# The Forests of Isle Royale National Park: Can We Preserve This Pristine Wilderness in the Face of Climate Change?

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CONSERVATION ISSUES

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# The Forests of Isle Royale National Park: Can We Preserve This Pristine Wilderness in the Face of Climate Change?

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**ABSTRACT**: Isle Royale National Park (IRNP) is an archipelago in west central Lake Superior. In 2010, the National Park Service Great Lakes Inventory and Monitoring Network initiated a long-term monitoring program at IRNP with the goals being to: (1) determine the current forest structure, (2) assess how succession and climate change will impact species assemblages, and (3) develop realistic management targets related to climate change impacts on IRNP forests. Five forest types were identified, with three of these (sugar maple (*Acer saccharum* Marsh.)/birch, eastern white cedar (*Thuja occidentalis* L), and balsam fir (*Abies balsamea* (L.) Mill.)) being climax types with little likelihood of succeeding into any other type over the next two to three decades. Two forest types (white spruce (*Picea glauca* (Moench) Voss),/trembling aspen (*Populus tremuloides* Michx.), and paper birch (*Betula papyrifera* Marsh.)) were in a state of transition. The long-term (> 50 year) successional pathways of all five forest types will be influenced by climate change, species' migration abilities, and disease. Many dominant species currently on the island, including balsam fir, black spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenb.), and white spruce, are expected to become extirpated, while the abundance of other common species, including paper birch and trembling aspen, is expected to decline. The 21 km distance between the mainland and the islands will prohibit timely immigration of new species onto the island in the face of climate change. Immigration will likely be led by avian-dispersed species (*Prunus* spp., exotic *Lonicera* spp., and *Rhamnus cathartica*, another exotic species) with dispersal of other taxa relying on stochastic events or human transport. Managers should consider assisted migration to ensure that species assemblages remain congruent; otherwise, stable ecosystems dominated by a few non-native taxa may result. This is especially relevant on the eastern side of the island where balsam fir forests dominate in shallow, bedrock-derived soils.

*Index terms:* boreal forest, climate change, Isle Royale National Park, long-term monitoring, northern hardwood forest

## INTRODUCTION

Climate-induced shift in species' assemblages are expected to be most pronounced at boundaries between biomes (Neilson 1993; Pitelka 1997; Allen and Breshears 1998). Here, more species are at the periphery of their ranges, and are thus more greatly subjected to environmental alterations than in biome interiors (Case and Taper 2000). The rate at which a species migrates into or out of an area is a function not only of climate shifts (Iverson et al. 2004; Woodall et al. 2009), but also of dispersal capability (Scheller and Mladenoff 2005), establishment potential (Ibáñez et al. 2008; Hillyer and Silman 2010), habitat connectivity (Collingham and Huntley 2000), and abiotic factors such as edaphic properties (Gengarelly and Lee 2005; Lee et al. 2005) and moisture (Gengarelly and Lee 2005).

Differential migration will necessarily impact species assemblages. Increased abundance of a few species due to competitive release is hypothesized to occur in fragmented habitats where migration rates of incoming species vary (Jump and Peñuelas 2005). One potential result of this is increased richness and abundance of weedy species, such that an area transitions to one of low ecological integrity. Alternatively, if established species' assemblages migrate into an area as a cohort, there is a greater likelihood of stable forests of native species resulting. If park managers wish for the latter to occur, now is the time to assess the current state of plant associations and develop long-term strategies. This is especially relevant for intact, functioning stable ecosystems that serve as refugia for key plant and animal species. One such area is Isle Royale National Park (IRNP).

Isle Royale National Park is a 72 km-long archipelago in west central Lake Superior. Although politically belonging to the State of Michigan, IRNP is 22 km from mainland Ontario, Canada, and 25 km from Grand Portage, in extreme northeastern Minnesota (Figure 1). The island sits at the boundary between boreal and northern hardwood forests with large components of both biomes. Climate-associated shifts in species composition at IRNP are expected to differ from those in mainland Minnesota and Ontario. First, the shortest distance from the mainland to the island is 22 km; this is at least twice as far as the effective dispersal distance of many tree species expected to migrate into the region (Ravenscroft et al. 2010). Second, the island has escaped many of the anthropogenic impacts present

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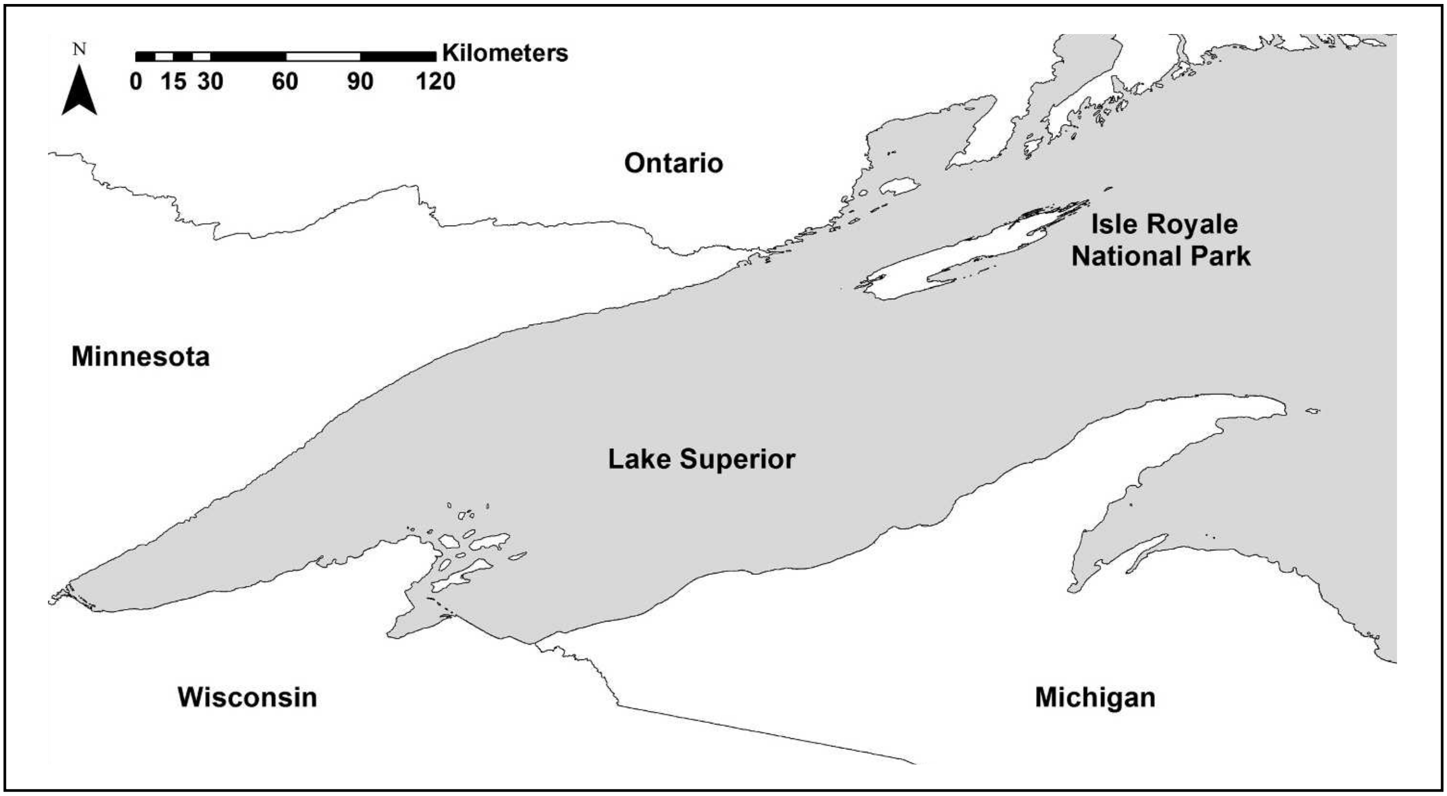

