Forest Ecology and Management 378 (2016) 1–13

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

The effects of agricultural history on forest ecological integrity as determined by a rapid forest assessment method

David J. Burke *, Chad Knisely, Michael L. Watson, Sarah R. Carrino-Kyker, Ronald L. Mauk

The Holden Arboretum, 9500 Sperry Road, Kirtland, OH, USA

ARTICLE INFO

Article history:
Received 29 February 2016
Received in revised form 28 June 2016
Accepted 4 July 2016

Keywords:
Forests
Invasive species
Land use history
Rapid assessment
Soil conditions

ABSTRACT

Forests are an important terrestrial biome, comprising large areas of the earth's surface and providing important ecosystem services. Conservation efforts frequently focus on minimizing perceived threats to forests that could impact these services, but often without a clear understanding of the site specific factors that affect local forest composition, structure and threat magnitude. In this study, we examined the factors affecting forest 'ecological integrity' in a 334 ha forest that includes mature forest remnants and areas recovering from agricultural activity. We developed a rapid upland forest assessment (RUFA) method to facilitate our examination of forest integrity since forest quality can vary at fine spatial scales (e.g., 100 m) and time consuming assessment methods may not be feasible for many local conservation organizations. In general, we found that land use history and especially soil conditions associated with history were the primary factors affecting forest 'ecological integrity' (i.e. composition, structure and threat presence). In forests that developed after agricultural abandonment, soil pH significantly increased, while soil carbon and nitrogen content declined. This was associated with increased presence of invasive, early successional tree, shrub and herb species and a general lack of some structural components, such as the presence of light gaps, within the forest. Our results are discussed in light of conservation efforts that seek to enhance overall forest quality and how rapid assessment methods, such as the one presented here, can be used to further conservation objectives in forest systems.

1. Introduction

Forests represent an important global terrestrial biome, constituting 30% of terrestrial land area and comprising 75% of terrestrial primary productivity (Pan et al., 2013). Forests provide important ecosystem services, acting as water recharge areas, providing fiber and pulp, and sequestering large amounts of carbon (C) in living biomass (Bellassen and Luyssaert, 2014; Bonan, 2008; McKinley et al., 2011). In addition, forests provide habitat and harbor a large percentage of the earth's plant and animal species. Recent estimates suggest that the earth's forests contain more than 3 trillion trees, seven times more than previous estimates; however, forests are also being lost at an alarming rate to deforestation and agricultural conversion, with an area equivalent to 192,000 km^2 lost each year (Crowther et al., 2015). It has been estimated that as much as 43% of the earth's forest cover has been lost since the beginning of the agricultural revolution (Crowther et al., 2015). Despite such losses globally, in many areas of northeastern North America the area of temperate forest has risen dramatically since the 1940s, with overall forest area increasing 20% due to large scale abandonment of agriculture in much of this region (USDA Forest Service, 2001). Some areas of New England are today more than 80% forested, a fact which has been hailed as an unrecognized environmental success story (Foster et al., 2004; McKibben, 1995). With the return of forest to much of eastern North America, large megafauna such as white tailed deer, black bear, and moose have returned to areas of their former range in which they have not been seen for several decades (Foster et al., 2002; Hristienko and McDonald Jr., 2007). However, despite the return of forest to much of eastern North America, much of this forest is early- to mid-successional growth, and generally less than 50 years old (USDA Forest Service, 2001); thus, it may not be equivalent to the mature forest that was lost in terms of species diversity, ecosystem services, productivity or resilience to human induced climate and environmental change (e.g., nitrogen saturation). Whether and to what degree newly developed forests provide these beneficial aspects, and whether current human activity pose threats to the development of these benefits is inconclusive. Further, the need

* Corresponding author.
E-mail addresses: dburke@holdenarb.org (D.J. Burke), cknisely@holdenarb.org (C. Knisely), mwatson@holdenarb.org (M.L. Watson), sarahrkyker@gmail.com (S.R. Carrino-Kyker), ron.mauk@gmail.com (R.L. Mauk).

http://dx.doi.org/10.1016/j.foreco.2016.07.004
0378-1127/

for management to enhance these beneficial aspects is not well developed.

It is well accepted that forest plant community composition reflects the long-term legacy of human land use activities (Dambrine et al., 2007; Dyer, 2010; Motzkin et al., 1999, 2004; Schneider, 1996). Agricultural practices can substantially affect soil conditions and especially soil nutrient availability, with consequences for plant community development following agricultural abandonment. Agricultural practices can either act as a nutrient subsidy to soil (e.g., liming, manuring of fields) or can withdraw nutrients from soil (e.g., continuous forage removal) (Compton and Boone, 2004; Compton et al., 1998; Dambrine et al., 2007; Dupouey et al., 2002). This pattern of nutrient removal and addition can create a highly heterogeneous landscape at even a local scale (100 m) since most traditional farms were small operations that occupied less than 100 ha (Compton and Boone, 2004; Dambrine et al., 2007; Dupouey et al., 2002). Studies in Europe have found that Roman land use practices generally resulted in increases in soil nutrient content and pH in areas that were intensively farmed, resulting in plant communities that are distinct from areas that were not under intense cultivation (Dambrine et al., 2007; Dupouey et al., 2002). These differences in plant communities have persisted almost 2000 years, indicating that human agricultural activities can have long lasting and profound differences on plant community composition (Dambrine et al., 2007; Dupouey et al., 2002). The effect of agricultural abandonment on plant community development has also been observed within eastern North America (Dyer, 2010; Motzkin et al., 1999, 2004; Schneider, 1996). Generally, plants adapted to disturbed, nutrient rich conditions establish and persist in many areas abandoned by agriculture (Motzkin et al., 2004), although this can depend on local use of land patches within the former farm (Compton and Boone, 2004; Compton et al., 1998). The fact that plant community composition reflects the legacy of agriculture millennia after land abandonment, has led some authors to conclude that these changes are irreversible (Dupouey et al., 2002; Motzkin and Foster, 2004).

