Chapter

Fire and Climate Change in the North American Great Lakes Pine Transition Forest

Steven I. Apfelbaum and Alan Haney

Abstract

This chapter explores potential changes in fire regimes and biodiversity given projected changes in climate in the Great Lakes Pine Transition Forest (GLPF), a portion of the southern boreal forest. We have studied how forest structure, composition, and biodiversity changed over nearly 500 years by comparing communities on comparable edaphic locations of various ages since stand-replacing disturbance. Our interpretation of probable future changes is based on how these ecosystems have reassembled after wildfire, blowdown, and insect disturbances in the past and projections of climate change in the next 75 years. Rapid climate change is now introducing different conditions from those to which this ecosystem was historically adapted, and therefore, projections of future change are more subjective.

Keywords: boreal forest, great lake pine forest formation, forest carbonpeat carbon, wildfire climate risk

1. Introduction

This chapter explores potential changes in fire regimes and biodiversity given projected changes in climate in the Great Lakes Pine Transition Forest (GLPF), a portion of the southern boreal forest. We have studied how forest structure, composition, and biodiversity changed over nearly 500 years by comparing communities on comparable edaphic locations of various ages since stand-replacing disturbance [1, 2]. Our interpretation of probable future changes is based on how these ecosystems have reassembled after wildfire, blowdown, and insect disturbances in the past and projections of climate change in the next 75 years. Rapid climate change is now introducing different conditions from those to which this ecosystem was historically adapted, and therefore, projections of future change are more subjective.

2. Ecosystem description and historic response to disturbance

The GLPF, as with most of North America's ecosystems, was historically adapted to periodic fire. With Indo-European settlement in the mid-to-late 1700s essentially all ecosystems of North America were altered increasingly as populations and technology advanced. Those not directly affected by timber harvests or forest removal, cultivation, or hydrologic alterations were altered by fire suppression and introduction of exotic species. Rapid climate change threatens to further change ecosystems, often unstable because of previous stresses, including loss of species. Although the GLPF has not lost many species, if any, the relative abundance and relationships have been altered. Ecosystems such as the GLPF, adapted to fire regimes that changed slowly over nearly 10,000 years, now must adapt to changes in fire regimes in a matter of several decades. Moreover, increased fire frequency and intensity, that now appears inevitable, will contribute more greenhouse gases emissions in a negative feedback loop.

The GLPF lies between the Boreal Forest Region in North America, which extends from Newfoundland to Alaska to the Great Lakes–St. Lawrence Forest Region, as defined by Rowe [3]. Circumpolar boreal ecosystems, of which the GLPF is a segment, are the largest remaining intact forested ecosystem on the planet [4]. The GLPF is distinguished most obviously by presence of red pine (*Pinus resinosa*) that sometimes occurs in nearly pure natural stands, but more often, when present, is a co-dominant. Eastern white pine (*Pinus strobus*) is also a signature species of the GLPF, although its range extends much farther south, well beyond the boreal forest biome. Otherwise, most of the trees common to at least the central boreal forest of North America coexists in the GLPF. Typical associates of red-and-white pine are jack pine (*Pinus banksiana*), balsam fir (*Abies balsamifera*), white-and-black spruce (*Picea alba and P. mariana*), paper birch (*Betula papyrifera*), tamarack (*Larix laricina*), northern white cedar (*Thuja occidentalis*), quaking aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*), proportions varying according to edaphic characteristics, and type and time since the disturbance that gave rise to the current community.

A classification of 13 upland plant communities found in the GLPF was developed by Ohmann and Ream [5] and Grigal and Ohmann [6]. Classification of lowland communities was developed by Heinselman [7] and Dean [8]. These eight lowland community types plus the 13 upland community types provide a baseline for predicting changes associated with climate change. Both the upland and lowland communities have abundant carbon present in standing vegetation and peat substrates, much of which might be released by increased fire.

The tree species listed above are dominant or codominant in all except three community types: lichen communities on exposed rocky outcrops; alder-willow shrub communities, primarily along streams or in frequently flooded areas; and marsh and open muskeg. A fourth wetland community is dominated by black ash (*Fraxinus nigra*) and American elm (*Ulmus americana*) that is becoming less common because of disease. The composition, structure, and diversity of all upland communities are strongly influenced by the intensity and extent of wildfire [1].

