		Sugar maple	Upland mixed	Mixed conifer/red oak	Mixed oak/aspen	Black ash mixed	Silver maple lowland
Life history	annual	4.14	1.00	2.25	2.33	4.75	4.75
	biennial	0.29	0.50	--	0.22	0.38	0.25
	perennial	76.86	64.70	71.25	67.67	88.62	44.75
Growth form	forb	45.85	29.00	37.25	30.78	50.75	27.50
	graminoid	6.86	6.60	6.00	6.11	11.50	8.50
	woody	28.58	30.60	30.25	33.33	31.25	13.75
Pollination	abiotic	22.00	21.40	20.25	19.78	27.31	17.25
	biotic	52.71	39.50	49.75	47.78	59.00	29.50
	N/A	6.58	5.30	3.50	2.67	7.44	3.00
Nativity	native	78.57	63.90	70.75	68.00	90.43	47.00
	non-native	1.43	1.20	1.00	1.33	1.44	1.25
	native/non-native	1.29	1.10	1.75	0.89	1.88	1.50

Twelve taxa that are considered problem invasives were located in plots at SACN (Table 28). Of these 12 taxa, six were forbs and were encountered infrequently. Three of the 12 taxa were grasses and included *Phalaris arundinacea*, which was located in five plots. Two invasive shrub taxa were located, including *Rhamnus cathartica*, which was located in 13 plots. One invasive woody vine was also found.

Table 28. Problem invasive plants located in monitoring plots.

Growth form and Latin name	Common name	Number of plots where located
Forb		
<i>Pastinaca sativa</i>	wild parsnip	1
<i>Hieracium aurantiacum</i>	orange hawkweed	2
<i>Glechoma hederacea</i>	ground ivy	2
<i>Rumex acetosella</i>	sheep sorrel	1
<i>Rumex crispus</i>	curly dock	2
<i>Lysimachia nummularia</i>	moneywort	1
Grass		
<i>Phalaris arundinacea</i>	reed canarygrass	5
<i>Poa compressa</i>	Canada bluegrass	7
<i>Poa pratensis</i>	Kentucky bluegrass	3
Shrub		
<i>Lonicera</i> sp. (exotic)	honeysuckles	3
<i>Rhamnus cathartica</i>	common buckthorn	13
Woody vine		
<i>Solanum dulcamara</i>	climbing nightshade	1

Modified floristic quality index values ranged from 4.5 (mixed oak/aspen forests) to 5.12 (mixed conifer/red oak forests) (Figure 11, top). The park-wide mean, all forest types, was 4.77. Mean plot species richness ranged from 45.75 in silver maple lowland plots to 93.75 in black ash mixed forests (Figure 11, bottom).

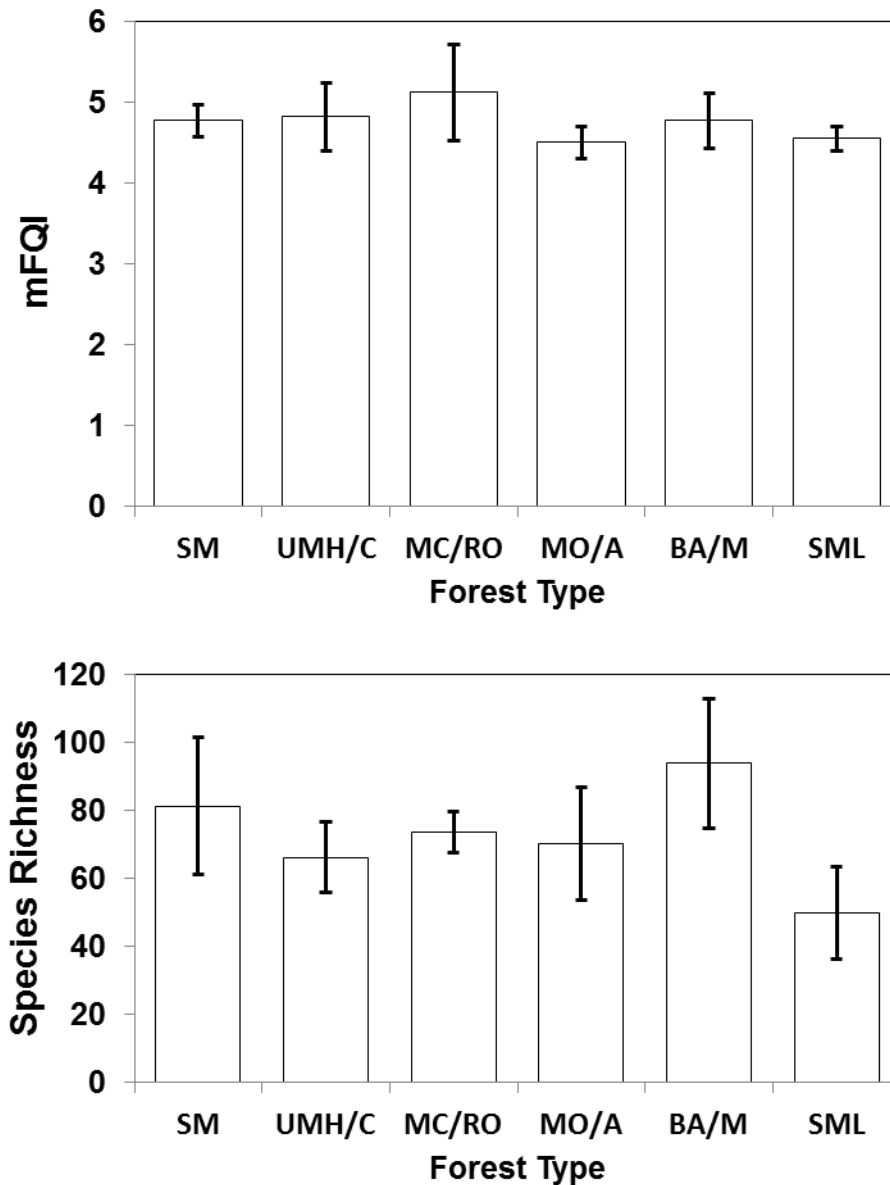


Figure 11. Modified floristic quality index (mFQI) values (top) and mean species richness (bottom) for the six forest types at St. Croix National Scenic Riverway, 2013. Error bars represent two standard deviations from the mean. Forest type codes are SM: sugar maple, UMH/C: upland mixed hardwood/conifer, MC/RO: mixed conifer/red oak, MO/A: mixed oak/aspen, BA/M: black ash/mixed hardwood, and SML: silver maple lowland.