**Figure 1. Isle Royale National Park showing the proximity to Ontario, Minnesota, and Michigan's Keweenaw Peninsula.**

on the mainland. There are few invasives (with limited distribution) and < 1% of the park is developed. Finally, the island is not managed for timber, although timber harvests did occur prior to the Park's enabling legislation in 1931. Collectively, these limit the invasability of weedy species and promote strong ecological integrity at IRNP. They also present park managers a unique opportunity, as well as unique challenges, to address forest change.

We established a long-term forest monitoring program at IRNP in 2010. Among the goals at the outset were to: (1) Determine the current and anticipated mid-term (next 50 year) forest structure. We can look at seedling density and tree and sapling size distributions to make predictions about the future; (2) Assess which species are likely to migrate into the region and how this will impact IRNP forests. These projections will be based on anticipated climate change, current and pending disease threats, and dispersal capability of tree species; and (3) Discuss realistic management targets in the face of climate change.

## METHODS

### Study Area

Isle Royale formed during the Precambrian era, as interlaid basaltic and sedimentary rocks were deposited regionally over a 25 million-year-period. Subsequent sagging and lateral pressure resulted in the Lake Superior basin, as well as tilted rock outcroppings. These outcroppings include Isle Royale on the northwest side of the compression zone and Michigan's Keweenaw Peninsula on the southeast side. The outcropped layers forming Isle Royale are now a series of parallel ridges of erosion-resistant basalts spanning the island, with one of these, the Greenstone Ridge, extending its entire length (Figure 2).

Three distinct vegetative zones exist at IRNP. Within the southwest area of the island, northern hardwood forests predominate and are typically dominated by either mature sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula alleghaniensis* Britton) or eastern white cedar (*Thuja occidentalis* L). The elevation on this side is generally higher, resulting in less exposure of the land mass to the moderating effects of Lake Superior. Soils on the southwest side of the island are primarily glacial derived tills. On the northeastern side of the island, dense, boreal, mature balsam fir (*Abies balsamea* (L.) Mill.) forests dominate. Here, a series of channels, bays, and inlets expose much of the area to the moderating effects of Lake Superior. Soils are bedrock derived and are thinner than those of the interior or southwestern side. The central part of the island was burned in 1936. These forests are now a mosaic of mature paper birch (*Betula papyrifera* Marsh.), white spruce (*Picea glauca* (Moench) Voss), trembling aspen (*Populus tremuloides* Michx.), and black ash (*Fraxinus nigra* Marsh.), with a smaller percentage of many other species.

In addition to vegetation, Isle Royale also supports 18 mammalian species and typically 55-60 species of breeding birds (Egan 2009). It is perhaps best known as the location of the oldest, continuous preditor-

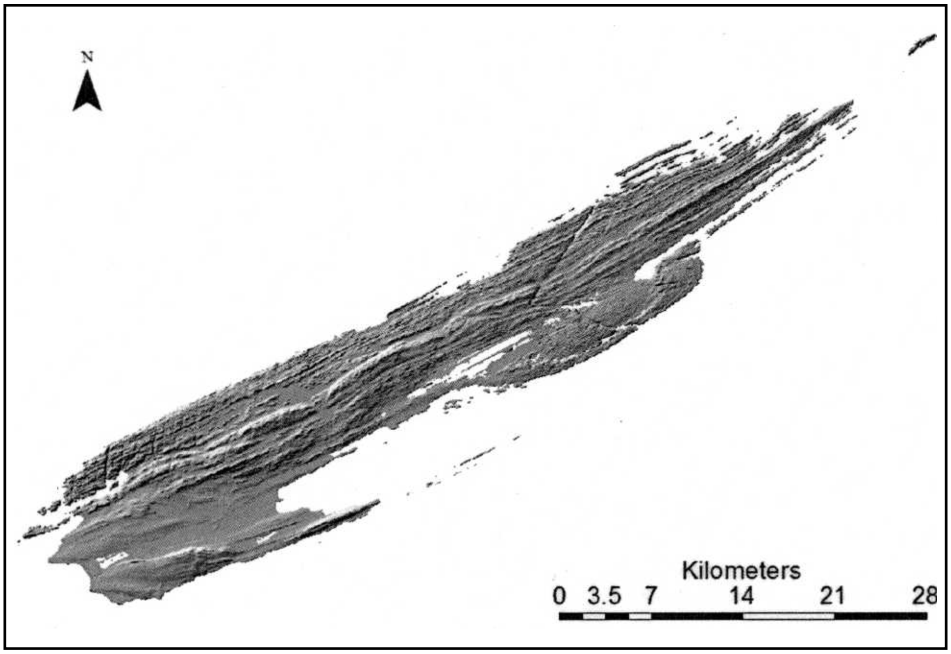

**Figure 2. Relief map of Isle Royale showing the ridge and valley pattern that dominates the topography. The Greenstone Ridge is the prominent ridge spanning the length of the island.**

prey study (Peterson 1999). Moose (*Alces alces* (L.)) arrived on the island in the early part of the twentieth century, while wolves (*Canus lupis* (L.)) migrated there via an ice bridge in the 1940s (Mech 1966). The closed nature of this island system limits migration and affords a high degree of precision to measures of population dynamics of both species. Over the course of the study, initiated in 1958, abundance estimates for moose have typically varied from 700-1200 individuals while those for wolves have ranged between 18 – 27. January 2011 population estimates were 16 wolves, a decline of three from one year prior, and 515 moose. This moose estimate marks the sixth consecutive year where the estimated abundance is approximately half of the long-term mean (Vucetich and Peterson 2011).