Lowland communities, historically, burned, usually after exceptionally dry periods, often several successive years with below-average precipitation. Under conditions of low humidity and high wind, crown fires can sweep across lowland communities even without prolonged drought. With drought, even substrates burn. In extreme cases, peat-filled depressions can become open ponds. Despite only covering around 3% of land surface area, peatlands are responsible for storing up to one-thirds of the world's soil carbon [9, 10]. This is twice as much carbon as in all the world's forest biomass combined. Peatlands play a critical role in filtering and storing water. They improve water quality and reduce floods [11, 12]. They are home to many rare and unique species. Following fire, pines, especially jack pine, typically dominate upland sites and spruce and fir or aspen dominates sites with deeper soil and more reliable moisture.

Strong straight-line winds are a secondary disturbance in the GLPF. High wind often results in extensive blowdown. Aspen is a vigorous root-sprouter, and when present in predisturbance communities, will dominate after blowdown or clear-cutting, especially on deeper soils with adequate moisture [1, 13–15]. Aspen, with wind-blown seed also can invade extensive burns from surviving parent trees that may be located well outside the burn. Aspen is intolerant and relatively short-lived; consequently, following blowdown, aspen dominance slowly gives way to more tolerant spruce and fir, although surviving aspen may persist as a scattered overstory for 100 years or more. In the long-term absence of disturbance, spruce-fir forests eventually replace aspen on deeper and more mesic sites. Where seed sources are present, white and red pine may also become established and persist into old-growth, 250 or more years [1]. Red pine more often regenerates after fire, whereas the more tolerant white pine may regenerate after fire or wind-throw. Both white and red pine develop thick bark that can withstand fire after 30 to 50 years, and they can survive for 400 or more years under favorable conditions, creating an overstory above spruce, fir, or jack (pine). Such old-growth communities are rare, in part not only because the commercial value of mature white-and-red pine led to widespread harvesting but also because intense fire associated with periodic drought regenerated forest communities, with or without white-and-red pine depending on whether parent trees survived long enough afterward to release viable seed.

Our studies have focused on vegetation and breeding birds [16] and blowdown [13–15], and corresponding breeding bird communities and species associated with the vegetation structure and compositional responses [17–20]. A synopsis of some likely changes include a decline in diversity of bryophytes and other understory vegetation is likely. Breeding bird diversity in jack pine-black spruce communities declines as these even-aged communities mature. As for several postfire years, diversity is higher, frequent fire might favor bird diversity. After intense stand-replacing crown fires in upland jack pine communities, a homogeneous jack pine or jack pine-black spruce is regenerated. The relatively low diversity of the bird community, dominated primarily by bark-gleaning and tree-foliage-searching foraging guilds, in the rather homogeneous jack pine forest stand is replaced by species that include ground brush foragers that feed on seeds and insects, tree foliage and brush foliage searchers that feed on insects, fly catching birds that sally forage for flying insects across the openings and open for structure of a newly burned site, woodpeckers that nest in the dead and dying trees and forage forest bark beetles, and numerous raptors that arrive in search of grouse another bird foraging on the lush insect and seed production at the ground story.

The presence of abundant aspen saplings provides food and cover for much wildlife, especially important for charismatic species such as moose and beaver. Food chains in young aspen is indicated by heavily browsed saplings and presence of fecal material of moose and snowshoe hare, associated with fecal material of wolves which contain the hair from these herbivores. Northern Goshawk (*Accipiter gentilis*) localize their nest around recent burns, where they actively have been documented to pursue their primary foodstuff, ruffed grouse (*Bonasa umbellus*) and where we have observed and documented their nesting [18, 21, 22].

3. Past and future regional climate

With projected climate changes, both blowdown and fire will become more frequent, and likely will become more extensive given higher temperatures and more extreme climatic events, especially thunderstorms. Although there are excellent records of climate change over the past 50 or more years, and very good models of how climate will change in the next 50 years, the relationship between climate and fire characteristics is much more nebulous. Much of the anticipated change in climate and projections of associated impacts for the Great Lakes Region is provided in a report (An Assessment of the Impacts of Climate Change on the Great Lakes) by the Environmental Law and Policy Center [23] prepared by 18 climate scientists with expertise in the region. That report, however, did not include a discussion of how climate change might affect forest ecology and fire.

