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Oak decline in the Boston Mountains, Arkansas, USA: Spatial and temporal patterns under two fire regimes

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Abstract

A spatially explicit forest succession and disturbance model is used to delineate the extent and dispersion of oak decline under two fire regimes over a 150-year period. The objectives of this study are to delineate potential current and future oak decline areas using species composition and age structure data in combination with ecological land types, and to investigate how relatively frequent simulated fires and fire suppression affect the dynamics of oak decline. We parameterized LANDIS, a spatially explicit forest succession and disturbance model, for areas in the Boston Mountains of Arkansas, USA. Land type distribution and initial species/age class were parameterized into LANDIS using existing forest data. Tree species were parameterized as five functional groups including white oak (*Quercus alba* L., *Quercus stellata* Wangenh., *Quercus muehlenbergii* Engelm.), red oak (*Qurecus rubra* L., *Quercus marilandica* Muenchh., *Quercus falcata* Michx., *Quercus coccinea* Muenchh.), black oak (*Quercus velutina* Lam.), shortleaf pine (*Pinus echinata* Mill), and maple (*Acer rubrum* L., *Acer saccharum* Marsh.) groups. Two fire regimes were also parameterized: current fire regime with a fire return interval of 300 years and a historic fire regime with an overall average fire return interval of 50 years. The 150-year simulation suggests that white oak and shortleaf pine abundance would increase under the historic fire regime and that the red oak group abundance increases under the current fire regime. The black oak group also shows a strong increasing trend under the current fire regime, and only the maple group remains relatively unchanged under both scenarios. At present, 45% of the sites in the study area are classified as potential oak decline sites (sites where red and black oak are >70 years old). After 150 simulation years, 30% of the sites are classified as potential oak decline sites under the current fire regime whereas 20% of the sites are potential oak decline sites under the historic fire regime. This analysis delineates potential oak decline sites and establishes risk ratings for these areas. This is a further step toward precision management and planning.

Keywords: Arkansas' Boston Mountains; Decline; Fire; LANDIS; Landscape model; Mortality; Oak; Risk; Simulation; Forest health

1. Introduction

"From earliest times, oaks have held a prominent place in human culture" (Johnson et al., 2002). "The oak tree is a symbol of American forests" (Smith, 2006). Oak-dominated forests represent 51% of eastern United States forests (Spetich et al., 2002). In the Boston Mountains of northern Arkansas, these complex ecosystems have been modified by both human and natural factors. These factors include drought, oak decline, and the interaction of humans and fire including fire suppression.

Native Americans have been an active part of the North American landscape for over 12,000 years. In fact, hardwood trees were the most important wood for native dwellings and oak was the most important species for fuelwood (Sabo et al., 2004), so these forests also played an important role in Native American culture. Native American forest and land management included the use of fire for agricultural clearing and driving game (DenUyl, 1954; Campbell, 1989; DeVivo, 1990; Reich et al., 1990; Denevan, 1992). Changes in Native American population likely led to changes in fire across the Boston Mountain landscape. For instance, during periods of relatively low-level population, the relationship of increasing population resulted in increasing fire frequency in the Boston Mountains (Guyette and Spetich, 2003; Guyette et al., 2006). By the mid 1800s, Euro Americans began settling in Arkansas and began clearing forest land for agriculture. They adapted many of the Native American methods, including the use of fire.

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This activity resulted in a mean fire return interval of 2.9 years in the lower Boston Mountains during the period of regional development from 1881 to 1910 (Guyette and Spetich, 2003). However, since 1910, fire suppression efforts have increased the mean fire interval to greater than 80 years.

Fluctuations in historic use of fire and fire suppression have likely influenced species composition in the Boston Mountains (Spetich, 2004). However, successful regeneration of oak has been problematic (Spetich et al., 2002). Throughout Arkansas and parts of Missouri, the complexity of both regeneration and stand development has been further complicated by a recent oak decline event.

In the Boston Mountains, stem densities have nearly tripled since the 1800s and this is likely due, at least in part, to nearly a century of fire suppression (Foti, 2004; Spetich, 2004). These high stem densities, combined with drought, likely led to the recent and extensive oak decline event in Arkansas and surrounding areas (Spetich, 2004). From 1856 to 1986, there have been 57 oak mortality events recorded in the eastern United States (Millers et al., 1989). This included one in 1959 in the Ozark Mountains of Arkansas, one from 1980 to 1981 in northwestern Arkansas, and one from 1980 to 1986 in nearby Missouri. The most recent oak decline event occurred from 1999 to 2005 in Arkansas and Missouri and severely impacted approximately 120,000 ha in Arkansas' Ozark National Forest alone (Starkey et al., 2004).