Yet, land management activities are often predicated upon the belief that plant communities can be returned to a former state, which may reflect the composition of the original plant community existing on a site before European settlement; as is the case in eastern North American landscapes (Palmer et al., 1997; Schama, 1996). Forests, both mature stands relatively unaffected by intensive agricultural activities as well as forests that have developed since land abandonment, are viewed as being subject to a number of threats that may impede the plant community from achieving a desired state or providing societal benefits (i.e., ecosystem services; Dukes and Mooney, 2004; Tierney et al., 2009). These threats may include the presence of invasive plant and animal species, overabundant deer herbivory, climate change, and atmospheric air pollution including acid deposition (Aber et al., 2003; Dukes and Mooney, 2004; Tierney et al., 2009). However, rarely do we consider the degree to which these threats may interact with land use history. This is an important distinction to make, because many land management practices address these threats directly as the primary potential cause of forest degradation and change. This is despite significant evidence indicating that past human activities can degrade original conditions and lead to a disturbed environment that favors different plant and animal species.

Understanding the relationship between land use history, forest community composition and current threats to forest plant communities is important if management activities are to be effective in controlling threats that degrade habitat quality, especially given limited resources and the number of practices that can be conducted at a given location or time. It has been proposed that rather than attempt to achieve a desired forest community, the overall goal of forest management should be to enhance 'ecological integrity,' where ecological integrity is defined as *"a measure of the composition, structure, and function of an ecosystem in relation to the system's natural or historical range of variation, as well as perturbations caused by natural or anthropogenic agents of change"* (Tierney et al., 2009). The approach described by Tierney et al. (2009) measures several metrics of the health of a forest, including structure (e.g., stand size distribution), composition (e.g., species diversity), function (e.g., soil fertility) and context within the landscape, which addresses surrounding land uses. Environmental or human mediated factors or 'stressors' that affect these metrics are also identified. This process results in a determination of overall 'ecological integrity' and identifies factors that may erode or degrade that integrity if not addressed. Tierney et al. (2009) indicate that these 'stressors' can then be mitigated through management actions. Under this management scenario, we argue that forests developing after land abandonment may not be expected to return to a former pre-agricultural condition, but rather should be managed to achieve a level of composition, structure and function that enhances overall forest integrity and the ecological services they provide.

However, completion of ecological integrity assessment using the Tierney et al. (2009) approach can be time consuming and requires data that many conservation organizations lack (e.g., long-term data, especially in relation to plant growth). Since many conservation organizations lack the resources to support extensive long-term monitoring, and since forests are often composed of many small patches with different land use histories and potential stresses, an alternative to in depth monitoring of a small number of locations is needed. Consequently, we sought to develop a rapid method for assessing forest integrity with a time commitment and skill level that is amenable to use by many local conservation organizations (e.g., local, county and state parks agencies, nature conservancies), which typically have limited resources. Our proposed rapid upland forest assessment (RUFA) system is based upon the Tierney et al. (2009) approach, but completes assessment of ecological integrity at a single subsampling site within 20 min. Unlike other methods for vegetation assessment, this method does not attempt to quantify plant community composition, but rather ecological structure and function into an overall metric of health. Our goal here was to first to develop the RUFA method and then to calibrate it, and if useful, employ the technique to assess the integrity of a large, heterogeneous forest in the glaciated region of Ohio. We calibrated the method in four ways: (1) by using land history and forest age to determine whether RUFA can distinguish between older and younger forest sites that are expected to differ in forest composition, structure and function; (2) by quantifying the relationship between RUFA scores and soil chemistry; (3) by examining how RUFA scores correlate with a more detailed assessment of plant community composition and ecological attributes in a proportion of our sites and; (4) by comparing RUFA integrity scores to the richness and diversity of spring ephemerals, which has been suggested as a useful gauge of forest maturity (Keddy and Drummond, 1996). We than assessed forest ecological integrity using the RUFA method within a 334 ha forest, called Stebbins Gulch, in Northeastern Ohio, USA located within the Holden Arboretum. Stebbins Gulch is a mosaic of mature forest remnants, as well as areas previously used for agriculture, and is, thus, an ideal location for assessing the RUFA method.

2. Materials and methods

2.1. Site description

The Holden Arboretum is located in Northeastern Ohio (41°36′N and 81°16′W) and is part of the glaciated Allegheny Plateau.