Climate is changing faster in the Great Lakes region than averages over the rest of United States. Averaged over 1985–2016 relative to 1901–1960, in the Great Lakes Basin the temperature has increased 1.6°F (0.53°C). This is faster than the 1.2°F (0.4°C) increase for United States [24]. Teasing these trends apart reveals an average increase across Wisconsin, for example, of over 4°F (1.3°C) in winter and 1°F (3.0°C) in summer. Total annual days of ice-cover for Lake Mendota in Madison, Wisconsin, where good records have been kept since 1860, shows a steady decrease from around 120 days to a present five-year running average of around 80 days. Arguably more important than averages is the increase in year-to-year variation. For example, the maximum percent of Great Lakes covered by ice has remained very close to the 50-year average of about 50%. The year-to-year variation, however, has increased substantially, with higher and lower extremes. Averaged over the same time periods, annual precipitation increased in the Great Lakes Basin by 10%, but much of the increase fell in winter and early spring where it has less effect on fire regimes. Summer precipitation in the Basin is predicted to decrease by 5–15% by the end of the century [25]. Again, the variation has increased with greater and lower amounts and more prolonged droughts.

Globally, extreme weather events are expected to become more common. In North America, heat waves and drought have become more frequent since the 1960s [24]. When comparing average annual daily mean temperatures for the 1976–2005 period to that predicted for the 2070–2099 period, an increase of 5.8–10.1°F (1.9–3.4°C). is projected for the Great Lakes Basin [23]. The range reflects two different scenarios; the lower scenario is based on optimistic reduction in greenhouse gas (ghg) emissions while the higher scenario is based on a projection of current trends in ghg emissions. Extremely warm days (those with temperatures exceeding 90°F (32.2°C)) are projected to increase by 17–40 days by the end of the century, the range reflecting the low- and high-ghg emission scenarios. Wintertime warming is expected to increase proportionately more than summertime high increases, as documented for Wisconsin above. The frost-free period will increase substantially. Days with minimal temperature exceeding 32°F (0°C) in the Great Lakes Basin are projected to increase by 27 and 42, with the low and high scenario models, respectively. These highly probable climate changes can only result in more frequent and more severe fire.

Based on historic fire patterns, conservative fire projections can be offered. Historic fire return intervals vary depending on cycles of drought and landform position, but average 70–110 years [1]. It has been rare that any upland forest escaped fire for more than 250 years. A few pockets of old growth up to 450 years have survived when protected by sheltering topography (e.g., draws, lakes, rock escarpments). There can be little doubt that with even the most optimistic climate projections for higher summer temperature, drier conditions, and more severe storms for the next 50 years, fire frequency will increase. Because this region is often where cold dry arctic air masses clash with warm, moist Gulf air masses, thunderstorms with substantial lightning are typical and, not infrequently, derechos develop with hurricane-force straight-line winds. Even under current conditions, winds associated with thunderstorms commonly exceed 60 mph (96.6 km/hr).

Lightning in the region is primarily generated by frontal and convective activity [26]. On average 27 thunderstorms occur annually in the Great Lakes region. Lightning occurs mostly mid-May to mid-September. Although forest conditions become increasingly dry as the growing season progresses, exposure to lightning decreases.

Prolonged dry periods, often extending over several consecutive years, have led to more widespread and more severe fires in the past [1]. Such drought periods are likely to continue and become more severe. Droughts may become so severe as to be the cause of the death of trees and dramatically reduce lake levels. Even one or 2 months with little to no precipitation during spring or early summer can set the stage for severe fires [1]. For example, the region experienced below normal precipitation from 1929 through 1936 and extreme high temperatures were recorded in 1936 leading to outbreak of many severe fires in the region. It is during such droughts that lowland communities often burned.

