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forest management

Five Anthropogenic Factors That Will Radically Alter Forest Conditions and Management Needs in the Northern United States

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The Northern United States includes the 20 states bounded by Maine, Maryland, Missouri, and Minnesota. With 70 million ha of forestland and 124 million people, it is the most densely forested (42% of land area) and most densely populated (74 people/km^2) quadrant of the United States. Three recent, large-scale, multiresource assessments of forest conditions provide insight about trends and issues in the North, and collectively these and other supporting documents highlight factors that will be extraordinarily influential in large-scale northern forest management needs over the next 50 years. This review article discusses five of those factors: (1) northern forests lack age-class diversity and will uniformly grow old without management interventions or natural disturbances, (2) the area of forestland in the North will decrease as a consequence of expanding urban areas, (3) invasive species will alter forest density, diversity, and function, (4) management intensity for timber is low in northern forests and likely to remain so, and (5) management for nontimber objectives will gain relevance but will be challenging to implement. Suggested actions to address these factors include the following: develop quantifiable state and regional goals for forest diversity, understand the spatial and structural impacts of urban expansion on forests, develop symbiotic relationships among forest owners, forest managers, forest industry and the other stakeholders to support contemporary conservation goals, and work to understand the many dimensions of forest change. In the next several decades, climate change seems unlikely to overwhelm or negate any of the five factors discussed in this article; rather it will add another complicating dimension.

Keywords: diversity, forest health, urbanization, land-use change, owner attitudes

The Northern United States includes the 20 states bounded by Maine, Maryland, Missouri, and Minnesota. With 70 million ha of forestland and 124 million people, it is the most densely forested (42% of land area) and most densely populated (74 people/km^2) quadrant of the United States. Three recent, large-scale, multiresource assessments of forest conditions (USDA Forest Service 2011, 2012, Shifley et al. 2012, Wear et al. 2013) provide insight about past, current, and projected forest conditions in the North. The information in those reports is supported by forest inventory information (Miles 2013, USDA Forest Service 2013a) and dozens of associated technical reports that provide additional details on projected changes in human population, socioeconomic conditions, and subsequent effects on forest dynamics (e.g., Butler 2008, Smith et al. 2009, Zarnoch et al. 2010, Wear 2011, Cordell et al. 2012, Skog et al. 2012, USDA Forest Service 2013b). Collectively these documents highlight factors that are extraordinarily influential in identification of large-scale northern forest management needs over the next 50 years.

This review article discusses five factors with clear anthropogenic origins and associated forest management issues. We also consider the likelihood that climate change may be highly influential over the long term (Iverson et al. 2008, Matthews et al. 2011, Vose et al. 2012, Woodall et al. 2013). However, these five issues have both short- and long-term impacts that will be highly influential regardless of the nature and magnitude of climate change impacts on forests in the region or policies that may be established to manage the causes or cope with the effects of climate change.

Northern forests today have been imprinted with the effects of society's land-use preferences and practices from prior decades and prior centuries. European settlers migrating westward across the

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region in the 19th century set in motion a sequence of events extending throughout the 20th century to shape the current northern forests conditions. These include a general sequence of exploitive timber harvesting, forest clearing for agriculture, forest burning for land clearing and to benefit livestock grazing, gradual abandonment of marginal agricultural lands, concerted forest fire suppression, increased urbanization, increased forest fragmentation and parcellation, and low forest management intensity (MacCleery 2011, USDA Forest Service Northern Research Station 2013). MacCleery (2011) notes that after prior centuries of decline, forest area stabilized in the early 20th century and began to increase, partly as the result of new technologies that increased farm yields per ha and reduced the farm area devoted to sustaining draft animals. Anthropogenic forest disturbances and weather-related disturbances have combined with natural forest processes of regeneration, tree and stand growth, intertree competition, aging, senescence, mortality, and species succession to shape the current spatial distribution, age distribution, structural distribution, soil characteristics, and species composition of northern forests. Collectively these persistent forces give northern forests great inertia; it can take decades for changes in patterns of human disturbances, when combined with normal forest dynamics, to become evident across millions of hectares at the state and regional scales. In the context of the many anthropocentric drivers of forest change that came with European settlement, climate change is a relatively recent arrival. Evidence of climate change effects on forests are accumulating (e.g., Vose et al. 2012), but many other drivers have greatly influenced forest change over the last two centuries. Past natural and anthropogenic disturbances have defined the current condition of northern forests and have set the stage for management issues of considerable concern. Five are discussed in the following sections.

This review article highlights five anthropogenic factors that will radically alter northern forest conditions in coming decades but that are also within the influence of the current generation of forest owners and managers. Further, it proposes actions that can help avert negative consequences associated with those factors.

Five Major Anthropogenic Factors Affecting the Future of Northern Forests

Northern Forests Lack Age-Class Diversity and Will Uniformly Grow Old without Management Interventions or Natural Disturbances

As an artifact of past disturbance, nearly 60% of northern forestland is clustered in age classes spanning 40–80 years (Miles 2013) (Figure 1). Young forests (age 20 years or less) comprise 8% of all forests in the region; forests older than 100 years comprise 5%. Age class is one of the simplest indictors of forest structural diversity, and one that is readily monitored. Past and current estimates of the distribution of forest area by age class and/or structure class (e.g., seedling-sapling, pole, and sawtimber) are reported by the USDA Forest Service Forest Inventory and Analysis (FIA) program (USDA Forest Service 2013a). The current pattern of forest area clustered in middle-age classes is the result of historical patterns of land management over the past century (MacCleery 2011). Within the North, this unimodal pattern of clustered age classes is repeated at smaller spatial scales for individual states and for individual forest-type groups (Shifley and Thompson 2011, Shifley et al. 2012). The unimodal age-class distributions common through the North are markedly different from those observed for other regions of the

