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Evaluating degradation in a North American temperate forest

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ABSTRACT

Forest degradation has been a focus of recent concern, especially in tropical countries, but temperate forests may also exhibit degradation. Our analysis of USDA Forest Service Forest Inventory and Analysis data shows that nearly 40% of the forestland in northern New England, USA, (Maine, New Hampshire, and Vermont) is in an understocked condition when species desirability and tree form are considered. This understocked area does not contain sufficient stand-level density of current or potential future sawlog trees, of preferred or secondary commercial species, to be able to fully utilize the growing space of the site following 10 years' growth (i.e., they are below the "C-line" in a stand stocking guide when desirable trees are considered). Although forests in the region show a slight trend of increased stocking, nearly all this increase comes from shade-tolerant hardwoods (e.g. *Fagus grandifolia*), trees with poor form (e.g. *Acer rubrum*), and from *Abies balsamea* which is subject to episodic eastern spruce budworm (*Choristoneura fumiferana*) outbreaks. This degraded condition is likely the result of past management activities that have not considered long-term silvicultural objectives and may entail reduced resilience to many climate-related risks for forests and the ecosystem services they provide. Forest management and policy alternatives must be designed and incentivized to restore forest productivity and diversity and to increase climate resilience of the forests in northern New England.

1. Introduction

Forest degradation is difficult to define and quantify but is accepted as a driver of losses in timber production, biodiversity, and carbon stocks. Thompson et al. (2013) have defined degradation based on five criteria: (1) productive functions; (2) biodiversity; (3) unusual disturbances; (4) protective functions; and (5) carbon storage. Much of the science and policy attention for degradation has been focused on tropical forest regions because of the United Nations Framework Convention on Climate Change (UNFCCC) financial mechanism to reduce emissions from deforestation and forest degradation (REDD) (Goetz et al., 2015; Miles and Kapos, 2008; Pearson et al., 2017). But forest degradation can represent a significant potential threat to timber production (as reviewed in Kenefic et al., 2014), biodiversity (Vanderwel et al., 2007), and carbon stocks (Hoover and Heath, 2011; Pan et al., 2011) in North American temperate contexts even where silviculture has been practiced for more than a century (Ashton and Kelty, 2018; Graves, 1914). Here, we focus on the timber production component of degradation in the temperate forests of northern New England in the USA (Maine, New Hampshire, and Vermont).

Recently, Belair and Ducey (2018) documented the patterns of forest harvesting in New England and New York and documented silvicultural outcomes based on post-harvest residual stand conditions. The characteristics of a disproportionate area of recently-harvested stands suggested a lack of silvicultural intent as harvests are implemented. Many stands showed a substantial reduction in the relative quality and species desirability of growing stock post-harvest without a compensating explanation in terms of a plausible regeneration or stand improvement scenario. Rather, other objectives such as short-term revenue seemed to take precedence over long-term landowner objectives that might include improving timber quality and value in many cases. Belair and Ducey (2018) show that commercial clearcuts (excluding those clearcuts that properly remove small-diameter and undesirable growing stock) and high-grading (partial harvests with strong negative impacts on species composition and grade without compensating gains) made up nearly a third of all harvested area throughout the region. These practices, also referred to as "exploitative cutting", have been recognized as a problem in the region for many years (Nyland, 1992). In another recent assessment of harvest activities in the region, Canham et al. (2013) documented frequent partial harvesting of a high proportion of basal area at each entry as a primary disturbance agent in Maine. Remote-sensing data also show accelerated loss and subdivision of intact mature forest which was attributed to partial harvesting practices being implemented more widely since the 1999

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Maine Forest Practices Act (Legaard et al., 2015). Continuation of these practices over an extended period could lead to degradation of forest productivity for long-term timber supply, loss of wildlife habitat, and a reduction of the climate change mitigation value of forests (Costello et al., 2000; Gunn and Buchholz, 2018; Kenefic et al., 2005; Schuler et al., 2017; Simons-Legaard et al., 2018; Yamasaki et al., 2014).

While these harvesting trends appear alarming on the surface, summary reports of timber volumes from USDA Forest Service Inventory and Analysis (FIA) data have consistently highlighted statewide growth rates in this region that exceed harvest rates and are generally optimistic about acceptable growing stock (AGS) available for the future (McCaskill et al., 2016; Morin et al., 2015). For example, an assessment through 2012 for New Hampshire and Vermont indicated that timber resources are the highest they have been since inventories began in 1948 and that "forest management practices over the past three decades have improved the general stocking condition across both states" (Morin et al., 2015). A recent assessment for Maine found that standing volume of live trees (> 12.7 cm diameter at breast height [dbh]) increased slightly statewide between 2003 and 2013 (McCaskill et al., 2016). However, the same statewide analysis for Maine also cautioned that there has been a 38% increase in hardwood rough cull volume since 2003, with red maple (*Acer rubrum*) alone increasing by 65% (McCaskill et al., 2016). The report for New Hampshire and Vermont highlights the dominance of American beech (*Fagus grandifolia*), white ash (*Fraxinus americana*), and noncommercial tree species in the sapling size class as a reason for concern about the future forest resource (Morin et al., 2015). Recently, Bose et al. (2017) further supported this trend with the finding that American beech abundance has increased substantially throughout New England over the last 30 years at the expense of more commercially-desirable species like sugar maple (*Acer saccharum*). These may be initial indications that past harvest practices are beginning to lead to signs of degradation.

