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Influences of land-use change and edges on soil respiration in a managed forest landscape, WI, USA

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Abstract

A critical issue in landscape ecology is to understand the effects of disturbances on landscape processes. While there is increasing interest in examining the ecological consequences associated with changes in landscape structure and composition, little is known about how soil respiration across landscapes might be affected within this context. We examined field-season soil respiration rates (SRR) and soil carbon fluxes in a managed landscape in northern Wisconsin related to land-use change, area-of-edge influence (between non-forested bare ground (NFBG) and other forest cover types), and spatial variation. We estimated SRR for all six cover types classified from Landsat images of 1972 and 2001 across the entire landscape using published SRR–T_s (soil temperature at 5-cm depth) models developed based on data collected in the study area. Between the 2 years, the landscape-level mean SRR increased by 0.5% (mainly as a result of a 33% increase in the proportion of young forests proportion), varying from −2.6 to 4% among 16 sub-landscapes, suggesting spatial variation in land-cover composition can affect landscape-level SRR significantly. If the influence of edges was considered, landscape mean SRR further increased by 0.03% in 1972 and 0.16% in 2001 as a result of an increase in NFBG from 3.1% in 1972 to 9.2% in 2001. Both land-use change and edges influence landscape-level SRR, but at different magnitudes. The former caused ±4% variation in landscape-level SRR while the latter, associated with increase in NFBG, introduced an additional 0.01–0.26% increase in landscape-level SRR. Smaller than expected edge influences on landscape-level SRR were partly due to the offset of T_s changes in the forested and NFBG sides of the edges. We present an empirical equation to predict edge influences on net changes in landscape-level SRR using net changes in two representative, class-level (NFBG) indices that are easily calculated from an existing spatial pattern analysis program.

Keywords: Area-of-edge influence (AEI); Remote sensing; Relative changes; Systematic sampling; Landscape; Soil respiration rates; Soil carbon flux

1. Introduction

Intensive land-use such as road construction, power line construction, urbanization, and forest management can result in profound changes in landscape

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composition and structure (Franklin and Forman, 1987; Ripple et al., 1991; Meyer and Turner, 1994; Zheng and Chen, 2000) and can impact community properties (Ranney et al., 1981; Franklin and Forman, 1987; Debinski and Holt, 2000). For example, harvesting introduces a considerable amount of area-of-edge influence (AEI) where plant and animal species composition (Yahner, 1988; Haefner et al., 1991; Chen et al., 1992), microclimate (Chen et al., 1995; Zheng et al., 2000), and ecosystem processes (Laurance et al., 1997) can undergo dramatic changes. In order to gain a clearer perspective of the mechanisms under these changes, links need to be established between landscape structure and processes such as cycles of materials and energy (Murcia, 1995), including the components of the carbon cycle. One of the least understood components within heavily managed landscapes is soil respiration, yet it may tilt the carbon balance of the entire system to either side of the source-or-sink equation (Tans et al., 1990; Field et al., 1992; Dixon et al., 1994; Ciais et al., 1995; Grace et al., 1995). Incorporating landscape structure in evaluations of soil respiration rates (SRR) across entire landscapes can provide a better understanding of carbon exchange within landscapes and between landscapes and the atmosphere.

Soil respiration mainly refers to the release of CO_2 from soils due to the production of CO_2 by roots and soil organisms, whose type, abundance, and production are directly related to land-use and management practices (Raich and Schlesinger, 1992; Ogle et al., 2003). Furthermore, soil respiration is a complex ecosystem process interacting with both biotic and abiotic factors. Soil temperature (T_s) and soil moisture (M_s) are the foremost abiotic controls over SRR at the landscape scale. While M_s has a greater effect on soil respiration in xeric environments, T_s has a greater impact on soil respiration in mesic-environments like our study area (Edwards, 1975; Houghton et al., 1983; Zheng et al., 1993; Davidson et al., 1998; Jones et al., 2003). The influence of temperature on soil respiration is non-linear and exponential, often expressed as a Q_{10} factor with values generally ranging from 2.0 to 3.4 with an average value of 2.4 (Raich and Schlesinger, 1992).

While most emissions of carbon from forestry practices and land-use change have been focused on regional and global scales (Ciais et al., 1995; Keeling et al., 1996; Houghton and Hackler, 1999; Hirsch et al., 2004), there is a lack of studies examining the consequences of fragmentation and the associated edge influences on SRR at the landscape-level. Landscape-level studies may improve our understanding of the relationship between land-use change and soil carbon emission while reducing the uncertainty of estimates. Over a landscape soil respiration is controlled simultaneously by many factors such as climate, vegetation type, depth-of-edge influence, availability of both nutrient and energy sources, and substrate and microbial population changes at multiple scales. To simplify a complex ecosystem process such as soil respiration and gain a clear understanding from a certain perspective, this study focused on detecting relative changes in field season (May–October) landscape-level SRR caused by changes in land-use between 1972 and 2001 and edge influences—one of the consequences resulting from land-use change. Studies on boreal and temperate forests reported that soil respiration from May to October accounted for about 75–78% of the annual soil respiration (Janssens et al., 1999; Kurganova et al., 2003).

This study was designed to answer three specific questions:

(1) How did changes in land-use from 1972 to 2001 affect field season landscape-level SRR and soil carbon flux and their spatial variation?
(2) To what degree was landscape-level SRR influenced by edges caused by harvesting as a consequence of land-use change?
(3) Can we link the changes in SRR caused by the influence of edges, that are difficult to measure at any landscape-level, to changes in landscape characteristics that are relatively easily quantified using an existing spatial pattern analysis program?

2. Materials and methods

2.1. Overview

The overall methodology was to assess indirectly changes in SRR ($g\,CO_2\,m^{-2}\,h^{-1}$) at the landscape scale associated with land-use changes using existing soil respiration models based on field measured data collected in the study area. Land-use changes were assessed by examining two satellite-derived land-cover maps from 1972 to 2001. The simulations of