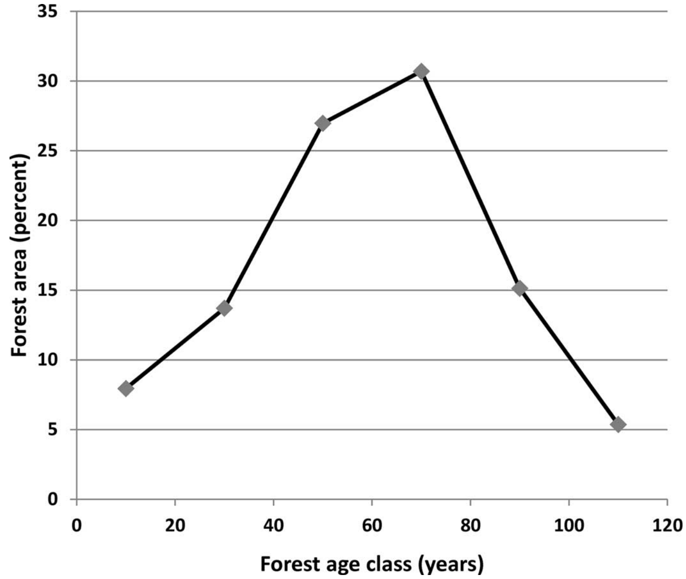

Figure 1. Proportion of forest area by 20-year age-class categories for the US North. Forest classified as older than 100 years is plotted in the 110-year-old class.

United States (Pan et al. 2011) and reflect historical patterns of harvest and other disturbance processes unique to the North.

Forest age class is an indicator of habitat structural diversity (Beck and Suring 2009, Greenberg et al. 2011, Hunter and Schmiegelow 2011). The current forest condition in the North has not escaped the notice of wildlife biologists who report that it has resulted in a loss of habitat for forest species that use early-successional forest habitat (Greenberg et al. 2011). We know of no methods suitable for quantitatively optimizing forest age-class diversity, but a management principle noted by Hunter and Schmiegelow (2011) is that "diversity begets diversity," Something closer to a uniform age-class distribution would certainly increase regional habitat diversity relative to the highly clustered, unimodal forest age-class distribution that currently exists. On many landscapes throughout the North, practices that increase the rate of forest regeneration and the establishment of young (early-successional) forest area will increase landscape-scale structural diversity (Shifley and Thompson 2011). Compared with young forest habitats, old forests are equally in deficit in the North, but the relatively low rates of disturbance over recent decades have millions of ha of forestland poised to move into age classes older than 100 years (Figure 1).

The Area of Forestland in the North Will Decrease as a Consequence of Expanding Urban Areas

Between 2010 and 2050, expanding urban[1] areas in the North are expected to subsume about 14 million additional ha of land, and the recent trend (1990–2000) has been for 37% of urban expansion to be within forestland (Shifley et al. 2012). Thus, a loss of about 5 million ha of forestland (or 7% of the current 70 million ha of forestland) to urban expansion seems likely by 2050 (Nowak and Walton, 2005) with the remainder of the urban expansion expected to fill agricultural or other nonforest land-use categories. This represents a huge loss of forestland on an absolute basis as urban area increases to accommodate changing lifestyles and a net increase of about 27 million people from 2010 to 2050 (Zarnoch et al. 2010, Wear et al. 2011, Shifley et al. 2012, USDA Forest Service 2012).

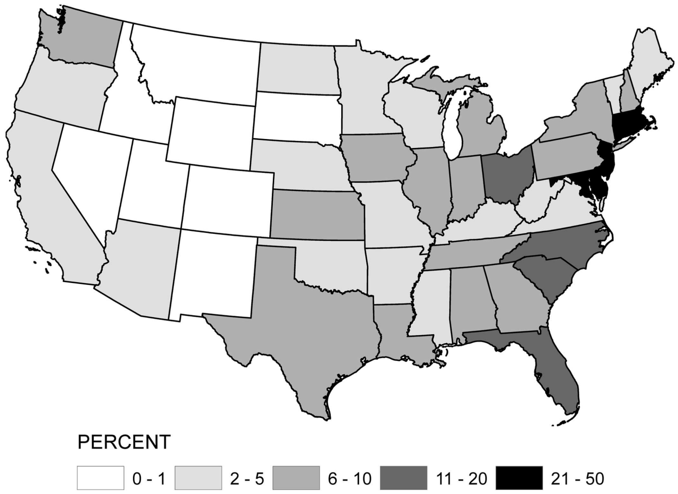

Figure 2. Projected percentage of nonurban forestland converted to urban, 2000–2050 (Nowak and Walton 2005).

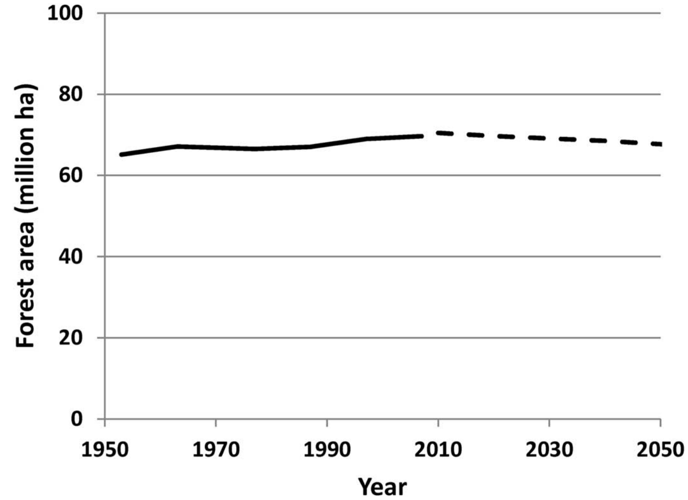

Figure 3. Past and projected forest area for the US North, 1953–2060. Projected forest area shows the mean value for three alternative scenarios (Smith et al. 2009, Wear et al. 2013).

Currently 80% of northern residents live in urban areas and that proportion is expected to increase (US Census Bureau 2013). Despite the projected increases in urban area, urban land is expected to remain a relatively small component (14%) of the northern landscape in 2050 (Nowak and Walton 2005). Relative to rural forests, forestlands in proximity to expanding urban centers will be focal areas for rapid change. The high level of interaction among people and trees in and around urban areas makes these areas of particular significance to managers (Radeloff et al. 2005). Urban and suburban forests are where the intense interaction of people and forests presents special management challenges that have high potential to affect the quality of life for millions of US North residents.