## Sampling Design

The Isle Royale long-term forest monitoring program is part of larger programs both within the Great Lakes Network national parks (Route and Elias 2007) and the entire National Park Service (Fancy et al. 2009). Sampling was conducted at IRNP from 8 June – 24 August 2010. Site locations were selected using a generalized random-tessellation stratified design (GRTS; Stevens and Olsen 2004), ensuring that sites are both randomly located but also spatially balanced throughout the park. We chose not to stratify sites by forest type as these are expected to change dramatically over the course of this long-term monitoring study. All potential sites were overlain on an aerial photography layer using geographic information systems prior to visiting them in the field. In this way, we were able to eliminate any potential sites that did not meet the minimum 10% forest cover requirement.

Sites were sampled using the hybrid plot (Figure 3), developed specifically for the Great Lakes Network long-term vegetation monitoring needs (Johnson et al. 2008). This plot is composed of three parallel transects oriented east-west. Data were collected on trees located in a 6-m wide band along the length of each of the three transects. Tree data included species, diameter at breast height (dbh), whether the tree was alive, and any evident damage or disease. Trees were defined as having a dbh ≥ 2.5 cm. Hence, "saplings" in the traditional sense (2.5 – 12.7 cm) were considered "trees" in this study. Seedling abundance was assessed within each of six 2.82-m radius (25 $m^2$ area) circles, located at the transect ends. Here, we counted seedlings of each tree species present. Seedlings are defined as tree species < 2.5 cm dbh, but at least 15 cm in height and showing evidence of growth from the previous year. We did not count seedlings of the current year due to extremely high first-year mortality and to the fact that there would be a bias against plots sampled earlier in the season. Assessments of coarse woody material, ground layer, and browse were also made as part of this project and will be presented elsewhere.

Because we may want to stratify by forest or habitat type during later analyses (i.e., post stratification), we planned to declare a forest type for each plot while we were at it, using the Kotar classification system (Burger and Kotar 2003). Under this system, the forest type of an area is based on the potential vegetation rather than the current vegetation. Potential vegetation is the expected climax forest in a stand and reflects the moisture level as well as the nutrient availability within the stand. Moisture and nutrient availability are inherent properties of the soil and are not expected to change over decadal time scales. While the Kotar system has been developed for the entire mainland Upper Peninsula of Michigan, classes have not been defined for all habitats on Lake Superior islands. Hence, we experienced difficulty classifying plots in the field using this system. Beginning in late June, we began classifying plots according to the National Vegetation Classification System (NVCS) (Federal Geographic Data Committee 2008), assigning plots to their current (2010) vegetation type. We continued to use the Kotar classification system as well, provided a plot clearly fell into one of the pre-defined classes.

We attempted to identify all plants to the species level 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 the park unless they were flowering or fruiting (e.g., *Crataegus* spp.), which often was not the case. In these instances, we made the decision to record to genus instead. For *Amelanchier* spp., the genus was subdivided into three groups of species complexes, with Group

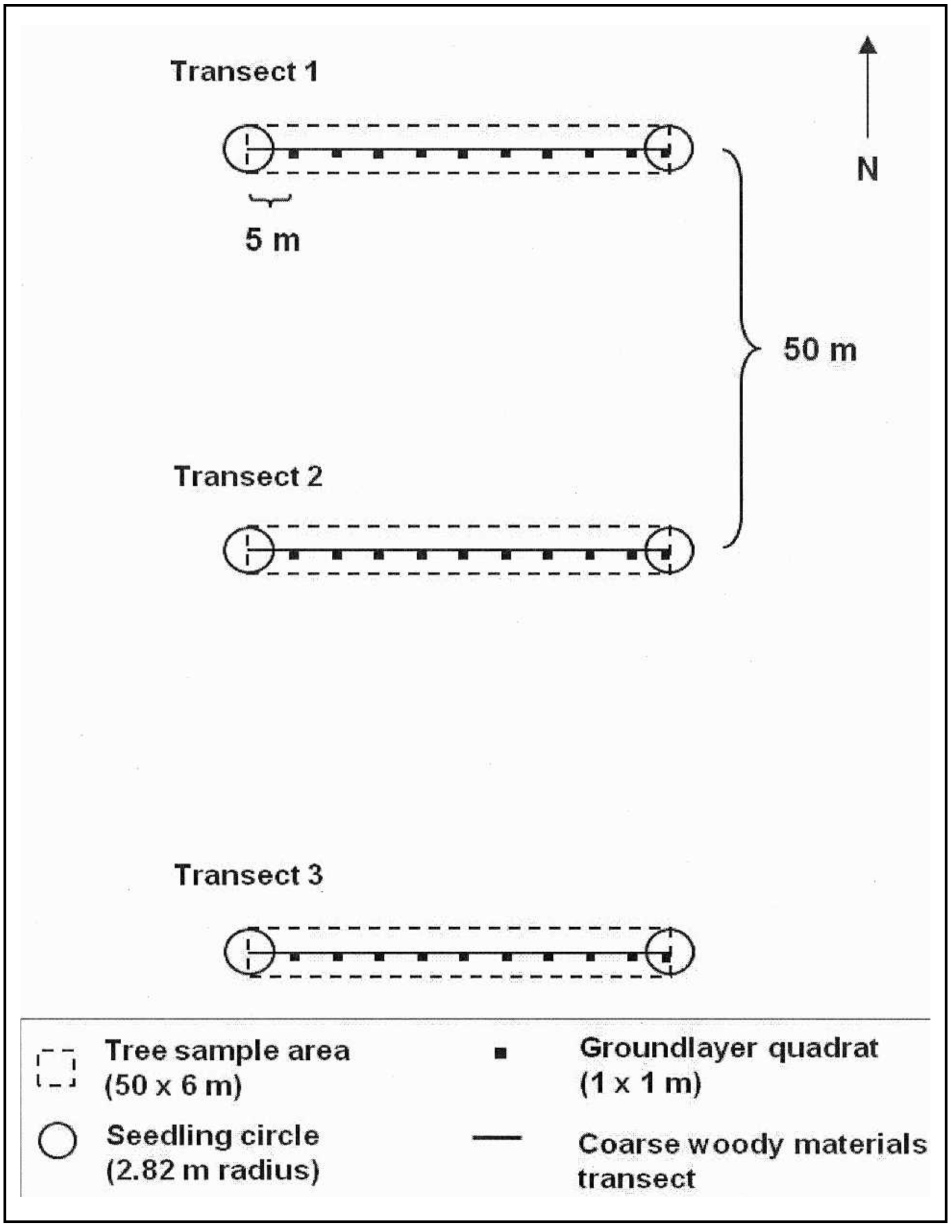

**Figure 3. Diagram of hybrid plot used for sampling the Great Lakes Inventory and Monitoring Network long-term vegetation monitoring plots.**

1 containing *A. bartramiana;* Group 2 containing *A. arborea*, *A. laevis*, and *A interior;* and Group 3 containing an uncertain number of species (Smith 2008).

As part of the Great Lakes Network's long-term forest monitoring program, Isle Royale National Park is scheduled to be resampled every six years.