4. Projections of how climate change will alter the GLPF

Heinselman [1] developed forest stand-origin maps of extensive portions of the GLPF using dendrochronology to determine forest tree ages. Fire scars and tree growth ring measurements have been used to identify periods of drought associated with wildfire patterns. Swain [27] used charcoal and other pyrolyzed material in annual lake varves to examine fire frequencies. These data were used to document return intervals and relationship of different communities to fire. Fire with return intervals of 65–100 years on upland sites have led to jack pine and aspen dominance over much of the region. In fire-protected draws such as lake margins and wetlands, white and red pine, spruce, and many species of shrubs may escape fire for 100–200 or more years. Many wetlands burned only during the most severe droughts [1].

Heinselman [1] found many, but not all, fire scars to be associated with major fire years, where intense crown-fires resulted in stand-replacement. However, during intervening years, ground fires that under-burned forests of multiple age-classes and origins, confused the interpretation of stand ages. For example, during droughts, peat becomes combustible and, once ignited, can retain fire for months, even into winter. The resulting patterns of vegetation largely reflect the combustibility of fuel, especially the difference between those fuels able to carry crown-fires and wetlands or protected areas more prone to lighter, ground fires.

5. Fires and biodiversity

Fire largely shapes vegetation composition which, in turn, largely controls the breeding and overwintering birds, mammals, insects, amphibians, and reptiles that persist in each community. In addition to biodiversity, fire and postfire succession shapes the structure of the vegetation [1]. Wind or insect outbreaks also influence which dominant species of trees and shrubs will develop, but fire can, and often does, trump those disturbances.

Addressing the most common community types, we can project the responses likely with climate change. Based primarily on Heinselman' s work [1, 28, 29], the most common community types in the GLPF are fir-birch (16%), jack pine-black spruce (11%), black spruce bog (7%), maple-aspen-birch-fir (6%), aspen-birch (6%), jack pine-fir (6%), and black spruce-feather moss (6%). Here, we summarize forest community changes likely with the projected climate changes.

1. *The fir-birch communities*. This community is commonly affected by periodic outbreaks of spruce budworm that cause die-off of balsam. The community is most often found on lower slopes near lakeshores, streams, and wetlands. While this community type occupies topographic positions somewhat protected from fire, it is vulnerable. Most have developed over 100 years since fire. Higher-fire frequency and greater intensity will tend to greatly reduce the fir component and lead to a birch-dominated younger forest type.

2. *Jack pine-black spruce communities*. This common community type occurs mostly on ridges and slopes. Most are even-aged stands that originated after dry periods and widespread fire in 1863–64, 1875, 1894,1903, 1910, and 1918. Biodiversity in this community type is lower than in most others. This may be a community, however, that is best adapted to increasing frequency and severity of fire and is the community type most likely to experience more fire. Both jack pine and black spruce reseed after fire. Jack pinecones are highly serotinous, but black spruce also has persistent cones that frequently contain viable seeds that are released after being exposed to crown fires. Jack pine trees as young as half a dozen years will produce cones. In the unlikely long-term absence of fire, jack pine will gradually die and be replaced by the more tolerant black spruce. Even-aged jack pine-black spruce stands will continue, but average age likely will be reduced to 25–50 years.

3. *Black spruce bogs and black spruce-feather moss community types*. These communities are either an acidic bog type or better drained with feather moss ground cover. The bog type usually has a bryophyte-dominated ground cover but may have an understory of speckled alder (*Alnus rugosa*) and associated species with greater diversity. Tree growth is slow, but this type is somewhat protected from fire by its topographic position and wet substrates. Peat accumulation under this and other lowland forest communities varies in depth. In depressional locations, peat can be 5–20 m in depth, with shallower deposits (i.e., <1 m in depth) in upland communities, and along margins of depressional landforms [9, 11]). During prolonged dry periods, wildfires often eliminate most of the shallower peats and burn to varying depths in the deeper depressional deposits. During normal or wetter conditions, crown fires readily burn over the peatland forest cover without combusting the peat. With changing climate, fire is likely to result in younger black spruce-dominated forests with less peat. Deeper peat will also be reduced, but likely will persist in lowlands that hold water through drought periods.