These special management challenges extend to neighboring forest stands and include forest fragmentation and altered forest management (Nowak et al. 2005a). As new infrastructure is constructed in forests, new forest edges that increase exposure of forests to urban stresses (Medley et al. 1995) and alter plant and wildlife populations and forest biodiversity are created. Urban expansion can also affect timber management and harvests. Whereas proximity to roads increases the likelihood of harvesting, proximity to development and higher population densities leads to reduced timber harvests (Barlow et al. 1998). For example, as population densities increase from 20 to 70 people/mile^2, the probability of local timber harvesting being practiced locally has been shown to decrease from 75 to 25% (Wear et al. 1999).

Large percentage losses of forestland are expected in states where rapid expansion of urban and suburban areas occurs on landscapes with relatively dense forest cover—Rhode Island, Connecticut, Massachusetts, New Jersey, Delaware, and Maryland (Figure 2). The anticipated decline in total forestland in the North over the next five decades is particularly noteworthy because it signals a reversal in the 100-year trend of gradually increasing forest cover (Figure 3). This projected change in trajectory is the consequence of urban areas expanding faster than the rate at which abandoned farmland will revert to forestland. Despite the fact that urban expansion will change millions of hectares of rural forestland to an urban classification, urban areas are not without tree cover. In the US North, the mean tree cover on urban land is 38%, almost as much as the 42% forest cover in rural areas of the North (Nowak and Greenfield 2012).

Nonnative, Invasive Species Will Alter Forest Density, Diversity, and Function

The introduction of nonnative, invasive animals and plants threatens northern forests by changing ecological trajectories, endangering rare native species, degrading wildlife habitat, and decreasing biodiversity (Chornesky et al. 2005). The US North has the dubious distinction of having the greatest number of invasive forest pests per county (Liebhold et al. 2013) (Figure 4). This is a consequence of relatively abundant opportunities for invasive species introductions (e.g., through international commerce), suitable hosts and habitats, and processes for invasive species spread (USDA Forest Service Forest Health Technology Enterprise Team 2012, 2014, Liebhold et al. 2013).

There are at least 455 nonnative forest insect species established in the United States (Aukema et al. 2010), and approximately 27% of the major insect pests in US forests are nonnative. Many have caused considerable economic and ecological damage to rural forest resources and urban landscapes of the United States and Canada (Pimentel 1986, Langor et al. 2009). Aukema et al. (2011) predict nationwide annual costs of dealing with nonnative forest insects solely in urban areas to be nearly \$1.7 billion in government expenditures and another \$830 million in lost property values.

Once an invasive species is established, addressing the consequences can be a long and costly endeavor. For example, more than a century after gypsy moth (*Lymantria dispar* L.) was introduced in US forests its spread has been significantly slowed, but not stopped (Tobin and Blackburn 2007, Slow the Spread Foundation 2012). Likewise, it has taken more than a century from the introduction of chestnut blight for tree breeders to develop blight-resistant cultivars of American chestnut (*Castanea dentata* [Marsh.] Borkh.) that are ready for large-scale field tests (USDA Forest Service Northern Research Station 2012).

The emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire) is an example of a recently established invasive insect with potentially dire consequences for rural and urban forests in the North. EAB kills ash trees (*Fraxinus* spp.) when damage from larval phloem galleries and outer sapwood cavities accumulates over 1 or more years, disrupting carbohydrate transport between roots and leaves and eventually killing the tree (Cappaert et al. 2005, USDA Forest Service

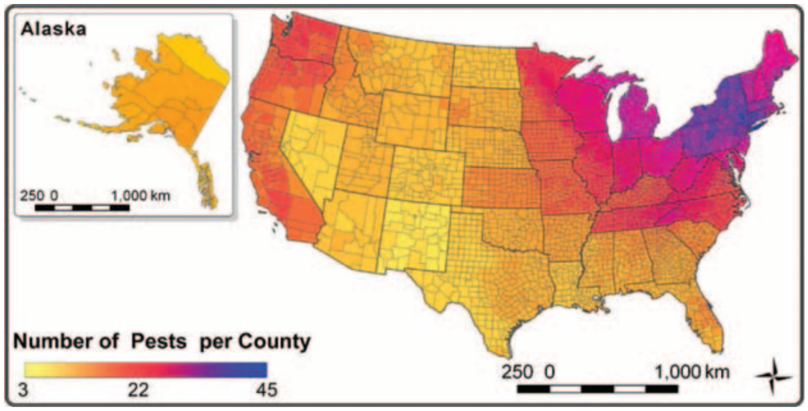

Figure 4. Number of damaging invasive forest pests per county. (Reproduced from Liebhold et al. 2013.)