### Analysis Methods

Because not all plots were classified by a single classification system, we used cluster analysis to group the plots into ecologically meaningful classes. Collectively, the 52 plots supported 19 taxa of tree stature. We determined the density and basal area of each tree species in each plot using Microsoft Access. These plots were clustered into five groups based on both of these variables using PC-ORD software with a Sørenson distance measure and a flexible beta linkage (ß = -0.25) (McCune and Grace 2002). Forest type names were assigned based on the dominant trees in these groups. Cluster groups for both variables were examined and compared with assigned Kotar and NVCS classifications; and the grouping, using density as the variable, was subjectively selected for assigning forest type classes.

Density-diameter distributions were calculated by summing the total number of each tree species in each 2.5-cm size class: 2.5 – 4.9, 5.0 – 7.49, 7.5 – 9.99, etc. Separate density-diameter distributions were constructed for conifers and hardwoods in each of the five forest types.

Traditional statistical tests were not employed for the current paper. While it is important to know species densities in a given habitat, for example, it is not of managerial relevance to know if one species is statistically more common than another. We will perform these analyses to test for changes over time once these plots are resampled. For the present work, however, we determined that descriptive statistics are more meaningful.

## RESULTS

A total of 52 plots were completed at IRNP (Figure 4). Twenty-four tree species were recorded in the sampling plots, as were 47 shrub species and 232 herbaceous species.

### Balsam fir mixed forests

Nine plots were in balsam fir mixed forests at IRNP, with eight of these located in the eastern third of the main island and one on Passage Island, 6.5 km northeast of the main island. These plots consist largely of balsam fir, but with inclusions of several other species including white spruce, black ash, and paper birch. Among the five forest types at IRNP, this one had the highest tree density, at 3490 trees/ha (Table 1). Individuals of balsam fir comprised 75% of that total (Table 1, Figure 5, top), while hardwood trees, collectively, comprised just over 9% (Table 1). Despite the high density of trees in balsam fir mixed forests, seedling density was 8474 seedlings/ha, the second lowest of the five forest types. Balsam fir and trembling aspen seedlings comprised 43% and 29% of the individuals, respectively.

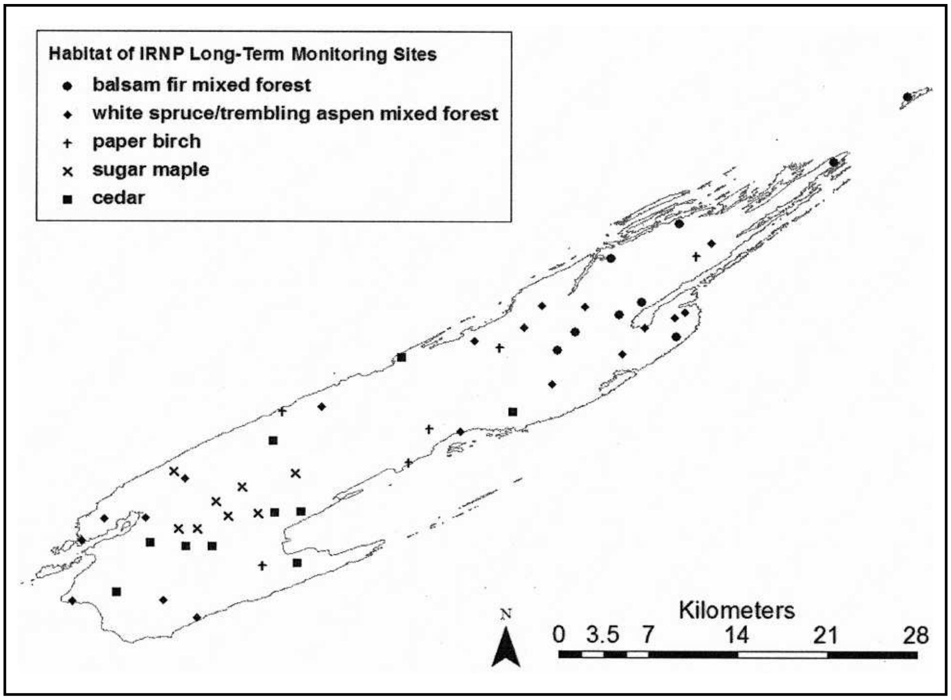

**Figure 4. Fifty-two long-term forest plots showing the five forest types into which they were grouped.**

## White Spruce/Trembling Aspen Mixed Forests

Nineteen of the 52 plots were classified as white spruce/trembling aspen mixed forests, making it the most common of the five forest types sampled. These plots were located throughout the island, and typically contain a significant white spruce component, although there is generally high tree species diversity (Table 2). Although both white spruce and white cedar are regenerating, as evidenced by the increasing density in successively smaller size classes (Figure 5, middle), balsam fir is also present in the smallest size classes. Trembling aspen, yellow birch, and paper birch were the most abundant hardwood species (Table 2), although paper birch was less abundant in the smaller size classes compared with larger classes (Figure 6, top). Balsam fir had the most conifer seedlings in this forest type with 1242 seedlings/ha, about five times greater than the density of white spruce seedlings. Abundant hardwood seedlings were trembling aspen, mountain ash (*Sorbus decora* (Sarg.) C.K. Schneid.), and mountain maple (*Acer spicatum* Lam.), although the latter two species do not typically reach pole size at IRNP.

## Paper Birch Mixed Forests

Six plots were classified as paper birch mixed forest type, the fewest number of plots in any of the five forest types. These plots were widely scattered, primarily within the central third of the island (Figure 4), and were typically open with rocky outcrops and large inclusions of beaked hazel (*Corylus cornuta* Marsh.) and green alder (*Alnus viridis* ssp. *crispa* Chaix (DC.)). Paper birch was the most abundant tree, comprising just over 49% of the individuals in the forest type (Table 3). Black spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenb.) and white spruce, collectively, comprised 76% of the conifer species (Table 3).

The greatest density of paper birch was in the 15.0 – 17.5 cm (dbh) size class with generally decreasing abundance in successively smaller size classes. There were no red maple (*Acer rubrum* L.) individuals sampled greater than 12.5 cm dbh, although red maple density generally increased in successively smaller size classes (Figure 6, middle). Of the five forest types sampled, the lowest density of seedlings occurred in the paper birch mixed forest type. Only three species (paper birch, trembling aspen, and mountain ash) had densities greater than 1000 seedlings/ha.