This community type often includes extensive shallow peat substrates with a shallow 15 cm depth which contains ~60–90 tons of carbon/hectare [30]. Using these tonnages for estimation and the acreage of GLPF and southern boreal forest in Ontario (26 million ha of forested peatlands), this conservatively suggests ~1500–2300 million tons of carbon to be present in the peat. If this burns, it releases 1.65 to 1.8 times this, or 2400 to 4140 million tons of CO_2 equivalent, or 0.2 to 0.4 gigatons of GHG emissions. More emissions would be expected if fires burned deeper peat deposits with increased summer heating and drought. Peatlands in this small example from Ontario represent a very small percentage of the estimated 600,000 million metric tons of peat estimated to be present across on earth [9, 11].

4. *Maple-aspen-birch-fir and aspen-birch community types*. These communities occupy more mesic sites than jack-pine cover types and can occur in any topographic location but are most common on lower slopes or more level areas. In addition to dominant aspen and birch, they have an understory of co-dominant fir. Many originated after old growth white pine were harvested. In areas not logged, most originated from fires in 1864, 1875, 1894, and 1910, or if after logging, from slash fires between 1895 and 1930. The mesic nature of these communities and the dominance of deciduous trees give these forests some protection from climate change. With increasing drought and high fire intensity, however, we can anticipate increased dominance of birch and growing presence of jack pine.

5. *Jack pine-fir communities*. This community type originated following fire, most often, between 1854 and 1925. The community is dominated by even-aged, pole-sized jack pine and scattered aspen with various understory and codominant fir with some black spruce. These are usually species-rich communities on mesic-to-dry sites. With climate change, jack pine is strongly favored to increase dominance, with less fir and more black spruce. Understory vegetation and breeding bird diversity will decrease.

6. Future fire and climate relationships

At the scale of the landscape, the following fire and ecosystem-scale changes are likely:

1. *More winter/spring precipitation*. The GLPF region absorbs solar radiation that quickly warms the land. Increased winter and spring precipitation may have little effect on fire regimes of the GLPF, but especially with warmer and drier summer conditions, may further cause a shift of fire to later in the season. Increased runoff with the overall increase in precipitation, coupled to fire disturbance, may increase the saturated zone around wetlands, and increase the duration of flooding, thereby reducing the combustibility of lowland forests. This may also increase their effectiveness as fire breaks, reducing the size and rate of spread of spring and early summer wildfires, thereby reducing burn patch sizes and continuity across the landscape.

2. *Ignition of wildfire*. Intensity of spring storms when the contrast between colder Canadian air masses and warmer Gulf air masses are greatest will increase the incidence of lightning ignition. Although thunderstorms are less frequent in

summer, they do occur and with warmer, drier conditions, lightning ignition will likely increase.

3. *Drier, warmer summers, and more extreme droughts*. Larger and more intense wildfires are quite likely, along with shorter fire return intervals. This will result in younger more even-aged forests, especially on better-drained topography. Stump and root-sprouting trees and shrubs (e.g., aspen, birch, mountain maple, and alder) will be favored, especially on mesic sites where jack pine is less aggressive. Peat and organic material of any nature will likely be decreased. With more intense storms and less-organic protection, uplands will be subjected to increased erosion, with resulting siltation and nutrient enrichment of lakes and streams.

4. *Old-growth remnants, already rare, will become even less common.* White pine, especially, will be disfavored as jack pine increases. Older (>300 years) and mid-age stands (150–300 years) will be replaced by younger stands that will be more homogeneous. As old growth stands and trees decline, so too will the nesting opportunities for Bald eagle, Osprey, barred owl, Great gray owl, ravens, chimney swifts, and such species as purple finch and red crossbills. Pine martens, fishers, bobcat, black bear, among other wildlife will also decline. Woodland caribou, moose, and timber wolves may be favored in the increased graminoid, and lichen-covered open ground.

7. System changes

Durability and longevity of carbon on the landscape in standing or downed woody biomass will decrease. GHG's emissions, in time, will decline as future fires burn through younger stands with less woody biomass, and most vulnerable peat in wetlands is burned.