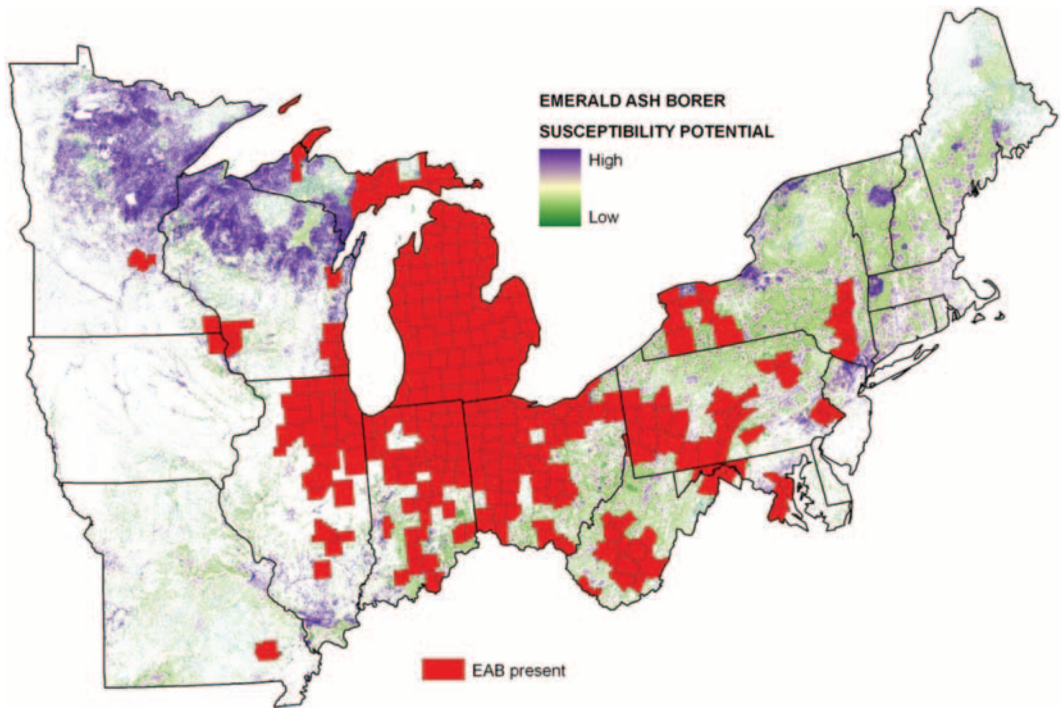

Figure 5. EAB susceptibility as a function of preferred host range (Wilson et al. 2012), urban ash trees, proximity of urban ash trees to natural forests, and past rates of phloem insect interceptions at US ports of entry (USDA Forest Service Forest Health Technology Enterprise Team 2012). Susceptibility is defined as the potential for introduction and establishment of a forest pest within a tree species or group over a 15-year period (USDA Forest Service 2010a, 2010b). Northern US counties where EAB was detected as of Apr. 2, 2012 are shown in red (USDA Animal and Plant Health Inspection Service Plant Protection, and Quarantine 2012).

2008). EAB has caused widespread damage to the US ash resource and continues to spread across North America. Since its accidental introduction to North America in the 1990s, EAB has spread across 23% of the range of ash and killed millions of ash trees in northern forests (Haack et al. 2002, Miles 2013) (Figure 5). EAB is spreading at approximately 20 km/year, which suggests that the beetle will occupy the entire range of ash in northern forests by 2050 (DeSantis et al. 2013b), although cold temperature may limit the spread of EAB in the northernmost parts of the region (DeSantis et al. 2013a) (Figure 6). Barring new scientific breakthroughs on EAB treatment or eradication, it is expected that most ash trees in northern United States will be killed (Herms et al. 2010)[2]. Increased ash mortality will have negative economic consequences for the wood products industry and for urban areas where ash has been widely used for landscape and street trees. Costs of treatment, removal, and replacement of affected urban ash trees may exceed a discounted cost of $10 billion (Kovacs et al. 2010). EAB will affect Native American tribes that use ash as a cultural resource (Cappaert et al. 2005), and it will affect the American pastime of baseball as white ash (*Fraxinus americana* L.) is a preferred species for wooden baseball bats (CBS News 2013). The ecological impacts of EAB infestation could affect associated wildlife and ecosystem function, especially in hydric systems where black ash (*Fraxinus nigra* Marshall) and pumpkin ash (*Fraxinus profunda* (Bush) Bush) are common (Burns and Honkala 1990).

The negative consequences of nonnative species are not limited to those of insects. There are more than 15 nonnative forest pathogens known to damage trees in North American forests (Liebhold et al. 2013). A prominent example is white pine blister rust (*Cronartium rubicola* J.C. Fisch.), first brought here on infected seedlings and trees from Europe in 1898. A second example is the virtual

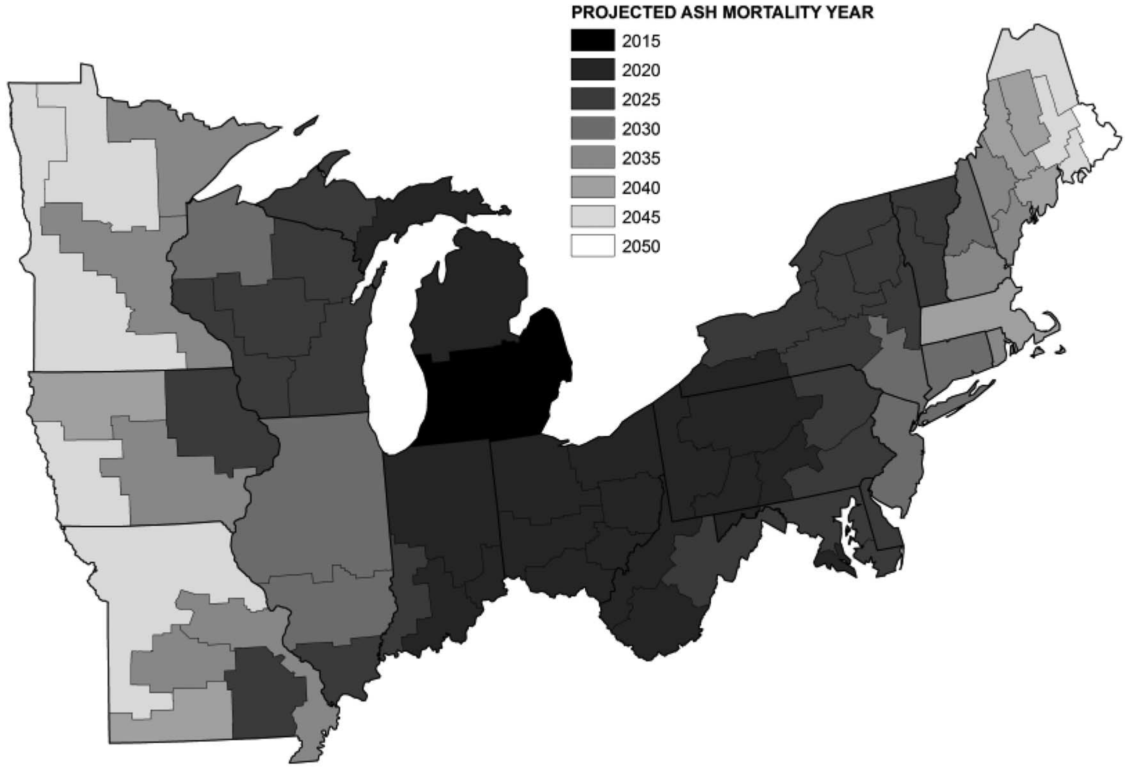

Figure 6. Projected ash mortality due to EAB throughout the North by FIA inventory units: assumes ash mortality when EAB spread subsumes an inventory unit; assumes that spread in New York, Vermont, New Hampshire, and Maine will be influenced by present infestations in regional municipalities of Ontario and Québec, Canada; assumes spread in northern US forests will not be influenced by infestations in other Canadian locations or southeastern US locations in Tennessee, Kentucky, or Virginia; and assumes spread rate is 20 km/year, with the initial extent of the insect based on EAB detection in northern US counties and Canadian regional municipalities (Canadian Food Inspection Agency 2012, P. Chaloux, USDA Animal and Plant Health Inspection Service, Riverdale, MD, pers. comm., Aug. 16, 2011).