## Eastern White Cedar Forests

Ten plots were classified as eastern white cedar forest type and these were primarily

**Table 1. Basal area and density of live trees in balsam fir mixed forests in nine plots on Isle Royale National Park in 2010.**

| Latin name | Common name | Basal area $m^2$/ha | Density trees/ha |
|---|---|---|---|
| Deciduous | | | |
| *Betula papyrifera* | paper birch | 3.23 | 54.32 |
| *Fraxinus nigra* | black ash | 0.44 | 70.37 |
| *Populus tremuloides* | trembling aspen | 5.39 | 106.17 |
| *Prunus pensylvanica* | pin cherry | 0.02 | 17.28 |
| *Sorbus decora* | mountain ash | 0.33 | 72.84 |
| Conifers | | | |
| *Abies balsamea* | balsam fir | 8.51 | 2,614.81 |
| *Picea glauca* | white spruce | 4.47 | 340.74 |
| *Picea mariana* | black spruce | 0.58 | 79.01 |
| *Pinus strobus* | white pine | <0.01 | 2.47 |
| *Thuja occidentalis* | eastern white cedar | 2.38 | 132.10 |
| Total | | 25.36 | 3,490.11 |

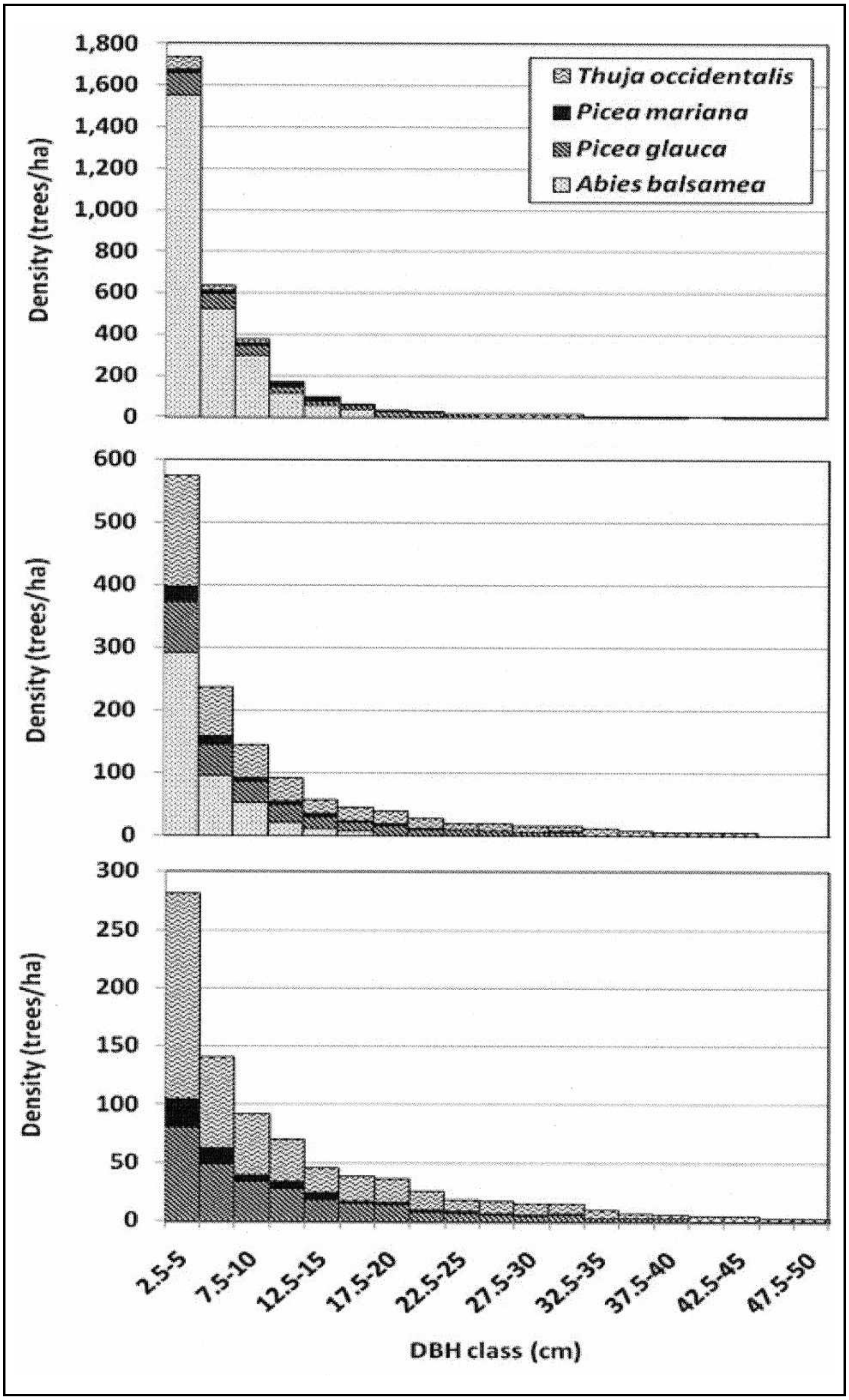

**Figure 5. Density-diameter graphs of common conifers in balsam fir mixed forests (top), white spruce-trembling aspen forests (center), and eastern white cedar forests (bottom).**

located in the western third of the island. Cedar was the most abundant species, comprising just over 75% of all trees sampled (Table 4, Figure 5, bottom). In eastern white cedar forests, the species with the greatest seedling density were cedar (3433/ha) and balsam fir (3380/ha). Three hardwood species (sugar maple, mountain ash, and mountain maple) had densities greater than 1000 seedlings/ha.

### Sugar Maple/Birch Forests

Eight plots were classified as the sugar maple/birch forest type and these were all in the western third of the island. Sugar maple comprised 91% of the hardwood species, while eastern white cedar represented 85% of the conifers (Table 5). Both paper birch and yellow birch were present in sugar maple/birch forests, although there were no clear patterns between density and size class for either birch species (Figure 6, bottom). Seedling density was highest in the sugar maple/birch cover type, with 26,750 seedlings/ha with sugar maple comprising 68% of these. White cedar had the greatest conifer seedling density at 2167 seedlings/ha.

## DISCUSSION

### Anticipated Mid-term Forest Structure

Cluster analysis revealed five forest types on Isle Royale. Cedar (Figure 5, bottom) and sugar maple (Figure 6, bottom) forests, both primarily on the western side of the island, as well as balsam fir forests (Figure 5, top) on the east side, are mature forest types. In addition, the small diameter class species cohorts are similar to current overstory assemblages. Barring stochastic events such as severe windthrow and fire, the overstory components of these forest types will likely remain unchanged through the next three to four decades. In contrast, both spruce/aspen (*Populus* spp.) mixed forests (Figures 5, middle; 6, top) and paper birch forests (Figure 6, middle) are in a transitional state.