Biodiversity, especially of understory species and neotropical birds will continue to go down. Habitat loss and climate change are already reducing migrant bird species. A recent report by the National Audubon Society estimates that two-thirds of North American birds are endangered species of extinction by the end of the century. In the GLPF, birds that nest or feed in open ground and that utilize brush and young postfire jack pine stands will be less impacted by changing fire regimes. Mourning Warblers, Chestnut-sided Warblers, Yellow-rumped warblers, and Ruffed Grouse are examples of birds that will be favored [18, 19]. Species that will decline during the replacement of mid-age and older stands by these younger stands will be the tree-foliage-searching guild, such as Solitary and Red-eyed Vireo, Parula, Canada and Black-throated Green Warblers, Ruby-crowned Kinglets, Spruce Grouse, Hooded Merganser, and Northern Goshawk [21, 22]. Woodpeckers, including northern black-backed and arctic three-toed woodpeckers, pileated and downy and hairy woodpeckers are all envisioned to increase and colonize burned settings with dead standing trees. Flycatchers are expected to increase as the dense stands open after fire with canopy mortality, foraging species that sally (e.g., olive sided flycatcher, least flycatcher), while species that forage on-wing (e.g., night-hawks, chimney swifts, tree swallows) would increase.

Plant species shifts will occur, but in our experience, no species is lost from the landscape following fire [2, 16]. Native graminoids (*Carex, Calamagrostis*, etc.) will increase as will species of more open sites such as berries (blueberry-*Vaccinium*, Blackberry and raspberry (*Rubus* spp), and bearberry (*Arctostaphylos* sp). Mountain

DOI: http://dx.doi.org/10.5772/intechopen.110734

ash (*Sorbus americana*), mountain maple (*Acer spicatum*), Haws (*Viburnum* spp) are also likely to increase. Species of bryophytes, especially mosses, leafy liverworts, and ferns of deep-forested settings, especially arboreal species found on the trunks of living trees are likely to decline.

8. Climate and fire

Climate change can acerbate effects that have not previously been considered. One such feedback loop is the changing fire regime and ghg emissions from carbon contained in the standing and downed timber and peat substates. To understand the differences in the magnitude of the GHG emissions as an example, we compare the carbon present in the forest cover and forested peatlands in Ontario [11].

Peatland carbon. Boreal forests comprise 83% of all North American forests. The above Ontario example (covering 26 million ha) only represents ~30% of all peatlands in Ontario's boreal region [9, 11]. Just in this region, as fires become more frequent and intense, 24–41 million tons of CO_2 equivalent could be released to the atmosphere from combusted peats.

Forest Carbon. Ontario forests containing 193–214 mega-tons of carbon/ha (MgC/ha) accrue additional carbon at rates of 2.1–3.7 MgC/ha-yr [30]. An additional 40% (or 193 MgC/ha × 1.40) is found in the roots, as below-ground carbon (or 77 MgC/ha). Using the same Ontario forested peatlands acreage as above, >7 million tons (5,043,090,000 MgC above-ground, and 2,012,010,000 MgC below-ground in roots) could be combusted with increased frequency and intensity of wildfires in this Ontario landscape.

9. Summary and considerations

Changes in climate and wildfire regimes are predicted to result in large impacts in the GLPF and release of carbon may have even more profound impact, especially when scaled to the entire boreal ecosystem. Significant increases in fire intensity, frequency, and the acreage burned are predicted in this ecosystem with climate change predictions [11, 12, 31].

Release of carbon from the biome may well influence future climate change, altering climate significantly more than the current predictions. This suggests several considerations for forest/ecosystem management as follows:

1. *Preemptive prescribed burning of expansive upland jack pine communities.* In the larger GLPF/boreal ecosystem, jack pine and spruce communities are the most widely distributed and are some of the most fire vulnerable of all communities. Where cool "under-prescribed burning" can be conducted to reduced ladder fuel loads and combustible fuel levels, this could reduce the future of crown fires that can spread rapidly over the remaining uplands and into forested lowlands.

2. *Preemptive prescribed burning to protect age class frequency distributions for mid and old growth forest systems*. Already rare, mid, and older growth forest systems will be increasingly stressed and will decline under the climate change predictions. Biodiversity of these older systems will shift to younger growth forest systems and with this a decline in regional diversity is likely. The use of preemptive

prescribed burning in forest communities around the locations with mid- and older-age communities may help reduce the risk of spread of regional fires to these older communities.