elimination of American chestnut (*Castanea dentate* [Marsh.] Borkh.) by the chestnut blight fungus (*Cryphonectria parasitica* [Murrill] Barr formerly *Endothia parasitica* [Murr.] A.&A.). A mere 50 years after the pathogen was introduced to North America, 80% of the chestnut trees were dead or dying (Anagnostakis 1987). A more recent example of a pathogen with potential lethality to northern US forests is sudden oak death (*Phytophthora ramorum* S. Werres, A.W.A.M. de Cock). First introduced on the West Coast, the pathogen has spread to plant nurseries in Missouri, along with states in the southeastern United States, through the transport of infected plants (Grünwald et al. 2012). Many oak species native to the northern region are susceptible to sudden oak death, including northern red oak (*Quercus rubra* L.) and northern pin oak (*Quercus palustris* Münchh.) (Moser et al. 2009). Other forest and urban woody species that can be infected by *P. ramorum* include rhododendrons and camellias, thus making the disease harder to contain (O'Brien et al. 2002).

Nonnative invasive plants have established a dominant presence in the forested understories of the region to the detriment of native plant communities (Schulz et al. 2013). The history of disturbance in the region is important because disturbance tends to disrupt existing communities and make growing space available to the invaders (Richardson and Bond 1991). Human-settled sites usually have productive soils, and the combination of people and productive soils creates fertile ground for establishment and spread of invasive plants (Fan et al. 2013). Invasive plants can persist long after the disturbed land is reclaimed by forests (DeGasperis and Motzkin 2007). These species can have negative impacts on forest composition and structure (Webster et al. 2006) and on seedling and sapling growth (Kurtz and Hansen 2013). Invasive species seem to have broad tolerances for climate and moisture availability, while also possessing traits that are advantageous for competition, such as prolific seed production, higher growth rates, and a short period until seed production (Rejmánek 1989, Goodwin et al. 1999, Rejmánek et al. 2004, Jakobs et al. 2004, Richardson and Pyšek 2006).

The USDA Forest Service, FIA program collects information about selected nonnative invasive plants (Moser et al. 2008, 2009, Kurtz 2013) and, on a coarser scale, all plants in the forest floor (Schulz and Gray 2013). Invasive plants have been found in forests in every state in the Northern Region (Kurtz 2013). Analyses of FIA data suggest that native species richness is inversely proportional to introduced species richness, at least in some locations (Schulz and Gray 2013).

Management Intensity for Timber is Low in Northern Forests and Likely to Remain So

Decisions about management practices and management intensity of northern forests are largely determined by the landowners. Owners make their decisions within the context of social norms, government regulations, and market forces, but the motivations and needs of the owners ultimately determine what, if any, actions will occur. Ownership objectives and constraints vary considerably across the private and public ownerships of the northern United States. Private forest ownerships account for 75% of the forestland

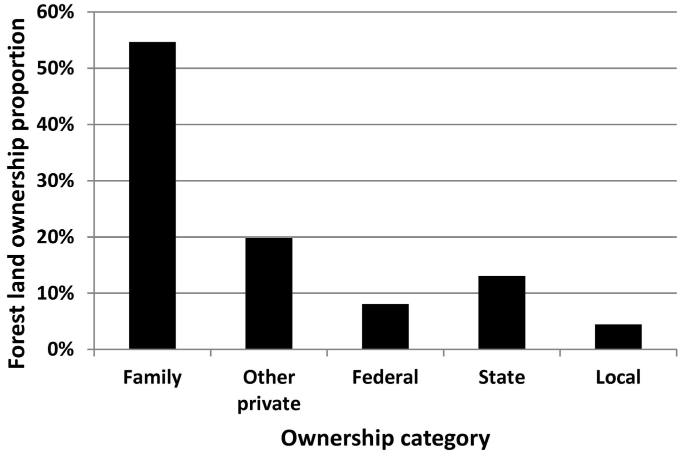

Figure 7. Proportion of forestland in the North by ownership group.

across the North and 95% of the annual timber harvested (Smith et al. 2009). Consequently, the cumulative management decisions on private lands dominate forest conditions in the North.

A majority of northern forestland (55%) (Figure 7) is owned by 4.7 million families, individuals, and trusts that collectively are referred to as family forest owners (Butler 2008). There is great diversity in their stated reasons for owning forestland with owner motivations falling into four broad categories: woodland retreat, working the land, supplemental income, and uninvolved owners (Butler et al. 2007). Only 8% of the family forest owners across the North reported timber production as a primary objective; these tend to be those with relatively large ownerships because collectively this group owns 22% of the family forestland. Twenty-four percent of owners (who collectively own 53% of the forestland) reported commercially harvesting trees at some point in the past (Butler 2008). These statistics indicate that many owners are willing to actively manage their land. However, the low percentage who have a written management plan (4% of owners who collectively own 16% of family forestland) or who have received professional management advice (13% of owners who collectively own 31% of family forestland) calls into question the readiness of forest owners to respond to forest threats (Butler 2008). A low propensity or low capacity for forest management reduces options for addressing perceived problems such as low forest diversity, invasive species, and other insect or disease problems. Compounding these issues is the fact that the average parcel of family forestland across the region is relatively small (7 ha) (Butler 2008) and will probably get smaller in the future. Small parcels present challenges for forest management due to economies of scale and the millions of ownerships that need to be engaged.