The six paper birch plots are widely scattered throughout the central part of

**Table 2. Basal area and density of live trees in white spruce/trembling aspen mixed forests in 19 plots on Isle Royale National Park in 2010.**

| Latin name | Common name | Basal area $m^2$/ha | Density trees/ha |
|---|---|---|---|
| Deciduous | | | |
| *Acer rubrum* | red maple | <0.01 | 0.58 |
| *Acer saccharum* | sugar maple | 0.04 | 4.68 |
| *Acer spicatum* | mountain maple | <0.01 | 0.58 |
| *Betula alleghaniensis* | yellow birch | 3.42 | 101.75 |
| *Betula papyrifera* | paper birch | 3.07 | 76.02 |
| *Fraxinus nigra* | black ash | 0.47 | 60.23 |
| *Populus tremuloides* | trembling aspen | 6.43 | 159.65 |
| *Prunus pensylvanica* | pin cherry | 0.01 | 0.58 |
| *Salix bebbiana* | Bebb willow | 0.02 | 0.58 |
| *Sorbus decora* | mountain ash | 0.09 | 4.68 |
| Conifers | | | |
| *Abies balsamea* | balsam fir | 0.30 | 73.10 |
| *Picea glauca* | white spruce | 7.35 | 466.08 |
| *Picea mariana* | black spruce | 0.38 | 24.56 |
| *Pinus banksiana* | jack pine | 0.19 | 4.68 |
| *Pinus resinosa* | red pine | 0.27 | 4.68 |
| *Pinus strobus* | white pine | 0.35 | 4.68 |
| *Thuja occidentalis* | eastern white cedar | 4.68 | 226.32 |
| Total | | 27.06 | 1,213.43 |

the island. The density-diameter graph revealed that the highest density was in the 15.0 – 17.5 cm dbh class, with density lower in progressively smaller size classes. Density in the smallest size class, 2.5 – 5.0 cm dbh was only 5.6 trees/ha. Paper birch is an early successional species, rarely living beyond 140 years (Safford et al. 1990) although survival beyond 90 years is not typical, due largely to windthrow (Rich et al. 2007). The paper birch recruitment that occurred after the 1936 burn is now senescing and these areas may be succeeding toward red maple, black ash, and black spruce assemblages over the next few decades.

In the white spruce/trembling aspen mixed forests, the transition is not as readily apparent, although balsam fir, as well as black ash, is increasingly abundant in the smallest size classes. In the absence of disturbance, these forests will likely transition to these species over the next 20 – 30 years, although trembling aspen will likely remain a large component.

## Species Migration

In general, the climate of the upper Midwest is expected to become warmer (Christensen et al. 2007) with the area covered in boreal forests anticipated to contract (Galatowitsch et al. 2009). Species in northern Minnesota that are currently near the southern end of their ranges are anticipated to migrate northward, out of our area. These include balsam fir, black spruce, white spruce, jack pine (*Pinus banksiana)*, red pine (*Pinus resinosa)*, and balsam poplar (*Populus balsamifera* L.) (Frelich and Reich 2009). This is primarily due to heat and drought, although the pines are also threatened by the mountain pine beetle (*Dendroctonus ponderosae*), balsam fir is vulnerable to the balsam wooly adelgid (*Adelges piceae*), and balsam poplar is susceptible to the Asian long-horned beetle (*Anoplophora glabripennis*).While none of these exotic pests are currently within the range of Isle Royale, they are spreading and should remain a concern for park managers. Tree species currently in our area expected to increase in abundance under climate prediction scenarios include basswood (*Tilia americana*), northern red oak (*Quercus rubra*), red maple (*Acer rubrum*), and yellow birch (Frelich and Reich 2009). Finally, a few species are expected to have range extensions and move into the upper Midwest and include black cherry (*Prunus serotina*) and cottonwood (*Populus deltoides*).

Isle Royale is in a unique position compared with other national parks, and other preserves in general, due to its isolation. While this isolation has allowed it to retain a high degree of ecological integrity, it might also hinder attempts to promote resilience. Species with greater long-distance dispersal capacity (e.g., black cherry, cottonwood) may favorably colonize the island over those species less capable of long-distance dispersal (e.g., oaks).

Table 6 lists the species from Frelich and Reich (2009) that are expected to migrate into the upper Midwest, and hence potentially into IRNP, along with effective dispersal distances, as developed by Ravenscroft et al. (2010). None of the species has an annual dispersal distance greater than 21.1 km, the shortest distance between the mainland and the island. Rather than a species' reliance on its adapted dispersal mechanisms of wind or seed caching, opportunistic or stochastic events will likely be the primary means by which seeds reach the island. This includes seeds incidentally transported in feathers or fur (e.g., elm, ash) or the drifting over via water (oaks). Currently there is concern whether the rate of temperature change will outpace that of native tree species' dispersal abilities (Iverson et al. 2004; McKenney et al. 2007; Mohan et al. 2009; Woodall et al. 2009). The time lag inherent in the long-distance colonization of IRNP will do little to dispel this concern. Further, unintentional introduction by humans remains a likely introduction source. Roughly 17,000 people visit the park annually and most of these come via either a Park Service owned and operated ship based out of Houghton, Michigan, or one of two concession-operated boats. Education of, and corrective action against, transporting seeds and plant material is presented each time the Park Service ship is loaded with passengers from the mainland. This is not necessarily provided by the concessionaires (Suzanne Sanders, pers. observation).

Species migration projections can be applied to the mid-term successional trends of the five current forest types at IRNP to make long-term forest species projections for the island. Forests on the southwestern side of the island will likely be the most stable as yellow birch and sugar maple are anticipated to increase in abundance in northern Minnesota in the face of climate change (Frelich and Reich 2009). These are currently the two most abundant species in maple/birch forests. Cedar forests are also likely to remain fairly intact, although with a probable increase in sugar maple and a corresponding decrease in balsam fir (Frelich and Reich 2009). Obscuring this picture, however, is an emerging problem with cedar bark whereby large fissures span several meters from the base of the bole upward. This is commonly observed in northern Wisconsin (Suzanne Sanders, pers. observation) where it can affect nearly all individuals in a stand. It appears that this is hydrologically related, potentially caused by either drought or increased freezing and thawing cycles. Where this occurs, the bark expands, becoming dissociated from the cambium. It does not appear that trees can survive in this state for more than a few growing seasons.

Projections of species' assemblages in the forests currently dominated by paper birch as well as white spruce and trembling aspen are less clear, although it appears that red maple will become a dominant species over the next 50 years. Early and significant seed production (Marquis 1975) and tolerance of a wide range of both light and moisture conditions (Stephenson 1974) will most likely allow red maple to dominate these sites. Nonetheless, red maple does not typically persist into climax stages (Lorimer 1984). Besides red maple, most other species currently present in these