Earthworm Assessments

We collected 151 earthworm assessment samples from plots in 2013 (Table 29). (Three plots were not assessed for earthworms due to time constraints, and three plots did not have the full complement of four replicate samples.) No evidence of earthworms was detected in a large percentage of the samples (86.1%), while several others (4.6%) were shown to be only minimally invaded. Fourteen samples (9.3%) were classified as either moderately or substantially invaded, with eight of these 14 in sugar maple forests.

Table 29. Earthworm assessment rankings by forest type and park-wide at St. Croix National Scenic Riverway, 2013.

Forest type	Total samples	Number of samples that are:				
		<i>Earthworm free</i>	<i>Minimally invaded</i>	<i>Moderately invaded</i>	<i>Substantially invaded</i>	<i>Heavily invaded</i>
Sugar maple	24	14	2	3	5	0
Upland mixed hardwood/conifer	27	23	2	1	1	0
Mixed conifer/red oak	16	16	0	0	0	0
Mixed oak/aspen	33	30	1	2	0	0
Black ash/mixed hardwood	39	35	2	2	0	0
Silver maple lowland	12	12	0	0	0	0
Whole park	151	130	7	8	6	0

Forest Change, 2007–2013

All 35 plots initially sampled in 2007 were resampled in 2013 (Table 30). In sugar maple forests, there was little change in either density (Figure 12a) or basal area (Figure 12b) of living trees between years. Density of standing dead trees decreased from 138 trees/ha to 125 trees/ha (Figure 12c), while the basal area of standing dead trees increased from 2.5 m²/ha in 2007 to 3.2 m²/ha in 2013 (Figure 12d).

Table 30. The number of plots sampled in each of the six forest types at SACN in 2013, and the number that represent a resample of those plots first visited in 2007.

Forest type	Total plots sampled	Number of resampled plots
Sugar maple	7	5
Upland mixed hardwood/conifer	10	9
Mixed conifer/red oak	4	3
Mixed oak/aspen	9	6
Black ash/mixed hardwood	16	10
Silver maple lowland	4	2

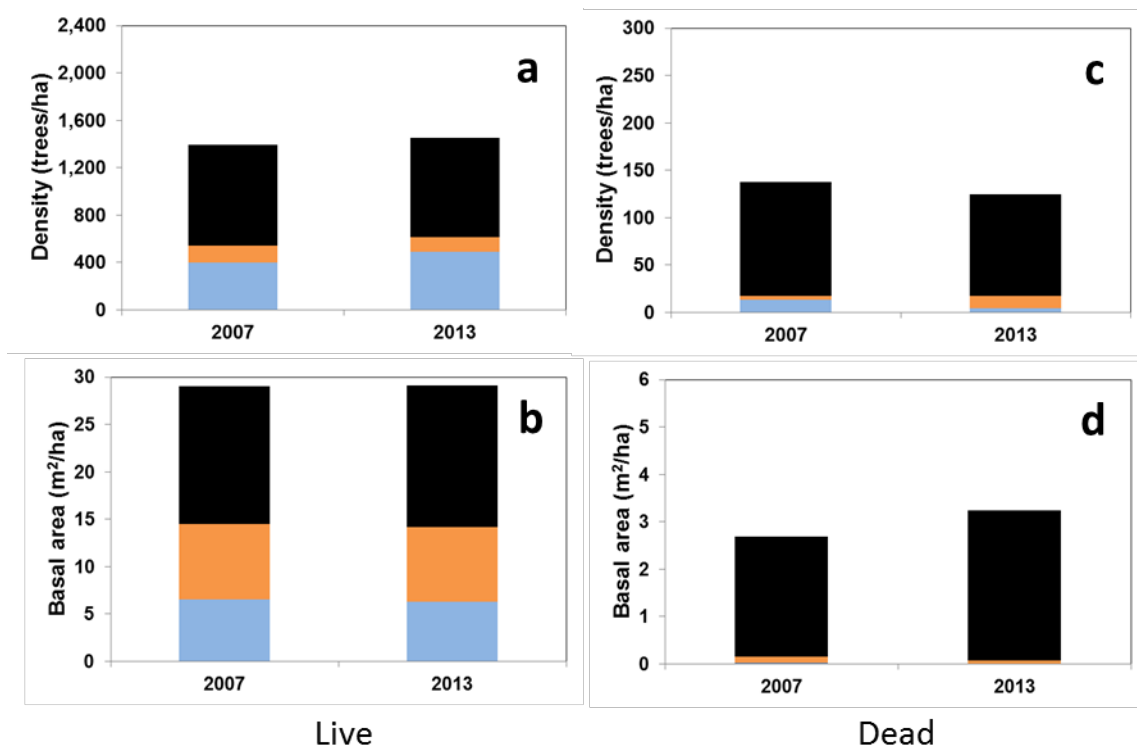


Figure 12. Density and basal area of live (panels a and b) and standing dead (panels c and d) trees in sugar maple forests at St. Croix National Scenic Riverway in 2007 and 2013. Light blue (■) represents *Acer saccharum*, orange (■) represents *Tilia americana*, and black (■) represents all other species.

In upland mixed hardwood/conifer forests, *Acer rubrum* increased during the six-year time interval. Density of living trees rose from 319 to 373 trees/ha (Figure 13a) and basal area increased from 3.28 to 3.98 m²/ha (Figure 13b). *Abies balsamea* was a large component of upland mixed hardwood/conifer forests. Although both the density and basal area of living individuals decreased during the six-year time interval (Figure 13a, b), these indices for standing dead *Abies balsamea* increased over that same time (Figure 13c, d).

