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Loss of aboveground forest biomass and landscape biomass variability in Missouri, US

Brice B. Hanberry [a,*], Hong S. He [a], Stephen R. Shifley [b]

[a] University of Missouri, 203 Natural Resources Building, Columbia, MO 65211, USA
[b] USDA Forest Service, Northern Research Station, University of Missouri, 202 Natural Resources Building, Columbia, MO 65211, USA

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ABSTRACT

Disturbance regimes and forests have changed over time in the eastern United States. We examined effects of historical disturbance (circa 1813 to 1850) compared to current disturbance (circa 2004 to 2008) on aboveground, live tree biomass (for trees with diameters ≥13 cm) and landscape variation of biomass in forests of the Ozarks and Plains landscapes in Missouri, USA. We simulated 10,000 one-hectare plots using random diameters generated from parameters of diameter distributions limited to diameters ≥13 cm and random densities generated from density estimates. Area-weighted mean biomass density (Mg/ha) for historical forests averaged 116 Mg/ha, ranging from 54 Mg/ha to 357 Mg/ha by small scale ecological subsections within Missouri landscapes. Area-weighted mean biomass density for current forests averaged 82 Mg/ha, ranging from 66 Mg/ha to 144 Mg/ha by ecological subsection for currently forested land. Biomass density of current forest was greater than historical biomass density for only 2 of 23 ecological subsections. Current carbon sequestration of 292 TgC on 7 million ha of forested land is less than half of the estimated historical total carbon sequestration of 693 TgC on 12 million ha. Cumulative tree cutting disturbances over time have produced forests that have less aboveground tree biomass and are uniform in biomass compared to estimates of historical biomass, which varied across Missouri landscapes. With continued relatively low rates of forest disturbance, current biomass per ha will likely increase to historical levels as the most competitive trees become larger in size and mean number of trees per ha decreases due to competition and self-thinning. Restoration of large diameter structure and forested extent of upland woodlands and floodplain forests could fulfill multiple conservation objectives, including carbon sequestration.

1. Introduction

Before Euro-American settlement, perhaps at least half of forests in the central eastern and southeastern United States during the 1800s were oak or pine forest ecosystems (Nowacki and Abrams, 2008; Hanberry et al., 2012a; Thompson et al., 2013). Oak and pine species have functional traits to survive, and possibly facilitate, low severity fire regimes (Beckage et al., 2009) that periodically removed biomass of fire-sensitive species and small diameter oak and pine trees, leaving large, thick-barked oak and pine trees (Nowacki and Abrams, 2008; Hanberry et al., 2012a). Stand structure of open oak and pine forest ecosystems probably was relatively simple, consisting of single canopy layer of large diameter trees and little development of understory layers, which allowed light to reach an herbaceous ground layer (Hanberry et al., 2014).

Nevertheless, a wide range of structural variation was present in forest ecosystems at many spatial scales due to environmental gradients of soil and moisture, which interacted with fire disturbance, to influence tree density and diameter and produce a continuum of forest ecosystems from savannas to open woodlands to closed woodlands to forests (closed woodlands have closed or nearly closed canopies but are open between the ground layer and overstory canopy layer; Guyette et al., 2002; Stambaugh and Guyette, 2008; Hanberry et al., 2012a, 2014). Flat and periodically dry landscapes spread fire that removed small diameter trees, whereas rocky and arid landscapes did not produce enough fine fuels (i.e., herbaceous vegetation and litter) to burn, wetlands of varying types were often too wet to burn, and rough topography disrupted fire spread (Grimm, 1984; Guyette et al.,

* Corresponding author. Tel.: +1 573 875 5341x230; fax: +1 573 882 1977.
E-mail address: hanberryb@gmail.com (B.B. Hanberry).

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2002; Stambaugh and Guyette, 2008). At the border of prairie grasslands and eastern forests in the United States, fire return intervals and spread were propagated by continuous fine fuels and flat topography of prairies and plateaus, but then fires were disrupted by fire breaks of dissected river hills and major stream networks draining to the Mississippi and Missouri Rivers.

Many open forest ecosystems destabilize without periodic fires to remove fire-sensitive plants (Nowacki and Abrams, 2008; Hanberry et al., 2014). In the eastern United States, even after fire exclusion during the first half of the twentieth century, oak and pine had the advantage of overstory dominance and advance regeneration. Nonetheless, a variety of fire-sensitive tree species established that are more competitive than oaks and pines without fire. Furthermore, previously distinctive forest ecosystem types with spatial variation in structure before Euro-American settlement have become more uniform in structure, as current forests reflect the cumulative effects of frequent tree cutting for various land uses (Birdsey and Lewis, 2003; Masek et al., 2008; Smith et al., 2009).