The group of "other private" owners includes corporations, nongovernmental organizations, Native American groups, clubs, and partnerships. Traditionally, the corporate category was dominated by vertically integrated forest industry companies, but in recent decades these lands have been largely sold to timber investment management organizations (TIMOs) and real estate investment trusts (REITs). TIMOs manage forestland on behalf of institutional investors and individuals of high net worth, investors who are typically focused on returns on investment and portfolio diversification. REITs are focused on the returns they can earn from their land for their shareholders and have legal constraints on the amount of nonreal estate assets the corporations can control. The transition from vertically integrated forest products companies to TIMOs and REITs has been driven by "mergers, alleviation of timber-scarcity concerns, new technologies for reducing the cost of fiber acquisition, redeployment of capital, and desire to reduce tax burdens" (Butler and Wear 2013). These new owners have motivations that are somewhat different from those of the traditional forest industry companies (e.g., no need to "feed" the processing mills), but the full impact on forest conversion and forest management is yet to be determined. The new owners are still very interested in timber production, and at least for the southern United States (Zhang et al. 2012), those lands appear to be managed similarly, if not more intensively, than lands owned by vertically integrated companies. Rates of conversion from forest to other land uses have yet to be quantified for these owner groups.

The public forestlands of the US North are controlled by a combination of federal (8%), state (13%), and local (4%) government agencies (Smith et al. 2009). The ownership and management objectives for these lands vary across the agencies and can be very different from those for private lands. Some agencies intensively manage their lands with timber production as a major objective, whereas timber harvesting and manipulative management in general, are banned by other agencies. The management objectives and constraints are the results of laws and regulations with the aim of managing the lands for the greatest public good.

It is certainly possible that greatly increased utilization of wood biomass for energy or for new cellulosic nanomaterials (USDA Forest Service Forest Products Laboratory 2013) will alter the status quo and provide new markets with opportunities for expanded timber management on private lands in the North. If such markets do develop, it seems likely that early implementation will be in areas that have large forest ownerships and large wood-using industries (e.g., northern Lake States or Maine) before they gradually expand to affect timber management alternatives for the millions of small private family ownerships throughout the North.

Management for Nontimber Objectives Will Gain Relevance but Will be Challenging to Implement

On a majority of public and private forestland in the US North, timber production is no longer the core forest management objective, and it is often considered incidental to a broader range of goals including increased recreation, watershed protection, habitat improvement, increasing forest diversity, and increasing ecosystem resilience across forest landscapes (Thomas 1996, Butler 2008). For example, the national forest area in the North treated with prescribed fire nearly doubled from 13,700 to 26,900 ha annually over years 2008 to 2012 (Carrie Sweeny, USDA Forest Service, Milwaukee, WI, pers. comm., June 21, 2013). In contrast, timber harvest on USDA Forest Service lands has been on a long decline from 65 million m^3 (12.6 billion board feet [bbf]) in 1988 valued at $2.4 billion (2012 basis) to 13 million m^3 (2.6 bbf) in 2012 valued at $138 million (USDA Forest Service 2013c). On national forests in the US North (Forest Service Region 9), the decline in volume and value was less precipitous, but harvest levels halved. Timber harvest totals for 1988 were 4 million m^3 (803 million board feet) valued at $50 million (2012 basis). In 2012 that dropped to 2 million m^3 (410 million board feet) of timber worth $31 million (USDA Forest Service 2013d). Across all public and private lands in the North, timber product output declined from 99 to 85 million m^3 from 1997 to 2012 (USDA Forest Service 2014).

The shift toward greater emphasis on forest management for nontimber objectives has been limited by costs and workforce capacity. Numerous cost-share programs and other policy tools support increased management for ecosystem services, but on public lands, the desired balance among timber and nontimber objectives continues to be debated (e.g., US House of Representatives 2013).

An unintended consequence of reduced timber harvesting is a reduced capacity to subsidize other restoration activities, either through revenue from timber sales or through manipulation of vegetation and woody fuels during logging. On public lands in particular, plans to manage forest habitats to achieve restoration goals or improve resilience are limited by available funding and trained labor. For example, practices such as savanna or woodland restoration, intended to increase tree structural diversity, herbaceous species diversity, and ecosystem resilience to wildfires, often require precommercial thinning to remove midstory and understory trees followed by a long-term regime of prescribed fire (Lorimer 1985, Nuzzo 1986, Ladd 1991, Bowles and McBride 1998). Merchantable forest products can help offset the costs of restoration projects. Primary management tools for all manner of forest restoration activities include a combination of planning, monitoring, planting vegetation, burning vegetation, cutting vegetation, applying herbicide, and/or protecting vegetation from disturbance. All of these practices require labor and knowledge of forest operations, equipment, and sufficient funding to offset the costs of implementation. Without sources of revenue, well-planned treatments to increase forest health, diversity, and resilience can become limited in area treated or in the capacity to maintain treatments through time.

Timber markets have been depressed in recent years, creating a greater challenge to the provision of revenues necessary to make management for timber and nontimber objectives an economically feasible proposition. Furthermore, a long economic recession, higher efficiency in production, and greater automation have had a direct impact on forest-related jobs (Woodall et al. 2012). From 2001 to 2010, the number of jobs in the US North in forestry and logging declined by 22% (North American Industry Classification System [NAICS] code 113) (US Department of Labor 2013). Employment in the wood products industry (NAICS 321, 322, and 327) in the Northern region experienced a 28% decline between 2005 and 2010 (Woodall et al. 2012). The depletion of the forest-sector workforce may threaten the ability to plan and conduct forest management activities in the future because fewer individuals have the necessary expertise.