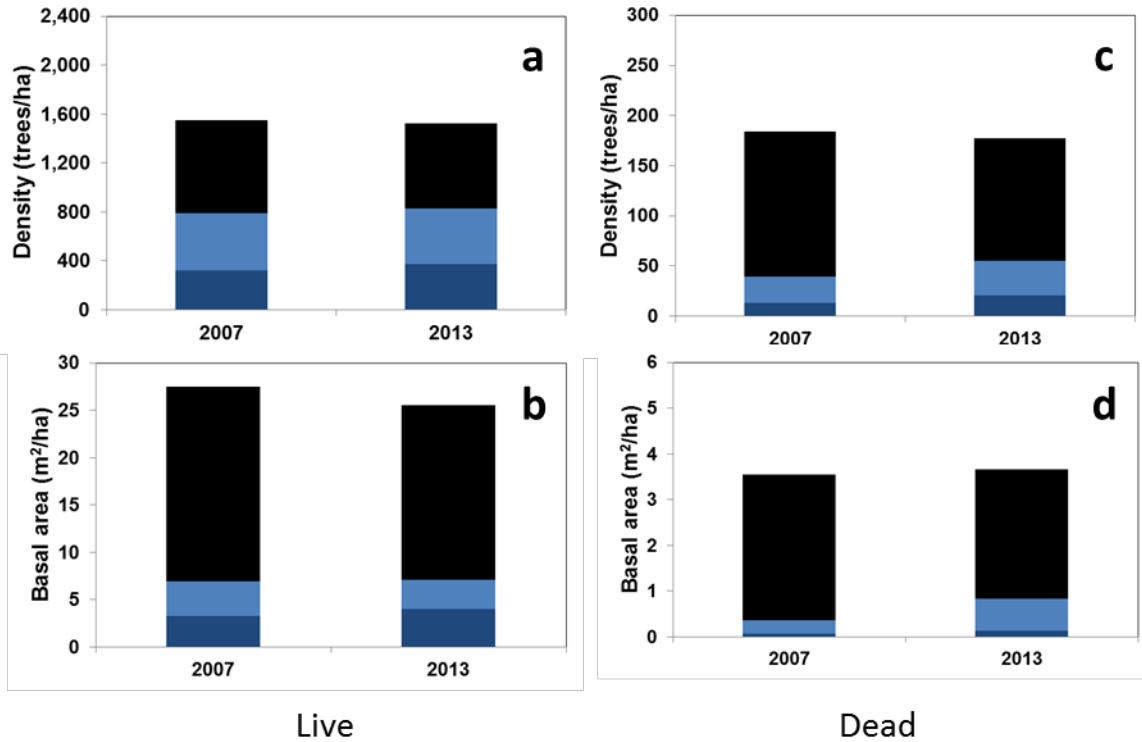


Figure 13. Density and basal area of live (panels a and b) and standing dead (panels c and d) trees in upland mixed hardwood/conifer forests at St. Croix National Scenic Riverway in 2007 and 2013. Dark blue (■) represents *Acer rubrum*, light blue (■) represents *Abies balsamea*, and black (■) represents all other species.

In mixed conifer/red oak forests, three of the four plots sampled in 2013 were first sampled in 2007 (Table 30). *Quercus rubra* increased in both density (367 to 489 trees/ha) (Figure 14a) and basal area (4.93 to 5.19 m²/ha) (Figure 14b), while density of *Populus tremuloides*, the most abundant tree species in this forest type, decreased during the same time. Basal area of *Pinus resinosa*, another common component of this forest type, increased during the six-year time interval (7.72 to 8.98 m²/ha), although both density and basal area of standing dead *P. resinosa* also increased (Figures 14c, d).

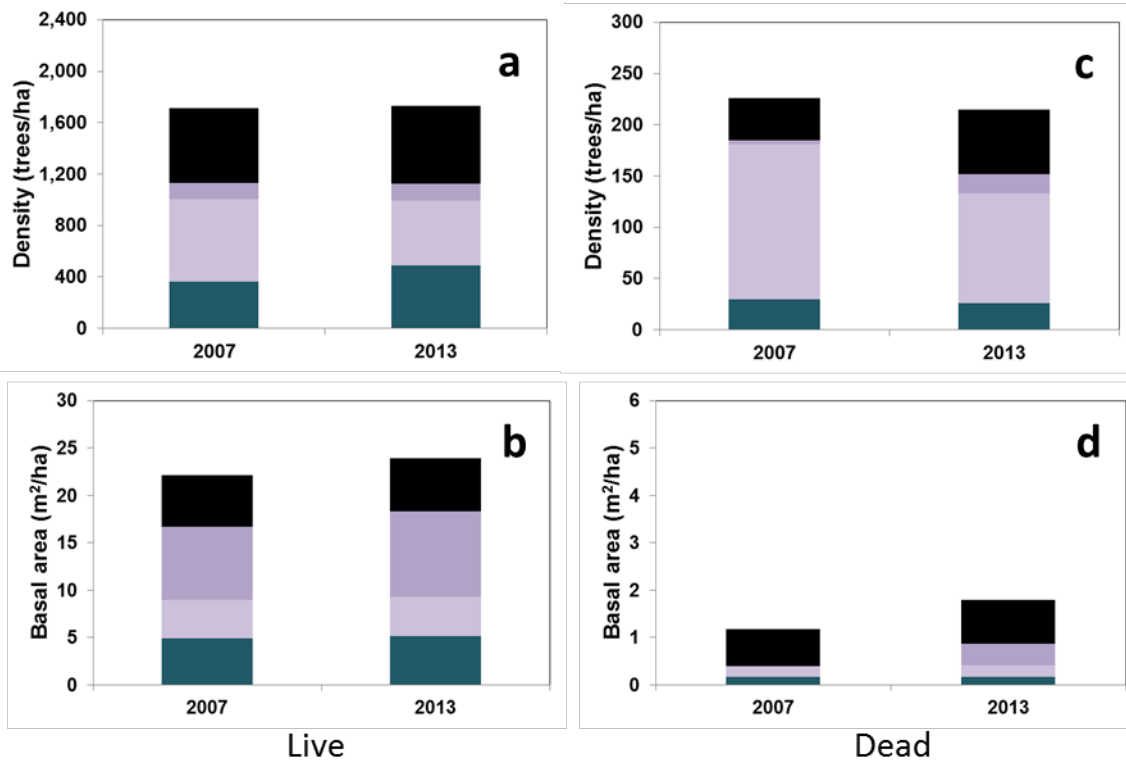


Figure 14. Density and basal area of live (panels a and b) and standing dead (panels c and d) trees in mixed conifer/red oak forests at St. Croix National Scenic Riverway in 2007 and 2013. Teal (■) represents *Quercus rubra*, lighter purple (■) represents *Populus tremuloides*, darker purple (■) represents *Pinus resinosa*, and black (■) represents all other species.