When forest degradation is defined based on the criterion of timber production (Thompson et al., 2013), the density and relative stocking of desired species and quality can be used to assess forest condition (Bahamondez and Thompson, 2016). Managing the density and relative stocking of desired tree species within a forest stand is a fundamental component of silviculture (Long, 1985; O'Hara and Gersonde, 2004). Silvicultural treatments that temporarily reduce stand density can enhance diameter growth on desired stems and species and optimize timber yield (Ashton and Kelty, 2018; Pretzsch, 2009). But forest resilience and productivity can be compromised if harvesting practices in naturally-regenerating stands do not consider density thresholds and the productive potential of a site (Bahamondez and Thompson, 2016). Quantifying and understanding tree density at the stand, management unit, and landscape scales are critical to designing management plans that ensure long-term timber supply and other management objectives such as carbon storage and wildlife habitat (Lilieholm et al., 1994; Smith et al., 1997; Woodall et al., 2006). The recent timber harvesting trends documented by Canham et al. (2013) and Belair and Ducey (2018) likely have immediate and long-term implications for the northern New England timber resource. However, there has not been a comprehensive evaluation of the current condition of the region's forests, accounting for species composition and tree quality, using modern methods for describing stand density and growing space partitioning. Here we assess the potential degradation of northern New England (Maine, New Hampshire, and Vermont) forests based on the current status and recent trends in their relative density and quality distribution using a regional continuous forest inventory dataset. The goals of the study include:

(1) establishing criteria for considering potential degradation,
(2) evaluating the current status of regional forests according to those criteria,
(3) identifying whether factors associated with management (such as ownership or reserve status) help predict where degradation has occurred, and
(4) quantifying recent trends in forest stocking components associated with degradation or improved status.

2. Materials and methods

2.1. Study region

The New England states of Maine, New Hampshire, and Vermont are some of the most heavily forested in the United States. According to FIA data, total forest area in Vermont is 1.8 million ha, 1.9 million ha in New Hampshire, and 7.1 million ha in Maine. In New Hampshire and Vermont, 76% of the forest is in private ownership (mostly family forest owners), 14% federal (dominated by Green Mountain National Forest in Vermont, White Mountain National Forest in New Hampshire), 7% state, and 3% local (town and county) (Morin et al., 2015). In contrast, Maine is 93% privately held with 5% of the forests in state ownership, 1% local, and less than 1% federal (McCaskill et al., 2016). The forest sector is an important economic driver in the region with an annual statewide contribution of around US$8 billion in Maine (NEFA, 2014). In New Hampshire and Vermont, the contribution is US$ 2.8 billion annually, with strong ties to the Maine forest economy through transport of harvested material between states for subsequent processing (NEFA, 2014). Dominant forest types include Northern Hardwood (American beech – birch, *Betula* spp. – maple, *Acer* spp.), Spruce-Fir (*Picea* spp. and *Abies balsamea*), and Eastern White Pine (*Pinus strobus*). As elsewhere in the eastern United States, forest health threats such as hemlock woolly adelgid (*Adelges tsugae*), emerald ash borer (*Agrilus planipennis*), and beech bark disease are becoming increasingly important as stand-altering disturbance agents (Dale et al., 2001). Ice storms and wind are also significant disturbance factors in northern New England (Dale et al., 2001; Irland, 2000).

2.2. Forest inventory data

The primary source of data for our analysis was the USDA Forest Service, Forest Inventory and Analysis (FIA) program, which is the national-level forest inventory in the United States. FIA collects data including diameter at breast height (dbh), among other attributes, for all trees with dbh > 2.54 cm, on a cluster of nested subplots at each of its Phase 2 sample locations. These sample locations are distributed systematically on all forested lands, with intensification of the sample on certain areas such as federal lands. In theory, 20% of FIA plots are remeasured in each inventory year, with each plot experiencing a 5-year remeasurement period, although logistics and other considerations sometimes cause the actual remeasurement period to vary slightly. Full details on the FIA program, and its associated designs and estimating equations, can be found in Bechtold and Patterson (2015). Each FIA cluster plot is mapped to one or more conditions, defined as a combination of land/water, forest/nonforest, reserved/not reserved, stand type, ownership, and accessibility (USDA Forest Service, 2015). We downloaded FIA data on 7 December 2017 and utilized the most recent remeasurement panel for each sample plot, corresponding to the population evaluation group for 2016 and its associated sampling weights from the FIA POP_EVAL_GRP and PLOTSNAP tables. In total, 5123 plots were included in the analysis, of which 4732 were remeasured plots. From the basic FIA data, we computed several stand-level variables for each plot (e.g., trees/ha, basal area/ha, and quadratic mean diameter) and, where applicable, the previous measurement for each plot. The sampling weights from the POP_EVAL_GRP and PLOTSNAP tables were used to expand stand-level estimates to areal estimates for the region; these weights for individual plots differ slightly between estimates of current status and those associated with growth or change, because not all plots in the current panel are remeasured plots (USDA Forest Service, 2015).