Oak decline has been studied extensively. Manion (1991) describes oak decline as the outcome of the interaction of three major groups of factors: predisposing factors, inciting factors, and contributing factors. Predisposing factors include physiologic age and oak density; inciting factors include a long drought; and contributing factors include opportunistic insects such as oak borers and diseases like hypoxylon canker. During the most recent oak decline event in Arkansas' Boston Mountains, predisposing factors included forests of high tree density, mature trees, and dry, rocky soils; the inciting factor was a 3-year drought that began in 1998; and contributing factors included armillaria root rot, oak borers, hypoxylon canker, and defoliating insects. White oak is generally more drought and fire tolerant (Abrams, 2003) and has greater longevity (Guyette et al., 2004) than red oak and, therefore, better adapted to sites exhibiting oak decline symptoms. Starkey et al. (2004) notes that species in the red oak group are impacted by oak decline more rapidly and to a greater extent than the white oak group. Most studies of oak decline have been conducted at site scales at which descriptive and experimental approaches were used to identify relationships among declined oaks, site conditions, and insect or disease agents.

In this study, we treat oak decline as a dynamic process occurring at large spatial extents and involving multiple ecological processes from small site scales to large landscape scales. Our premises include: (1) oaks that are susceptible to decline can be delineated by species composition, age structure, and site conditions spatially, and (2) the dynamics of oak succession and mortality can be predicted using simulation models temporally. At site scales, succession of individual tree species and establishment of new species affect the dynamics of species composition and age structure and, thus, affect the dynamics of oak decline, whereas at landscape scales, the shifting mosaic of species composition and age cohorts caused by fire and environmental heterogeneity (land type association) will also affect the dynamics of oak decline.

The objectives of this study were to delineate potential current and future oak decline areas using species composition and age structure in combination with ecological land types, and to investigate how relatively frequent fires and fire suppression affect the dynamics of oak decline. A spatially explicit model (LANDIS) and modelling approach were employed to assess spatial and temporal variation in oak species composition and age structure, and in the spatial pattern of oak decline sites, under two fire regime scenarios.

2. Methods and materials

2.1. Study area

The Boston Mountains are the highest and most southern member of the Ozark Plateau Physiographic Province. These sharply dissected mountains run approximately 320 km east to west, forming a band 48–64 km wide north to south, with elevations from 275 m in valley bottoms to 762 m at the highest point. Most ridges are flat to gently rolling and generally less than 0.8 km wide. Mountainsides consist of alternating steep simple slopes and gently sloping benches. Vegetation across the landscape is a forest matrix with inclusions of non-forest. The forest is oak dominated. The study site consists of a 427,660 ha area within these mountains (Fig. 1). The landscape within the study area is hilly, highly dissected, and includes a variety of land types.

2.2. LANDIS model description

LANDIS is a spatially explicit, raster-based succession and disturbance model (Shifley et al., 1997; Mladenoff and He, 1999; He et al., 2005). In LANDIS, a heterogeneous landscape can be delineated into various forest ecosystems (land types or ecoregions, depending on the study scale). At a given focal resolution, such as within each forest ecosystem, environmental conditions such as climate and soils are assumed to be homogeneous, as is species establishment (Mladenoff and He, 1999; He et al., 1999). Each raster unit or cell is a spatial object that tracks: (1) the presence or absence of age cohorts of individual species parameterized from forest inventory data; (2) the land type (slope, aspect, position) a cell encompasses; (3) the establishment coefficients of all species in this cell; and (4) disturbance and harvest history if simulated. For each cell, non-spatial processes such as vegetation dynamics – including species birth, growth, and death – are simulated using species vital attributes (Table 1). ''Birth'' simulates a new species seeding in from another site, or on-site species establishment. ''Birth'' also simulates the vegetative reproduction for species that can reproduce by sprouting, based on vegetative reproduction probability and minimum age required for such reproduction (Table 1). ''Death'' typically simulates species