In mixed oak/aspen forests, the density of *Populus* spp. (both aspen species together) increased (435 to 639 trees/ha) while basal area decreased (8.6 to 4.8 m²/ha) (Figure 15a, b). During the same time interval, density of *Quercus alba* decreased (224 to 197 trees/ha) (Figure 15a) while basal area increased (2.0 to 2.7 m²/ha) (Figure 15b). Overall, there were large increases in both density and basal area of standing dead trees from 2007 to 2013 (Figure 15c, d).

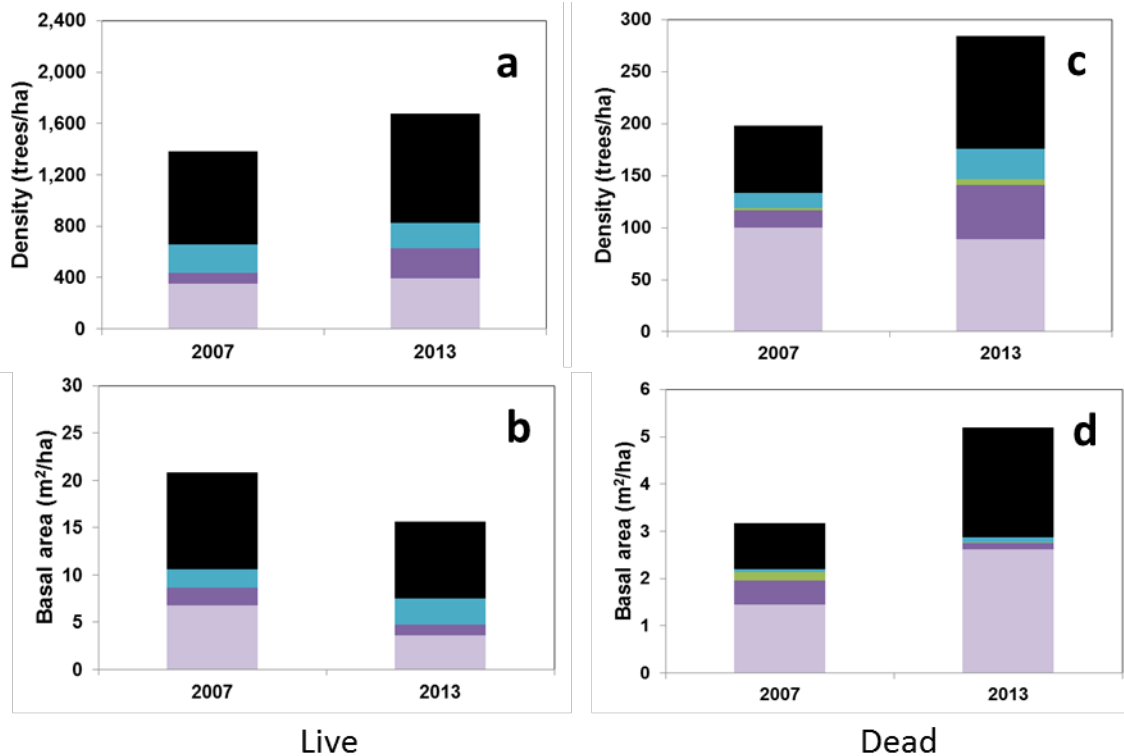


Figure 15. Density and basal area of live (panels a and b) and standing dead (panels c and d) trees in mixed oak/aspen forests at St. Croix National Scenic Riverway in 2007 and 2013. Lighter purple (■) represents *Populus tremuloides*, darker purple (■) represents *P. grandidentata*, turquoise (■) represents *Quercus alba*, green (■) represents dead *Populus* spp. unidentifiable to species (shown only in panels c and d), and black (■) represents all other species.

In black ash/mixed hardwood forests, 10 of the 16 plots completed in 2013 were established and sampled in 2007. *Fraxinus nigra* increased in density between the two sampling periods (774 to 1,010 trees/ha) (Figure 16a) while decreasing slightly in basal area (5.8 to 5.4 m²/ha) (Figure 16b). Although there was little change in either density or basal area of standing dead trees for all species collectively, both indices increased for *Fraxinus nigra* (Figure 16c, d).