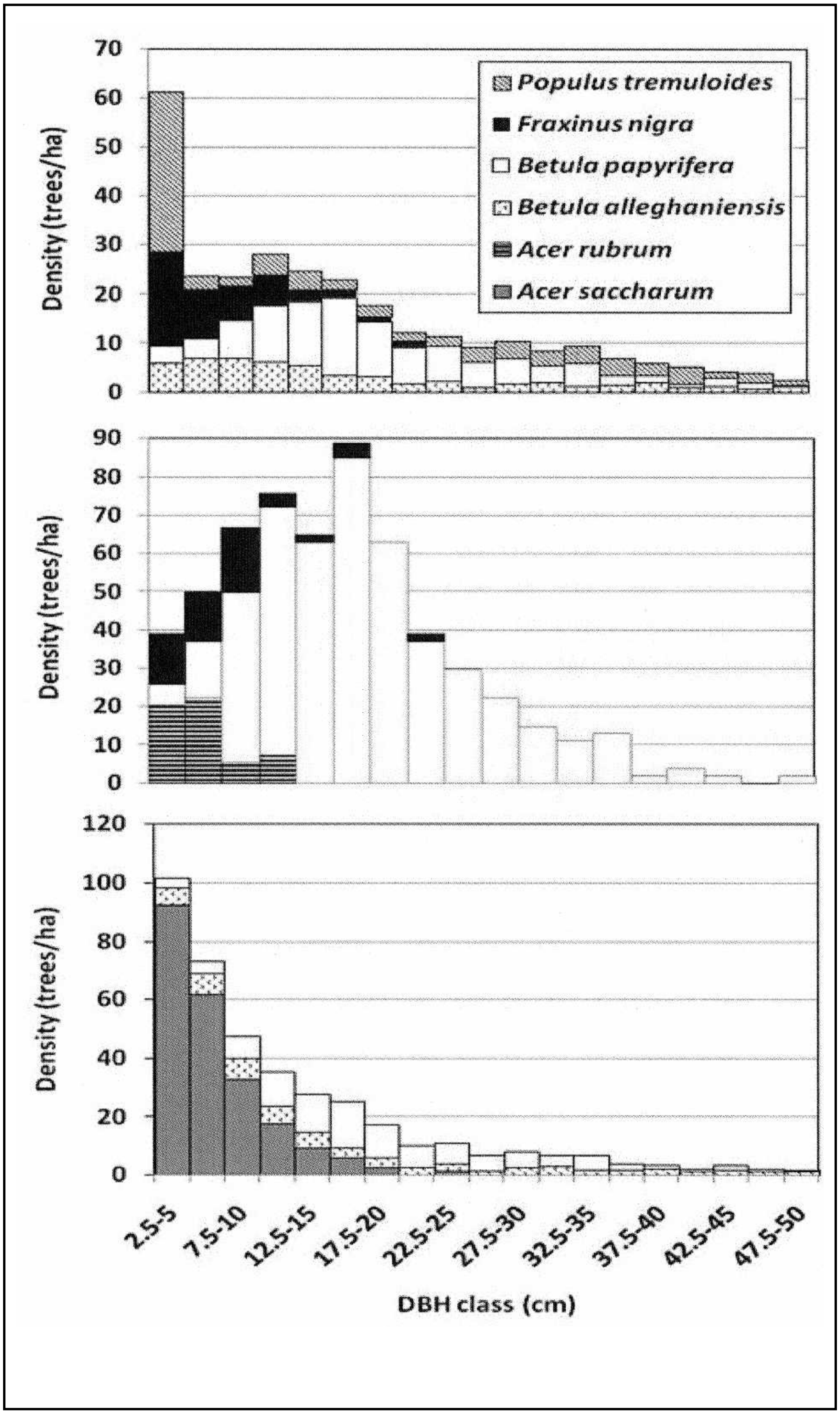

**Figure 6. Density-diameter graph of common hardwood species in white spruce-trembling aspen forests (top), paper birch forests (middle), and sugar maple forests (bottom).**

**Table 3. Basal area and density of live trees in paper birch mixed forests in six plots on Isle Royale National Park in 2010.**

| Latin name | Common name | Basal area m$^2$/ha | Density trees/ha |
|---|---|---|---|
| Deciduous | | | |
| *Acer rubrum* | red maple | 0.19 | 55.56 |
| *Acer saccharum* | sugar maple | 0.01 | 1.85 |
| *Acer spicatum* | mountain maple | <0.01 | 3.70 |
| *Betula alleghaniensis* | yellow birch | 0.03 | 1.85 |
| *Betula papyrifera* | paper birch | 13.34 | 477.78 |
| *Crataegus douglasii* | Hawthorn | <0.01 | 1.85 |
| *Fraxinus nigra* | black ash | 0.37 | 53.70 |
| *Populus tremuloides* | trembling aspen | 0.66 | 9.26 |
| *Sorbus decora* | mountain ash | <0.01 | 1.85 |
| Conifers | | | |
| *Abies balsamea* | balsam fir | 0.01 | 7.41 |
| *Picea glauca* | white spruce | 2.07 | 105.56 |
| *Picea mariana* | black spruce | 0.91 | 170.37 |
| *Thuja occidentalis* | eastern white cedar | 0.22 | 79.63 |
| Total | | 17.81 | 970.37 |

two forest types are expected to decrease in abundance or become extirpated (Frelich and Reich 2009). Ultimately, these sites could transition into either sugar maple or possibly red oak (*Quercus rubra* L.) forests. This latter species, while not present in large numbers currently, is a slow growing, semi-shade tolerant tree capable of growing in a range of soil moisture, texture, and nutrient availability, and light conditions (Weaver 1960; Archambault et al. 1990; Sandor 1990).

The balsam fir-dominated boreal forests on the eastern end of the island will likely undergo drastic changes. While certain areas such as Passage Island or cool, north-facing coves may provide refugia for this species, balsam fir will likely become extirpated from most areas where it is now found. The shallow, bedrock-derived soils may not be able to support any of the species expected to migrate inward, and this area could potentially transition to shrubland or grassland. Currently, balsam fir is a primary winter food source for the island's moose (McInnes et al. 1992). A reduction in abundance of balsam fir can negatively impact moose (and therefore wolf) populations. These impacts will likely be dwarfed, however, by direct impacts of climate change, specifically increased temperatures, on moose populations. Lenertz et al. (2009) showed a reduction in northern Minnesota moose abundance in response to increased temperatures. Moose are intolerant of heat, and those on Isle Royale are already near the current southern boundary of their distribution. It is likely that the population will become extirpated on Isle Royale due to warming temperatures before significant climate warming impacts on balsam fir are manifested.

While most native species have relatively short dispersal distances and will primarily rely on opportunistic events to colonize islands, many non-native species rely on ingestion and deposition by birds for dispersal. This allows for much faster rates of spread and imparts the ability to bridge large gaps between areas of suitable habitat (i.e., colonize islands). Non-native taxa that have the potential to invade IRNP include *Rhamnus cathartica* (common buckthorn) and *Lonicera* spp.

