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Research Paper

Distribution of forest ecosystems over two centuries in a highly urbanized landscape

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HIGHLIGHTS

- Assessed spatial and temporal distribution of urban region remnant forest cover.
- Conversion was related to landscape features, land use, and socioeconomic factors.
- Increased urbanization resulted in greater fragmentation but not overall conversion.
- Remnant forest had higher canopy cover, basal area, and native dominance.
- Urbanization effects on cover relatively lower in naturally fragmented landscapes.

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ABSTRACT

Urban development often results in diminished forest cover and severely fragmented landscapes, but most research on effects of urban development has been focused on densely forested regions and has not distinguished remnant from recently established forest cover. Urban development may have different effects in heterogeneous landscapes with high pre-urban fragmentation. Our study investigated spatial and temporal distribution of remnant forest ecosystems across a large urban landscape to assess effects of landscape structure and development patterns on forest conversion. Forest ecosystem distribution within the greater Chicago region (18,822 km^2) was mapped in three time periods using Public Land Survey records (1830′s) and aerial imagery (1939 and 2010). Loss of original forest between sampling periods (conversion) was related to landscape features, land use, and sociodemographic factors. In 2010 ~17% of pre-urban forest area remained, which represented ~40% reduction relative to 1939. Conversion did not differ greatly with urbanization, but fragmentation was greater in areas with high population density and rapid population growth. Conversion was lower in areas close to waterways, where there was less impervious surface, and also differed among land uses (highest in agricultural and industrial). Remnant forests had higher canopy cover, basal area, and native species dominance than recently established forests. Urbanization may have lower relative effects on total forest cover in naturally fragmented landscapes, but may result in extreme fragmentation. Remnant forests had characteristics consistent with high functional value, but creating connectivity among ecosystems in highly urbanized areas will require promotion of canopy cover in urban land uses.

1. Introduction

Development in urban regions can have deleterious effects on forest cover and connectivity (Medley, McDonnell, & Pickett, 1995; Nowak & Walton, 2005; Riitters et al., 2002), but spatial and temporal patterns of canopy loss within these landscapes can be complex (Sanders, 1984). Intense development in the urban core can lead to extreme loss of canopy cover, although recent urban tree planting may ameliorate this effect to some degree (Zhou, Huang, Pickett, & Cadenasso, 2011). In densely forested regions, this conversion can result in landscapes with strong urban-rural differences in canopy cover and habitat connectivity (Miller, 2012). This is especially true in areas where rural canopy cover has recently increased due to regrowth of forest cover related to agricultural abandonment (Zhou et al., 2011). More recent suburban and exurban develop-

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ment has led to increasing fragmentation of forest cover relative to pre-urban conditions in areas beyond the urban core (Radeloff, Hammer, & Stewart, 2005). Such development may decrease differences in canopy cover between core and rural areas, but these differences likely persist in most densely forested regions (Miller, 2012; Zhou et al., 2011).

Much of the research on the effects of urbanization on forests has been conducted in densely forested regions, but many urban areas are situated in landscapes that were either unforested or had a heterogeneous landscape composed of a variety of ecosystem types prior to urbanization (Nowak et al., 1996; Schleeweis et al., 2013). At the sparsely forested end of this spectrum are biophysical regions such as plains or deserts, where the pattern of tree canopy cover in the urban landscape is essentially the opposite of that in densely forested regions, with greater canopy cover in more urbanized parts of the landscape due to tree planting and water diversion (Nowak et al., 1996). However, intermediate on this spectrum are more heterogeneous, partially-forested landscapes, where the effect of urban development on canopy cover and habitat connectivity relative to the original landscape condition may be less straightforward and more uncertain (Bigsby, McHale, & Hess, 2014; Gillespie et al., 2012).

An example of a region where forested ecosystems were patchily distributed and thus relatively fragmented prior to urban development is the central part of North America, which historically consisted of a mixture of prairie and forest ecosystems (Anderson, 1991; Bowles, Hutchison, & McBride, 1994). Modern patterns of forest cover in metropolitan areas in this region have been shaped by this landscape legacy as well as development patterns (Fahey, Bowles, & McBride, 2012; Iverson & Cook, 2000; Sharpe, Stearns, Leitner, & Dorney, 1986; Ward, Kromroy, & Juzwik, 2007). In Midwestern US cities such as Chicago, modern forest cover is strongly concentrated in protected reserves in parks and other natural areas, which are more prevalent in areas closer to the urban core than in the exurban and highly agricultural rural parts of the landscape (Chicago-Wilderness, 2004). In the rural parts of the Midwestern US, intensive agricultural production has persisted into the modern era resulting in relatively little forest regrowth related to agricultural abandonment. Highly urbanized areas in this region could, therefore, have retained equivalent or greater levels of remnant forest (and connectivity between these ecosystems) than surrounding rural landscapes. However, in contrast to urban areas in arid regions, this effect would be more strongly related to development patterns than eco-climatic factors (Nowak et al., 1996).