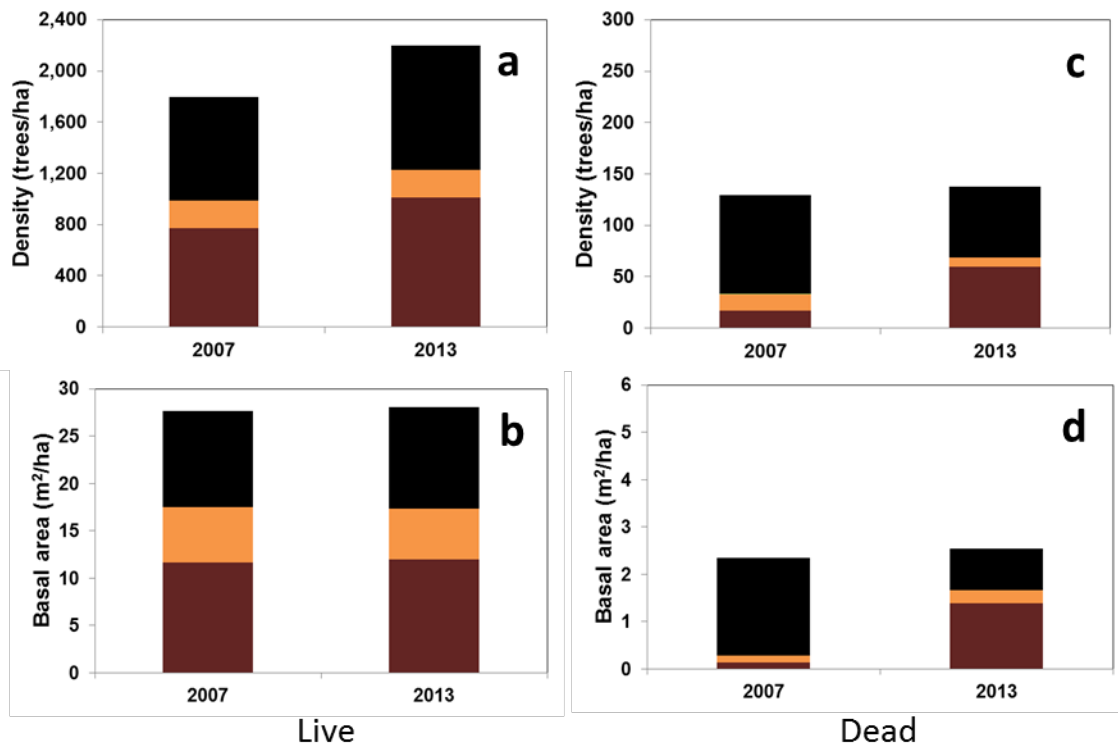


Figure 16. Density and basal area of live (panels a and b) and standing dead (panels c and d) trees in black ash/mixed hardwood forests at St. Croix National Scenic Riverway in 2007 and 2013. Russet (■) represents black ash, orange (■) represents *Tilia americana*, and black (■) represents all other species.

No comparisons were done for the silver maple lowland forests, since only two of the four plots in this forest type were sampled in both 2007 and 2013.

Spatial Extent of *Fraxinus*

The ash component was greatest, both in terms of area and length, along the upper St. Croix River where 20% of the forests were dominated by ash and 55% of the riparian edge was lined with ash forests (Table 31, Figure 17). Both the Namekagon River and the middle stretch of the St. Croix River, supported large ash stands, as well. Ash was limited on the lower St. Croix River (Table 31, Figure 17).

Table 31. The percentage of ash-dominated vegetation along four stretches of the riverway.

River Stretch	Percent ash by area	Percent ash by length
Namekagon River	5	28
Upper St. Croix River	20	55
Middle St. Croix River	17	18
Lower St. Croix River	1	2

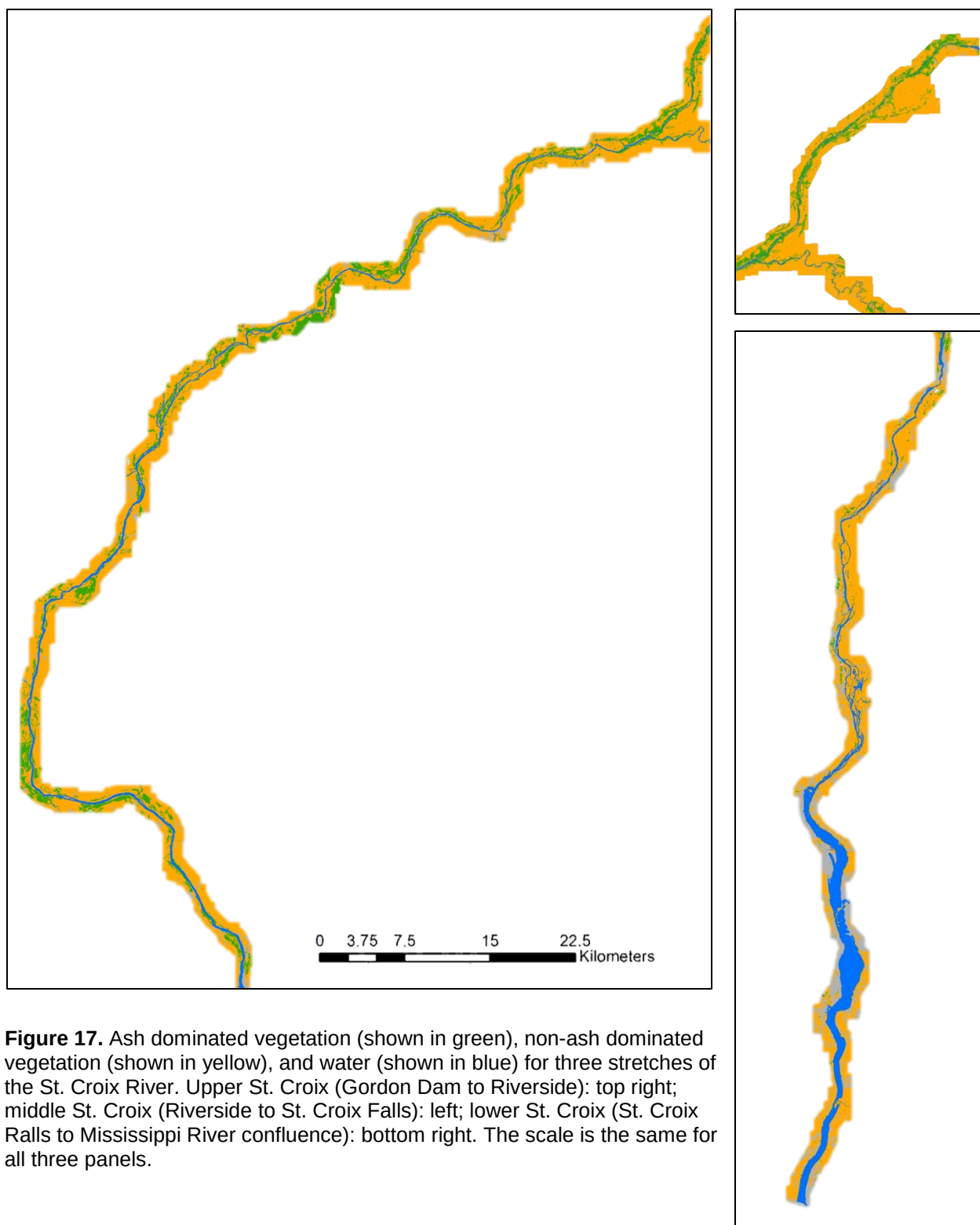


Figure 17. Ash dominated vegetation (shown in green), non-ash dominated vegetation (shown in yellow), and water (shown in blue) for three stretches of the St. Croix River. Upper St. Croix (Gordon Dam to Riverside): top right; middle St. Croix (Riverside to St. Croix Falls): left; lower St. Croix (St. Croix Falls to Mississippi River confluence): bottom right. The scale is the same for all three panels.