The effects of historical fire disturbance compared to current land use disturbance on biomass in open forest ecosystems are not well-known and yet important for management of forests and carbon. Forests in Missouri during historical surveys of the 1800s were the product of different disturbance regimes than those that influence current forests. Past forests were largely shaped by a long term fire regime that varied across the landscape in frequency and intensity whereas forests of the past fifty years have been characterized by gradually increasing forest area with periodic partial harvesting concentrated on trees at least 30 cm in diameter. Fire and tree cutting both remove biomass and may temporarily reduce aboveground carbon sequestration, but fire removes biomass based on environmental gradients and ignition patterns, creating forests that reflect underlying environmental variation, whereas tree cutting reflects land use and harvest intensity (Yang et al., 2007). Across Missouri landscapes, or ecological sections of the Ozarks and Plains (Ecomap, 1993; Fig. 1), our objective was to quantify aboveground biomass and biomass variability by smaller scale ecological subsections in pre-settlement forests that were shaped by gradients in fire regimes and compare those past forests to current forests that are disturbed primarily by tree cutting. We additionally examined whether biomass resulting from the historic fire regime produced differences in total aboveground live forest carbon sequestration compared to current forest management and land use.

2. Methods

2.1. Tree surveys

We used the Missouri surveys by the United States General Land Office (GLO) conducted predominantly during 1813 to 1850. The GLO surveys divided public lands into square townships measuring 9.6 km × 9.6 km (6 mi × 6 mi) and subdivided townships into 36–1.6 square km sections (1 square mile). Surveyors selected two to four bearing trees at survey points located at section corners and midpoints between section corners. Surveyors recorded the species, diameter, distance, and bearing of these trees. This produced a sample of current forest conditions, but the sample was biased. We excluded trees with diameters <13 cm measured at 1.3 m above the ground to maintain a consistent minimum diameter threshold, resulting in 290,000 trees in the Ozarks ecological section and 86,000 trees in the combined Till Plains and Osage Plains ecological sections (Ecomap, 1993; Fig. 1).

We estimated historical density for each ecological subsection (Ecomap, 1993; Fig. 1) with the Morisita estimator (Morisita, 1957) for surveys that approximate the point-center quarter method

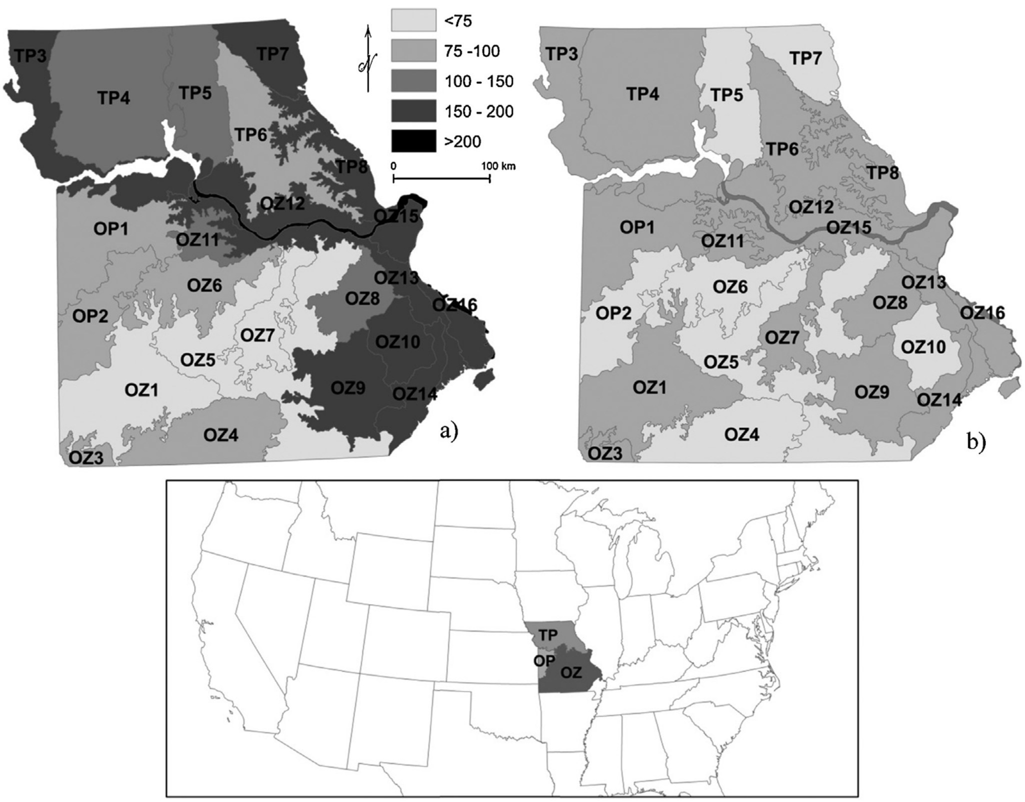

Fig. 1. Historical (upper panel 1a) and current (upper panel 1b) modeled biomass (Mg/ha; trees ≥13 cm diameter) by ecological subsection (outlined and labeled) in the Missouri Ozarks ('OZ' prefix) and Plains ecological sections ('TP', Till Plains; 'OP', Osage Plains). Ecological sections are displayed in lower panel.