3. *Preemptive prescribed burning to protect age class frequency distributions for mid- and old-growth forest systems.* Already rare, mid, and older growth forest systems will be increasingly stressed and will decline under the climate change predictions. Biodiversity of these older systems will shift to younger growth forest systems and with this, a decline in regional diversity is likely. The use of preemptive prescribed burning in forest communities around the locations with mid- and older-age communities may help reduce the risk of spread of regional fires to these older communities.

4. *Preemptive mitigation of dewatering of peats and landscapes from mining, development, and water and forest management projects.* Dewatering of landscape surface and ground water resources is a common intentional and inadvertent activity associated with mining and development. Many silvicultural activities involve intentional dewatering to gain growing season access to timber resources. Restoration of hydrology to reverse the effects of dewatering should be considered to reduce the increases in the normal year drying (and drought year) effects and increases the risk of wildfire and its spread and intensity.

5. *Rare species and community-specific plans for mitigation of fire frequency and intensity changes will be needed.* Some species and communities, particularly fire microsites, springs, and seeps, and in fens and other rare peatland resources will decline with predicted climate change.

6. *Monitoring to understand trajectory of effects and changes.* As one of the largest global scale forest and peat-rich areas on earth, a real-time monitoring program should be put into place to measure and monitor drying trends, fire-risk trends and locations with the aim of emulating natural fire regimes and ensure that the above outcomes, among others, are built into management plans.

7. *Creation of assessments and action plans to address each these considerations*. (a) Reducing the potential for the spread of wildfires with appropriate economic incentives to create landowner participation. (b) Protection of loss of mid- and older-growth communities. (c) Restoration of landscape hydrology and developing alternatives for water sourcing. (d) Rare species and microsite mapping and management of biodiversity refugia to reduce losses and extirpation and (e) Establishment of on-the-ground monitoring and remotely sensed imaging to target mitigation and remedial restoration strategies for restoration and management of the GLPF/boreal ecosystem.

Author details

Steven I. Apfelbaum[1*] and Alan Haney[2]

1 Applied Ecological Institute, Inc., Brodhead, WI, USA

2 University of Wisconsin, Stevens Point, WI, USA

*Address all correspondence to: steve@aeinstitute.org

References

[1] Heinselman M. The Boundary Waters Wilderness Ecosystem. Minneapolis: University of MN press; 1996. p. 334

[2] Apfelbaum SI, Haney A, Wang F, Carlson J. Old-growth southern boreal forest stability response to a stand-replacing wildfire. Natural Areas Journal. 2017;**37**(4):474-488

[3] Rowe JS. Forest Regions of Canada. Canadian Dept. of Environment: Canadian Forest Service Publ; 1972. p. 1300

[4] Collinson AS. Introduction to World Vegetation. Springer; 1978

[5] Ohmann LF, Ream RR. Wilderness Ecology: Virgin Plant Communities of the Boundary Waters Canoe Area. U.S. Forest Service res. Paper NC-63; 1971

[6] Grigal DF, Ohmann LF. Classification, description, and dynamics of upland plant communities within a Minnesota wilderness area. Ecological Monographs. 1975;**45**:389-407

[7] Heinselman M. Landscape evolution, peatland types, and the environment in the Lake Agassiz peatlands natural area, Minnesota. Ecological Monographs. 1970;**40**:235-261

[8] Dean JL. Wetland Forest Communities of the Eastern Boundary Waters Canoe Area. University of Minnesota; 1971. M.S. thesis. (Cited from Heinselmann, 1996)

[9] Joosten H. The Global Peatland CO_2 Picture: Peatland Status and Drainage Related Emissions in all Countries of the World. Ede: Wetlands International; 2009. Available from: https://unfccc.int/sites/ default/files/ draftpeatlandco2report.pdf

[10] Scharlemann JP, Tanner EV, Hiederer R, R., and V. Kapos. Global soil carbon: Understanding and managing the largest terrestrial carbon pool. Carbon Management. 2014;**5**(1):81-91. DOI: 10.4155/cmt.13.77

[11] United Nations Environment Programme. 2022. Global Peatlands Assessment: The State of the World's Peatlands