Discussion

Successional Trajectories

The current structure and composition of sugar maple forests and both lowland forest types on the St. Croix National Scenic Riverway largely reflect expected successional trajectories and disturbance processes. In sugar maple forests, *Acer saccharum*, *Tilia americana*, and *Ostrya virginiana* are all present throughout the range of size classes, including the small size classes, which is an indicator that these species are regenerating. *Acer rubrum* is also common in sugar maple forests, though its presence only at low density in the smallest size class suggests it may not be competing as well as other species in the low light environment of the understory. The minimal change observed in sugar maple forests between 2007 and 2013 is not surprising, as the sugar maple–basswood type is often viewed as a climax forest type in the region. Bray (1956) examined gap phase replacement in a sugar maple–basswood forest northwest of Minneapolis, Minnesota. He found the overwhelming majority of trees were *A. saccharum* (63%) followed by *T. americana* and *Ulmus americana*, each with 8.2% of the total. Because of the percentage of seedlings, saplings, and stump sprouts of these species in the understory, he noted that the forest appeared to be moving toward a stable, self-reproducing community.

Both black ash/mixed hardwood forests and silver maple lowland forests support large populations of *Fraxinus nigra*, a species tolerant of saturated conditions (Wright and Rauscher 1990). The changes observed in black ash/mixed hardwood forests between 2007 and 2013 reflect major recruitment during the previous five-to-ten years. *Fraxinus nigra* reproduces by both seed and root suckers, with reproduction via seed more common as flooding duration decreases (Tardif and Bergeron 1992). The high seedling species richness and sapling density in this habitat suggests limited recent flooding, suggestive that recruitment of *F. nigra* here may be largely by seed.

In three forest types (upland mixed hardwood, mixed conifer/red oak, and mixed oak/aspen), the structure and composition largely reflect the elapsed time since fire or other major disturbances. Several species present in these forest types, including *Quercus ellipsoidalis*, *Q. alba*, *Pinus resinosa*, and *P. banksiana* are indicative of historic fire presence (Heinselman 1973). In the absence of burning, fire-dependent species gradually die out and are replaced by mid-successional species that can compete better in lower light conditions, a process now widely known as “mesophication” (Nowacki and Abrams 2008, Hanberry et al. 2012). *Acer rubrum* has been identified as a species favored by these conditions, while *Abies balsamea* also opportunistically encroaches into areas where fire is now suppressed. Indeed, in upland mixed hardwood forests, *Acer rubrum* and *Abies balsamea* dominate the sapling layers and comprise 22% and 35%, respectively, of the total trees (see Figure 13b). These mesic species alter the understory by promoting greater shade, cooler temperatures, and higher humidity (Nauertz et al. 2004), which directly reduces flammability. Flammability is further reduced by the faster decomposition rates and a subsequent loss of fuel loads (Nowacki and Abrams 2008).

The changes observed in mixed oak/aspen forests also likely reflect the effects of a severe wind event on 1 July 2011. On this date, straight-line winds are estimated to have exceeded 160 km/hr throughout Burnett County, Wisconsin, and the surrounding area (NOAA 2014), downing trees along the upper and middle St. Croix River as well as the lower reaches of the Namekagon. The coarse textured soils throughout this area leave forests highly prone to wind damage. The sharp increase in density is largely in the smallest size class, as adventitious shoots growing in response to increased light reached 2.5 cm DBH in size, just large enough to be tallied. The sharp increase in density of standing dead trees in this forest type is reflected across all species and is largely a result of the

windstorm breaking tops off of trees. Many plots had an unusually high number of standing dead trees and amount of coarse woody material. The loss of these larger trees is reflected in the marked decrease of basal area of live trees.

Plots in mixed conifer/red oak forests, which are all on the lower Namekagon River, also contain a great deal of *Populus* spp., although these are being replaced by *Quercus rubra* and *Picea mariana*. The presence of *Pinus banksiana* and *P. resinosa* suggest these areas may have burned in the past. These plots may be too dry to support a large amount of *Acer rubrum*; instead, stands are largely being replaced by *Quercus rubra*.

Emerald Ash Borer and its Projected Consequences

While successional processes at SACN have been largely driven by fire and wind, the impending arrival of the emerald ash borer (EAB) will also have profound effects on the forests at this park. The loss of ash, particularly black ash, will likely lead to a chain of cascading impacts on the entire terrestrial-aquatic interface of the riverway. Projections of these changes in the St. Croix and Namekagon rivers are difficult due to the complexity of the system. While numerous formulae exist for projecting key metrics expected to change (e.g., flow (Yen 2002) and sedimentation (Bagnold 1977; Järvelä 2002, 2004)), the accuracies of these projections would be questionable. The impending arrival of EAB is expected to impact many linked biotic and abiotic components of the riparian system, making it difficult to quantitatively project all of these changes. Here, we summarize existing knowledge of EAB and likely impacts, which we then qualitatively place into context with the St. Croix/Namekagon River system.

Although EAB has not yet been detected within the riverway boundary, it is now in the vicinity. EAB presence was first reported in St. Paul, Minnesota in 2009; this population has been spreading since that time. As of April 2014, the eastern-most point of its spread is now near the Pigs Eye Lake area, approximately 24 km (15 miles) to the west of the southern end of the Riverway boundary. In 2013, it was also discovered in Superior, Wisconsin, approximately 56 km (35 miles) northeast of the northern-most boundary of the riverway. Both counties are now under quarantine, although further spread is highly probable.