**Table 4. Basal area and density of live trees in eastern white cedar forests in 10 plots on Isle Royale National Park in 2010.**

| Latin name | Common name | Basal area m$^2$/ha | Density trees/ha |
|---|---|---|---|
| Deciduous | | | |
| *Acer rubrum* | red maple | 0.02 | 2.22 |
| *Acer saccharum* | sugar maple | 0.25 | 66.67 |
| *Acer spicatum* | mountain maple | 0.01 | 5.56 |
| *Betula alleghaniensis* | yellow birch | 2.98 | 33.33 |
| *Betula papyrifera* | paper birch | 3.67 | 72.22 |
| *Fraxinus nigra* | black ash | 0.09 | 45.56 |
| *Populus tremuloides* | trembling aspen | 2.94 | 24.44 |
| *Prunus pensylvanica* | pin cherry | 0.02 | 1.11 |
| *Sorbus decora* | mountain ash | <0.01 | 2.22 |
| Conifers | | | |
| *Larix laricina* | tamarack | 0.22 | 8.89 |
| *Picea glauca* | white spruce | 3.30 | 162.22 |
| *Picea mariana* | black spruce | 1.48 | 126.67 |
| *Thuja occidentalis* | eastern white cedar | 25.51 | 1,693.33 |
| Total | | 40.57 | 2,252.22 |

**Table 5. Basal area and density of live trees in sugar maple/birch forests in eight plots on Isle Royale National Park in 2010.**

| Latin name | Common name | Basal area m$^2$/ha | Density trees/ha |
|---|---|---|---|
| Deciduous | | | |
| *Acer rubrum* | red maple | 0.05 | 9.72 |
| *Acer saccharum* | sugar maple | 10.09 | 1,400.00 |
| *Betula alleghaniensis* | yellow birch | 9.60 | 113.89 |
| *Betula papyrifera* | paper birch | 1.29 | 9.72 |
| *Populus tremuloides* | trembling aspen | 0.21 | 1.39 |
| Conifers | | | |
| *Abies balsamea* | balsam fir | 0.30 | 5.56 |
| *Picea glauca* | white spruce | 1.13 | 38.89 |
| *Picea mariana* | black spruce | 0.08 | 2.78 |
| *Thuja occidentalis* | eastern white cedar | 13.27 | 294.44 |
| Total | | 37.03 | 1,879.17 |

(honeysuckles). Both of these taxa are highly invasive and localized populations exist on both the northern and southern shores of Lake Superior. Songbirds routinely fly from mainland Minnesota along the north shore to the western end of Isle Royale; under favorable conditions, they will also fly from the Keewenaw Peninsula of Michigan to the island (Alex Egan, Isle Royale National Park, pers. comm.). These two exotic plant taxa should be a concern for park managers, not only in the future, but at the present time. This is particularly relevant in rocky areas where species native to the upper Midwest may be slow to get established.

**Table 6. Species anticipated to migrate northward in the upper Midwest (Frelich and Reich 2009), along with their effective migration rates (Ravenscroft et al. 2010).**

| Species | Effective migration rate m/yr |
|---|---|
| *Acer negundo* (box elder)[b] | not available |
| *Acer rubrum* (red maple)[a] | 1,000 |
| *Acer saccharum* (sugar maple)[a] | 200 |
| *Betula allegheniensis* (yellow birch)[a] | 400 |
| *Fraxinus pensylvanica* (green ash)[a] | 300 |
| *Populus deltoides* (cottonwood)[b] | not available |
| *Prunus serotina* (black cherry)[b] | 3,000 |
| *Quercus alba* (white oak)[b] | 1,000 |
| *Quercus ellipsoidalis* (pin oak)[b] | 1,000 |
| *Quercus macrocarpa* (bur oak) [b] | 1,000 |
| *Quercus rubra* (red oak)[a] | 1,000 |
| *Salix nigra* (black willow)[b] | not available |
| *Tilia americana* (basswood)[b] | not available |
| *Ulmus americana* (American elm)[a] | 400 |

[a] Species already present at IRNP but are expected to increase.

[b] Species not currently present at IRNP, but are expected to migrate in.

## Management Directions

Climate change adaptation strategies focus on resisting change, promoting resilience to change, and facilitating change (Galatowitsch et al. 2009). While resistance strategies are not likely to work beyond the short-term – Millar et al. (2007) compare it to paddling upstream – they do provide the opportunity to "buy time" until more effective resilience strategies are developed. Resistance strategies may include altering hydrology, spraying for insect outbreaks, and controlling the populations of herbivores.

Resilience strategies focus on maintaining stable, functional ecosystems so that native species assemblages can migrate in, preventing the development of a stable ecosystem dominated by a few non-native species. Park managers should focus on promoting resilience to forest change. Unfortunately, immigration of non-native taxa will likely outpace that of native taxa, necessitating proactive measures to ensure ecological integrity. One such measure is the use of facilitated adaptation, also known as assisted migration. This is a strategy whereby individuals and populations of key native species are introduced as a means to promote resilience. This is a controversial topic with two obvious drawbacks being the disruption of coadapted gene complexes and the potential introduction of unforeseen diseases or pathogens. Despite these risks, facilitated adaptation is perceived by many to be a better alternative than no facilitation of species movements. Managers at IRNP should consider this adaptation strategy in the next few decades as new species begin to appear in the park. Research into propagation and establishment potential for IRNP should commence within the next few years. This would allow a quicker response time with more advantageous results when/if action is needed.

While the initial immigration over to the island is expected to be concentrated on the western end of the island (due to proximity of seed sources and the prevailing wind), consideration must also be given to colonization of the central and eastern portions. Currently these areas are dominated by balsam fir, a species whose range is expected to migrate north of Isle Royale. Poorly developed soils and shallow bedrock predominate the eastern third of IRNP. Although a target list of species has been developed for the region based on temperature and moisture conditions (Table 6), it is unclear whether soils in the eastern portion of the island can support these species. This area could potentially become a grassland or shrubland under a changing climate. Special consideration must be given to native taxa adapted to the climate and soil conditions present here. Otherwise, the open nature of this area will leave it especially susceptible to invasion by exotic shrubs and grasses.

Development of a forest change response plan for Isle Royale is warranted. This should be written in such a manner that it is both fiscally and logistically possible and ecologically practical. It should contain the following parts: (1) Identification of species expected to move onto the island under various temperature and moisture conditions (see Prasad et al. 2009); (2) Assessment of assemblage potential of these species (i.e., what species grow with what other species); (3) Identification of species (tree, shrub, or grass) that are adapted to the shallow soils of the eastern third of the island; (4) Identification of research needs related to facilitated adaptation. This should include a range of alternatives and account for multiple possible projections. The emphasis should be placed on species function, rather than assemblages; (5) Logistical plans for carrying out facilitated adaptation. This is not to say that we are advocating this currently, but a course of possible action should, at the very least, be spelled out; and (6) A thorough assessment of costs for the work associated with facilitated adaptation.

We acknowledge that some ideas and scenarios presented in this paper are controversial and, at this point in time, may appear to be completely unwarranted. We also acknowledge, however, that we are entering a time of great uncertainty and change, and that decisions made today, whether for action, or for inaction, will strongly influence the forests of tomorrow (Polasky et al. 2011). Isle Royale occupies a unique niche both ecologically and geographically. It is ecologically sound and not being managed for resource extraction. Geographically, its northerly location and proximity to Lake Superior provide the potential for it to become a refuge for many species; for some taxa, IRNP could potentially support the only populations in the conterminous United States. Traditional dogma on forest management will quickly become outdated (at best) or even deleterious. Managers must grasp onto new doctrines to meet the changing demands of the next 50 to 100 years.

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