Management of forestland for nontimber objectives will gain greater relevance in the years to come as population grows and the wildland-urban interface expands in area (Radeloff et al. 2005). Water will arguably be one of the most important nontimber products with increased societal demand for quantity and quality. Protection of the Catskill/Delaware Watershed system to provide water to New York City (NYC) is a prime example of forest management with specific environmental objectives and watershed protection in particular, yet without ignoring traditional timber markets. The watershed supplies 4.9 billion liters of water/day to 9 million consumers in NYC and in upstate communities (USDA Forest Service TEAMS Enterprise Unit 2011). That watershed management effort started with the creation of the city's Watershed Agricultural Council in 1993 as a not-for-profit organization to administer the voluntary, incentive-based (e.g., easement) Watershed Agricultural Program (Watershed Agricultural Council 2002). A comprehensive watershed protection program includes the progressive acquisition

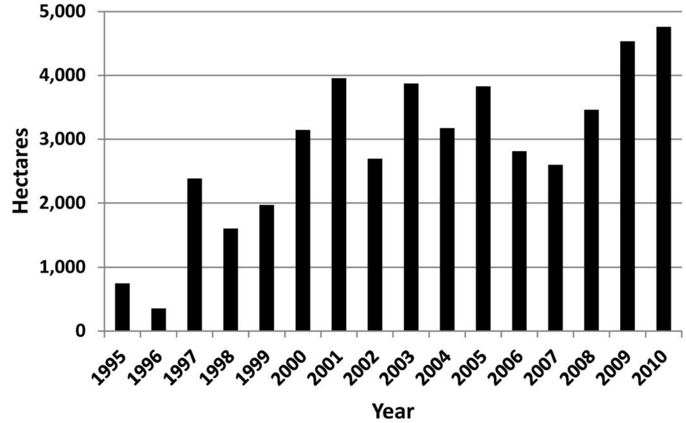

Figure 8. Hectares of land in land acquisition executed contracts (including fee-simple and conservation easement contracts) by year by the NYC Watershed Protection Program (NYC Department of Environmental Protection 2011b, p. 18).

of land and the use of conservation easements (Figure 8) to protect forest cover and conduct management following best management practices (NYC Department of Environmental Protection 2011a). In 2011, the NYC Department of Environmental Protection launched a Watershed Forest Management Plan developed in partnership with the USDA Forest Service for city-owned forestlands. The development of the plan is a key component of the 10-year Filtration Avoidance Determination awarded to NYC by the US Environmental Protection Agency, which allows the city to be one of only five large cities in the nation to get a majority of its water from unfiltered sources. It is important to stress that environmental objectives do not need to be contrary to wood products industry demands for timber. The forest management plan has the potential to help protect or create more than 80 full and part-time jobs on an average annual basis over 10 years, contributing to >$2.5 million in economic activity through the logging and sale of sawtimber and low-grade wood products (NYC Department of Environmental Protection 2011a).

At a larger scale, multiple cost-share payment programs have been established by US government and nongovernment organizations to promote on private lands the conversion of nonforest land into forest, maintenance of forest cover, protection of watersheds and wildlife habitat, and sustaining long-term timber supplies (Bullard and Straka 1988, Siikamäki and Layton 2007, Jacobson et al. 2009). Cost-share programs are public policy tools intended to achieve ecological and production objectives. In the US North, about 9% of family landowners with <100 acres of forest ownership have participated in cost-share programs, whereas participation is 19% among those with more than 100 acres of forestland (Song et al. 2014). These figures suggest that there are many opportunities to potentially expand cost-share program participation in the region, particularly among those with smaller ownership areas.

Cost-share programs may be classified as a type of payment for environmental services (Schomers and Matzdorf 2013) because they help pay for the adoption of land management practices with direct environmental benefits. Likewise, conservation easements on private lands help direct forest conservation efforts that are triggered by concerns over changes in the supply of environmental services caused by changes in land cover. About 52,835 easements, or 65% of the total number of easements in the United States, are found in the North (USDA Natural Resources Conservation Service [NRCS]

2011). Consequently, the US North currently has approximately 6 million acres of lands under conservation easements or about 35% of the US total. In the US North, state governments hold 42%, the federal government 9%, other local governments 4%, and land trusts and nongovernment organizations 45% of all conservation easement contracts (The Conservation Registry 2012).

Proposed Actions to Pursue Now

Develop Quantifiable State and Regional Goals for Forest Diversity

There is still much to learn about how changes in forest age diversity, structural diversity, and vegetation diversity relate to changes in wildlife diversity, ecosystem resilience, ecosystem services, and associated forest attributes. However, it is clear that northern forests currently lack structural habitat diversity based on one of the most elementary indicators—forest age class. Increasing forest age-class diversity should increase other measures of diversity and increase resilience to many types of future forest disturbances. Failure to address the age-class problem has long-term consequences for forest sustainability. Over time, unaddressed deficits of forest area in the 10-year-old age class become deficits in the 20- and the 30-year-old age classes and cause this issue to persist for decades. Through management, it is possible to quickly create new forest habitat in the 0- to-10 year age class, but it takes decades to create new habitat in the 20- or 30-year-old age classes. Over time more comprehensive indicators of forest diversity can be implemented; management to increase age-class diversity is a good place to start.

Learn More about the Spatial and Structural Impacts of Urban Expansion on Forests

There is a direct link between forests and cities and the two are intertwined across the landscape. As the urban population grows, urban development tends to expand, increasing the extent and impact of urban lands on natural forest areas. Urban development not only directly alters forest structure and functions through the construction of roads and buildings but also puts more people within and around forest stands, altering forest use patterns (e.g., recreation) and potential timber harvests (e.g., Nowak et al. 2001). The mobility of the urban population also creates additional forest management challenges related to the spread of insects, diseases, and invasive species that may be introduced and/or spread by urban populations.

Understanding the potential extent and distribution of urban development in the coming years will be critical to understanding where significant transitional forest changes are likely to occur due to urbanization and also the potential magnitude of these changes. By understanding where and what changes to forests are likely to be due to future urbanization, policies and plans can be implemented to help minimize either the urban development itself or the negative impacts of urbanization on forest environments.

Not only is it important to understand where future urbanization is likely to influence forest environments, but it is also important to better understand what these influences will be on forest composition and health. With expanding human populations and increasing numbers of invasive insects, diseases, and plants, the potential impacts of these invasive organisms on forest composition and health increase. Urban populations may be a focal point for the distribution of the organisms into forest areas, but informed people also can help detect, limit, or potentially eradicate undesirable organisms.