Because adults generally feed on host trees within a few meters of their larval host tree, EAB spread is generally slow, except when assisted by humans, via firewood transport. Females generally lay 50-80 eggs in cracks or crevices of ash trees. Upon hatching, the larvae burrow into the tree, establishing themselves within the cambial layer. Here, they feed on the phloem and outer layer of sapwood, establishing extensive galleries. This disrupts both the xylem and phloem, inhibiting the flow of water and nutrients between the roots and canopy. Most trees typically die within two to four years of infestation (Herms et al. 2004). Prepupal larvae overwinter and adults emerge in May or June and feed on ash leaves for 3-6 weeks (Cappaert et al. 2005).

Within the riverway, ash-dominated forests are most common along the upper and middle reaches. Here, upwards of 20% of forests lining the riverway support large amounts of *F. nigra*. Perhaps the greatest impact of EAB, at least initially, will be the direct influence on river flow. Floodplain trees, such as black ash, impact hydrology by creating flow resistance during periods of overbank flow (Järvelä 2002, 2004), influence the water balance through plant uptake and evapotranspiration (Tabacchi et al. 2000), and slow surface runoff into the main channel (Malanson 1993).

The contribution of floodplain vegetation to flow resistance is well documented. Groundlayer vegetation, including herbs and graminoids, provide friction from their leaves and stems, increasing the drag of the water at the river-streambed interface (Järvelä 2002, Green 2005). Floodplain trees also create flow resistance via direct impedance from their boles. Stem density and pattern largely influence river drag (Nepf 1999, Ishikawa et al. 2000, Kothyari et al. 2009), although nuances in stem roughness (Tanaka et al. 2011), stem flexibility (Järvelä 2002), and leaves (Järvelä 2004) will also play a role.

Riparian hydrology is also largely influenced by water uptake for storage in trees and, ultimately, loss through evapotranspiration. Catchment-wide water balance is commonly quantified by *water yield*, a measure reflecting the difference between precipitation inputs and losses from plant uptake and evapotranspiration. Increases in water yield reflect greater precipitation inputs relative to evapotranspiration losses. Water yield change is typically assessed by direct measurements of stream discharge with the values, usually reported in millimeters, reflecting the water volume difference integrated over the entire surface area of the catchment (Konukcu et al. 2005). For example, a hypothetical water yield increase reported as 17 mm for the Namekagon River catchment would reflect an annual increase in precipitation of this amount, relative to evapotranspiration, over the entire 262,661 ha area of the Namekagon River watershed. This would be detected by an annual stream discharge increase of $4.48 \times 10^7 \text{ m}^3$.

Catchment-wide water yield change in response to vegetation change is well-documented. Increased water yield from vegetation loss has been shown using both paired catchment studies (see Bosch and Hewlett (1982) and Stednick (1996) for reviews) and time-trend studies (Brown et al. 2005) that examined catchment management on hydrology. Bosch and Hewlett (1982) reviewed water yield studies of 94 experimental catchments. Among the general conclusions reached, they found (1) forest cover change (such as loss from logging activities) was inversely related to water yield changes, and (2) annual water yield changes of ca. 25 mm per 10% change in deciduous hardwood cover were documented.

Increases in water yield on the Namekagon/St. Croix system are anticipated once the impacts of EAB take hold. Projections of water yield changes on these rivers must include a temporal component. Ash loss will occur gradually, both due to the advancement of the beetle's distribution over the length of the riverway, and to the time allowed for a given tree or group of trees within a given area to succumb to borer-inflicted damage. This differs from harvest effects which are immediate. Typically, pulses in flow resulting from logging return to pre-harvest levels within a few years due to regrowth. However, regrowth following black ash loss will be hard to predict.

It is unclear which species, if any, will fill the niche vacated by *F. nigra*. This species grows in a number of vegetation cover types and the responses of the vegetation to EAB in these types will likely vary. Understanding the current constraints on species assemblages, particularly in riparian corridors, will guide projections of species that may fill this niche. Overstory community assembly in floodplains is shaped by broadscale physiography, including channel structure, channel slope, and floodplain width (Hodges 1997), and by flood intensity and duration (Auble et al. 1994, Nilsson and Berggren 2000). These characteristics drive fluvial processes and structural traits at the local scale, including soil moisture holding capacity (Tabacchi et al. 1998), nutrient cycling (Pinay et al. 1995), and oxido-reduction cycles (Pinay et al. 1995). In addition, land use history can exert strong influences in current vegetation (Schulte et al. 2007). Collectively, these factors act in concert to promote foreseeable patterns of vegetative assemblages that transition along the entire length of a river from the headwaters to the outlet.

On an active floodplain, floods mechanically remove many seedlings and small saplings by force, while others die from hypoxic conditions associated with long periods of inundation. In floodplain systems, significant floods scour the floodplain floor, allowing germination sites for woody species; when this is followed by a brief period (e.g., one-to-three years) of low-to-no flooding, the woody species can become established (Scott et al. 1996). Once floods recommence, individual saplings of those species with mechanical and physiological adaptations to tolerate both the scouring force of water and long periods of hypoxia (i.e., floodplain tolerant species or “tolerators”) will have greater survival. The result is a community composed primarily or exclusively of floodplain tolerators, with lower overall density and fewer individuals in small size classes compared with upland sites (De Jager et al. 2012). Indeed, it appears that these are the processes acting on the silver maple ash lowland forests along the St. Croix River. However, a persistent high water table is also impacting community assembly. In pockets where this occurs, the persistent hypoxic conditions, facilitated by the presence of fine-textured mucky soils, imposes further restrictions on species and, in places, limits the overstory exclusively to *F. nigra*. In places, this is accompanied with a dense alder shrub layer.

It is unlikely that any native overstory species will replace *Fraxinus nigra* in lowland forests due to the physiological adaptation needed. These areas will transition to a two-species system dominated by *Acer saccharinum* and *Ulmus americana*, the only native overstory species currently common in these forests. Areas where *F. nigra* was the sole overstory species will likely become dominated by herbaceous hydrophiles or by *Alnus incana* ssp. *rugosa*. The understory species commonly observed in 2013 included dense stands of *Calamagrostis canadensis* and *Laportea canadensis*, while ferns were also common in the understory, including *Onoclea sensibilis* and *Matteuccia struthiopteris* (L.) Tod. (ostrich fern). Stands of *Alnus incana* ssp. *rugosa*, in which *Fraxinus nigra* was the only overstory species present, were also observed here. One native species which may increase in density in response to black ash loss is *Zanthoxylum americanum* Mill. (prickly ash). This large shrub was frequently observed in dense patches either within or adjacent to black ash stands. Arévalo et al. (2000) found gradual increases in density of *Z. americanum* over a 14-year time interval following overstory loss due to a severe blowdown in Minnesota.