Absolute canopy cover and the connectivity of this cover is extremely important to many of the ecosystem benefits associated with trees and forests in urban regions (Nowak & Walton, 2005). However, whether or not this cover is constituted by remnant forest patches, spontaneous forests (naturally regenerated following initial clearing for urban or agricultural development), or intentionally planted trees could make a very large difference for some ecological functions and could be very important to the overall functioning of urban region landscapes (Nowak, 1993; Zipperer, 2002). Remnant forests have been shown to support greater biodiversity, store more carbon, and have fewer invasive species relative to spontaneous forests (Dupouey, Dambrine, Laffite, & Moares, 2002; Zipperer, 2002). Patterns of development over time are likely to have had a great impact on the balance of remnant versus spontaneous/planted forests and, thus, also on ecosystem functions and services associated with urban regions. It can be difficult to determine whether urban canopy cover is associated with remnant or spontaneous/planted forests, but investigation of a time-series of imagery can aid such assessment (Qian, Zhou, Yu, & Pickett, 2015; Ward et al., 2007; Zhou et al., 2011).

Historically, the wooded ecosystems of central North America were highly dominated by oaks (*Quercus* spp.), which functioned as foundational species in these ecosystems by creating structure, providing habitat, and driving disturbance regimes (Abrams, 2003). There has been a significant reduction in the dominance of oaks across this region over the past two centuries, due to a variety of direct and indirect anthropogenic impacts (Abrams, 2003; Lorimer, 1993) as well as climatic shifts (McEwan, Dyer, & Pederson, 2011). For example, in the highly urbanized Chicago metropolitan region, the dominance of oak has been reduced from ~60% of the basal area at the time of Euro-american settlement in the 1830′s to ~20% in the modern era (Fahey et al., 2012). Although decreases in oak dominance have resulted from compositional shifts related to successional processes and changes to disturbance regimes (Bowles, Jones, McBride, Bell, & Dunn, 2005), a primary factor in the loss and fragmentation of oak ecosystems has been urban and agricultural development (Fahey et al., 2012; Kromroy, Ward, Castillo, & Juzwik, 2007; Ward et al., 2007). Remnant forests are more likely to have retained oaks (and other associated native species) as a component of the ecosystem and thus provide the benefits associated with these species. Understanding changes in the area dominated by these remnant ecosystems and fragmentation of remnant patches will be essential to assessing functional changes in the landscape related to urban development (Ward et al., 2007).

The primary goals of this project were to evaluate changes in the extent of forest ecosystems (which were largely oak-dominated) over the past ~180 years (1830′s to present) in the greater Chicago metropolitan region, to assess the impact of landscape features and development patterns on the preservation or conversion of these ecosystems, and to compare patterns of forest conversion and fragmentation in this region to other urban areas. Our first specific goal (Objective 1) was to understand how the spatial distribution of forest ecosystems has changed over time across land uses and a gradient in urbanization – including how core habitat and connectivity in this ecosystem type have changed. Our second goal (Objective 2) was to assess what specific landscape features and sociodemographic factors have been associated with conversion of forest ecosystems in this landscape. Finally, we also evaluate how the species composition and structure of remnant forest ecosystems differ from the urban forest of the region as a whole (Objective 3).

2. Methods

2.1. Study area

The study area encompassed the Illinois portion of the Chicago metropolitan region, which covers 18,822 km^2 and all or part of 18 counties (Fig. 1). The Chicago region is home to ~9 million people and contains a wide variety of land uses, cultural and social milieus, population densities, and around 145,000 ha of natural reserves (Chicago-Wilderness, 2004). The surficial geology of the Chicago region includes glacial material deposited in the last 20,000 years, primarily glacial drift (end moraines, till plains and outwash) and the former bed of glacial Lake Chicago (Willman, 1971). The area is located within the "Prairie Peninsula" (Transeau, 1935), a region with unpredictable summer drought (Borchert, 1950). The pre-Euroamerican settlement landscape of the Chicago region was about 60–80% grassland, with the remainder comprised of a savanna-woodland-forest gradient corresponding to increasing fire protection (Bowles et al., 1994; McBride & Bowles, 2001). Wooded ecosystems at the time of settlement were largely constrained to fire breaks along the east side of major waterways and other fire-protected landscape positions (Fahey, Maurer, Bowles, & McBride, 2014; Fahey et al., 2012).