[12] International Union for Conservation of Nature. Securing the Future for Global Peatlands. Hawaii: World Conservation Congress Resolution WCC-2016-Res-043-EN; 2016. Available from: https://portals.iucn.org/library/sites/library/filesresrecfiles/WCC_2016_RES_043_EN.pdf

[13] Burris JM, Haney AW. Bird communities after blowdown in a late-successional Great Lakes spruce-fir forest. The Wilson Bulletin. 2005;**117**(4):341-352

[14] Burris JM, Haney AW. Bird communities before and after a catastrophic blowdown in a Great Lakes pine forest. Bird Populations. 2006;**7**:10-20

[15] Lain EJ, Haney A, Burris JM, Burton J. Response of vegetation and birds to severe wind disturbance and salvage logging in a southern boreal forest. Forest Ecology and Management. 2008;**256**(5):863-871

[16] Apfelbaum SI, Haney A. Bird populations before and after wildfire in a Great Lakes pine forest. The Condor. 1981;**83**(347):354

[17] Apfelbaum SI, Haney A. Nesting and foraging activity of the Brown creeper in Northeastern Minnesota. The Loon. 1977;**49**(2):78-80

[18] Apfelbaum SI, Haney A. Changes in bird populations during succession following fire in the northern Great Lakes wilderness. In: Proceedings – National Wilderness Research Conference: Current Research, 10-16. General Technical Report INT GTR-212. Forest Service: Intermountain Research Station: U.S. Department of Agriculture; 1985;**6**

[19] Apfelbaum SI, Haney A. Bird population changes in recovering conifer forests documented (Minnesota and Ontario). Restoration and Management Notes. 1985;**3**(1):34-35

[20] Haney A, Apfelbaum S, Burris JM. Thirty years of post-fire succession in a southern boreal forest bird community. American Midland Naturalist. 2008;**159**(2):421-433

[21] Apfelbaum SI, Seelbach P. Nest tree, habitat selection, and productivity of seven north American raptor species based on the Cornell University Nest record card program. Raptor Research. 1983;**17**(4):97-113

[22] Apfelbaum SI, Haney A. Note of foraging and nesting habits of goshawks. The Loon. 1984;**56**(132):133

[23] ELPC, (Environmental Law and Policy Center). An Assessment of the Impacts of Climate Change on the Great Lakes2019. p. 70

[24] USGCRP, (US Global Climate Change Research Program). 4th National Review and Report. 1800 G Street, NW, Suite 9100, Washington, DC, 20006, USA; 2017. Available from: Globalchange.gov

[25] Byun K, Hamlet AF. Projected changes in future climate over the Midwest and Great Lakes region using downscaled CMIP5 ensembles. International Journal of Climatology. 2018;**38**:e531-e553

[26] Baker DG, Hines DA, Strub JH Jr. Precipitation facts, normal, and extremes. Climate of Minnesota, Part V, University of Minnesota Agricultural Experiment Station Tech. Bull. 1967:254

[27] Swain AM. A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. Quaternary Research. 1973;**3**:383-396

[28] Heinselman M. Fire and succession in the conifer forests of northern North America. In: West DC, Shugart HH, Botkin DB, editors. Forest Succession, Concepts, and Applications. New York, N.Y: Springer-Verlag; 1981. pp. 374-405

[29] Heinselman M. Fire intensity and frequency as factors in the distribution and structures of northern ecosystems. 1981:7-57. in H.A. Mooney, T.M. Bonnicksen N. L. Christensen, J.E. Lotan, and W.A. Reiners, coordinators Fire regimes and ecosystem properties. Proc. Of conference Honolulu, Hawaii, 1978. USDA Forest Service Gen. Tech. Rept. WO-26

[30] Natural Resources Canada. Canadian Forest Service. Frontline Express: Great Lakes Forestry, Bulletin #84

[31] Intergovernmental Panel on Climate Change. In: Hiraishi T, Krug T, Tanabe K, Srivastava N, Baasansuren N, Fukuda M, et al., editors. Supplement to the 2006 IPCC Guidelines for National Greenhouse gas Inventories: Wetlands: Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment. Geneva, Switzerland; 2014. Available from: https://www.ipcc.ch/publication/2013-supplement-to-the-2006- IPCC-guidelines-for-national-greenhouse-gas-inventories wetlands/