Unfortunately, silver maple lowlands will be highly susceptible to invasion of non-native buckthorn species. *Rhamnus frangula* L. (glossy buckthorn) can outcompete native vegetation in moist areas such as wetland margins (Mills et al. 2012), while *Rhamnus cathartica* L. (common buckthorn) more commonly invades upland areas. Nonetheless, there is evidence that common buckthorn can also invade and compete in moist areas (Kurylo et al. 2007). While these species have been common in the more southern reaches of the riverway, and at more disturbed areas such as landings, they are beginning to infiltrate forest interiors. *R. frangula* in particular appears to have a fairly high tolerance for saturation based on its extensive invasion of the Bibon Swamp State Natural Area in northern Wisconsin (S. Sanders, personal observation). While this has not been found in any of our vegetation monitoring plots as of 2013, it may become a problem invasive species in these lowland habitats in the future as a result of EAB’s arrival and the subsequent loss of ash trees.

Black ash is also frequently observed in areas with a higher pH, on sandy substrates where underlying clay can impede drainage (Fowells 1965). Along the St. Croix River, *F. nigra* was abundant on sandy floodplains, along with *U. americana*, *T. americana*, and *A. rubrum*, although several other overstory species were also present. In these areas, typical of our black ash/mixed hardwood forest type, the herbaceous layer was diverse, with many species common in mesic forests also present here. Common groundlayer species observed in black ash/mixed hardwood forests included *Aralia nudicaulis* L. (wild sarsaparilla), *Arisaema triphyllum* (L.) Schott (Jack-in-the-

pulpit), *Circaea canadensis*, *Eurybia macrophylla*, *Fragaria virginiana* Duchesne (wild strawberry), *Geranium maculatum*, *Lycopus uniflorus* Michx. (bugleweed), *Mitella diphylla*, *Rubus pubescens*, and *Viola* sp. These species assemblages indicate that the duration, frequency, and power of floods in the higher black ash/mixed hardwood forests are less than those observed in silver maple lowland forests. In these higher forests, density may be constrained by light and resource availability. In contrast to silver maple lowland forests, it is likely that current overstory species in black ash/mixed hardwood forests may fill the niche vacated by black ash. Nonetheless, the threat of *Rhamnus* spp. invasion in black ash/mixed hardwood forests remains an issue, especially once the ash trees begin to die and light in the understory is less limiting (Gourley 1985, Knight et al. 2007, Burnham and Lee 2010).

While the loss of ash is expected to have profound impacts on hydrology and forest successional dynamics, cascading effects will result in numerous other impacts. Potential impacts include reduced nutrient buffering capacity, increased river sediment loads, decreased litter input, shifts in macroinvertebrate assemblages, increased stream temperature, reduced and lower quality juvenile fish habitat, reduced and lower quality mussel habitat, and fewer avian nesting sites.

While the impacts of EAB are anticipated to be dramatic and occur over a relatively short time period, other serious changes are occurring more subtly. The forests along much of the Namekagon River, particularly the lower reaches, were historically dominated by pines. Coarse textured soils and high bluffs still provide ideal habitat, but longer fire return intervals resulting from fire suppression are shifting local species' composition to more mesic assemblages.

Management Directions

Park managers face unprecedented challenges over the next few years. In addition to the problems detailed above, the threat of non-native species remains a constant pressure. This includes not only those that invade forests (e.g., buckthorn and honeysuckle [*Lonicera* sp.]), but also those impacting aquatic systems. It is quite possible that Asian carp will be present within the St. Croix River, upstream of the St. Croix Falls dam, within the next five years. The impacts to hydrology will be compounded by those from the loss of ash. Managers may wish to consider the impacts that both of these may have on rare and/or endangered mussel species. Options such as translocation may be desirable.

Fourteen target areas within the riverway have been selected for prescribed fire, but as of 2013, not all of these have been burned. These targets include oak and pine savanna, pine barrens, and prairies, with five of the target sites located on the Namekagon River near the Wisconsin towns of Cable (30 ha site), Springbrook (4.6 ha), and Trego (3.1 ha), as well as the more remote sites known as Olson Prairie (3.4 ha) and Barker's Farm (34 ha). These latter two sites are located in oak-pine savanna on the lower Namekagon River at distances ranging from 0.25 to 7.75 km from the four long-term vegetation monitoring plots. While the prescribed burning does not simulate the extent and frequency of the pre-settlement burn regime, maintaining burning, even on a limited basis will, promote biodiversity. Jack pine and red pine forests support a suite of understory herbaceous species not commonly observed in other systems. Maintaining these open areas provides an opportunity for further reproduction and persistence on NPS lands. Park managers may wish to address regeneration of fire-dependent species by use of alternative methods. Herbicidal spraying, manual control (chainsaws, loppers), and manual seedbed preparation could allow significant regeneration of key species.

We feel that the park should develop a response plan for the arrival of emerald ash borer. Developing protocols and ushering them through the NEPA process prior to the arrival of the EAB will not only save significant effort down the line, but could put the park in a better position ecologically to counter the impacts.

Implementation: Problems, Logistics, and Future Plans

Sampling at SACN in 2013 went slowly throughout the month of June, largely due to the substantial rainfall and subsequent high water. Despite this, we were able to complete our target of 50 plots. Current plans are to revisit SACN in 2022 and every nine years thereafter.

We recommend that future sampling crews use T-posts for marking those permanent endpoints that are currently located in black ash habitat. Many of our witness tree endpoints are >10 meters away, which will make precise relocation of these endpoints a challenge in 2022. This is complicated by the fact that many are in areas submerged for long periods in the spring and early summer.

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