Forests and forest management have a direct impact on the health and well-being of the people who live in or near to forests. As urban populations affect and are affected by nearby trees and forests, they can become actively engaged in influencing forest health and can have significant impacts on forest management through planning or political processes. Forest management can be enhanced by engaging the urban population and utilizing their desires and skill sets to develop integrated forest plans and policies that enhance not only forest health, but also human health and the needs of a burgeoning human population. New tools to inventory and estimate ecosystem services (e.g., air pollution removal, carbon sequestration, and altering building energy use) and values derived from tree and forest resources are available (e.g., Nowak et al. 2008, US Department of Agriculture 2014) to aid forest management (e.g., Driscoll et al. 2012). These tools have been used for regional forest assessments in the Houston (Nowak et al. 2005b), Kansas City (Nowak et al. 2013a), and Chicago (Nowak et al. 2013b) metropolitan areas. These assessments reveal structural forest values in the range of $51 to $206 billion and annual ecosystem service values ranging from $233 to $456 million. Assessments of regional forests in conjunction with urban forests are aiding discussions on regional forest values and providing data to develop regional forest plans and policies.

Urban areas encompass a gradient from heavily developed downtown cores to sparsely developed rural areas, and forest management plans should encompass the entire range of forest conditions from natural stands in rural areas to urban trees and forests in city centers. This integration across a regional landscape that encompasses both seminatural and heavily human-influenced trees and forests can provide a better mechanism to incorporate the growing influence of urbanization and better meet the needs of a growing urban population (Rains 2013). Sustaining urban trees, urban forests, and urban people will be high priorities in the 21st century.

Develop Symbiotic Relationships among Forest Owners, Forest Managers, the Forest Industry, and the General Public to Support Contemporary Conservation Goals

Forest management practices, whether for commodities, amenities, or ecosystem services, all require labor and cost money to implement. Planning, harvesting, burning, planting, applying herbicide, fencing, and monitoring are among the most widely applied actions to manage forests for a multitude of objectives. Sale of forest products can be a mechanism to support other compatible conservation goals and to sustain rural communities. A decline in the number of forest workers, a low propensity to manage by private forest owners, and low forest-based income can limit implementation of practices intended to increase forest health, diversity, and resilience. Effective partnering with foresters, loggers, and other woods workers will require a long-term commitment to shared goals with mutually beneficial outcomes.

The recent expansion of payment for ecosystem services such as cost-share programs or easements highlights the importance of acknowledging and monetizing the multiple nonmarket benefits forests provide to society. Although the adoption of payment for ecosystem services is not a panacea to solve all environmental problems, recognition of the economic value for these services by allocating a monetary value to water provision or soil conservation or by reducing costs of land management practices aimed to enhance them is a step in the right direction (Kinzig et al. 2011). Indicators that better capture how society effectively values forests' multiple uses would improve estimates of forest sustainability. Economic values are a strong driver behind forest management and conservation, and failure to measure and/or monetize the value of ecosystem services can be a barrier to management for noncommodity ecosystem services. Establishment of a system of payment for the provision of nontimber goods and services increases practical management options for these and other forest values. For instance, forests that are solely valued by stumpage can sharply decline in value when timber markets are depressed. Forests that are valued for multiple commodities and services (e.g., timber, water and soil protection services, carbon sequestration, and wildlife habitat provision) will be better positioned to cope with disruption in a single market and, thus, may have a higher likelihood of being sustainably managed and conserved.

In most cases the *process* of managing for forest products or ecosystem services, individually or collectively, is identical:

1. Develop indicators of desirable, sustainable, resilient future forest conditions at stand, landscape, regional and national scales.
2. Measure current conditions via quantitative and qualitative indicators.
3. Plan actions at local and regional scales to move toward desirable conditions.
4. Finance appropriate actions.
5. Implement appropriate actions.
6. Monitor for desired outcomes.
7. Repeat.

The specific details of planning how best to achieve the desired condition hectare by hectare on the ground may be complex, but procedures can generally be designed to move forests toward a desired future condition while simultaneously averting negative consequences from multiple sources. In many cases the limitation will not be a lack of understanding about what to do but rather finding practical ways to implement and finance the selected treatments, monitor outcomes, and repeat as needed.

Work to Understand the Many Dimensions of Forest Change

Forest management gets harder with the increasing number and complexity of factors considered relevant to management decisions. In general, silviculturists, biologists, ecologists, urban foresters, and other specialists have a good grasp of the on-the-ground manipulations needed to push a forest stand or unit of habitat to favor a particular condition, species, or community. Understanding the cumulative effects of individual management practices across large landscapes and over long periods of time is much more elusive, especially with respect to identifying winners and losers among the many vegetation, wildlife, and human communities that are dependent on those landscapes for their well-being. Human choices, human impacts, and human benefits are central to each of the five factors discussed in previous sections. Human attitudes and choices about the amount of money or other resources to invest in, say, invasive species eradication or managing age class diversity, are difficult to quantify.

Other anthropogenic factors will add to those outlined in earlier sections. For example, there is broad consensus that climate will change in the US North, and currently much research is devoted to potential climate impacts on forests (e.g., Intergovernmental Panel on Climate Change 2007, Vose et al. 2012, USDA Forest Service 2012, USDA Forest Service Northern Institute of Applied Climate Science 2013, Wear et al. 2013). Although the projected rate and magnitude of climate change remain subject to some uncertainty, a range of modeled climate scenarios bracket the expected changes (Hayhoe et al. 2007, Intergovernmental Panel on Climate Change 2007). In future decades, climate change may cause the spatial distribution of tree species in northern forests to be substantially different from now (Prasad et al. 2007, Iverson et al. 2008, Swanston et al. 2011). Recent analyses that model short- and long-term forest changes associated with alternative climate scenarios indicate that for the North, differences in volume, biomass, carbon, and species composition attributable to alternative climate scenarios become apparent in roughly 2040 (Wear et al. 2013). Climate change is unlikely to overwhelm or negate any of the drivers of forest change discussed previously in this article; rather it appears destined to add another complicating dimension.

No doubt other influential, anthropogenic drivers of forest change will emerge in the coming decades. However, pressing issues associated with aging forests, urbanization, low management intensity, declining forest-associated employment, invasive species, commodity production, and ecosystem services production are already apparent.

Endnotes

1. A US Census Bureau designation for areas with a population density of 386 people/km^2 (1,000/mile^2) and including surrounding developed areas of lower population density.
2. For more information, see www.emeraldashborer.info/.

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