12
Spatial Patterning of Soil Carbon Storage Across Boreal Landscapes

Merritt R. Turetsky, Michelle C. Mack, Jennifer W. Harden, and Kristen L. Manies

Abstract

The boreal forest covers 14% of the earth's vegetated surface but contains about 27% of the world's vegetation carbon and between 25% and 30% of the world's soil carbon. Unique features of this biome include cold climates, large areas of relatively flat topography, discontinuous permafrost, large and severe fire events, and the accumulation of peat. These characteristics are important in controlling energy and carbon cycling and either influence or are influenced by regional climate and hydrological regimes. Total carbon accumulation within an ecosystem reflects the balance between net primary production (NPP), decomposition, and nonrespiratory losses (dissolved carbon export, fire, and land-use changes). In this chapter, we use soil carbon storage as a long-term estimate of net ecosystem productivity (NEP; the balance between NPP and decomposition) and nonrespiratory losses that integrates annual variability in the ecosystem processes contributing to carbon balance. Our overall hypothesis is that a combination of regional and local physiography creates spatial heterogeneity in hydrology and soil temperatures. Hydrology and thermal regimes, in turn, influence distributions of fire, permafrost, peatlands, and vegetation and ultimately control long-term carbon storage in many boreal climatic zones. Soil carbon storage varies tremendously between boreal stand types or features and is particularly large in poorly drained peatland and permafrost ecosystems. Landscape composition, then, is important for scaling carbon storage in boreal regions. However, whether the configuration of upland and lowland ecosystems influences carbon processes has not been adequately explored but likely is important to variations in carbon emissions during fire. Biological controls such as herbivory and insect outbreaks are important to the distribution of plant species and nitrogen availability in forest ecosystems, but their influence on wetland systems or long-term carbon dynamics is not well understood.

Introduction

The boreal biome covers 18.5 million km^2 across interior Alaska, Canada, Fennoscandia, Russia, and parts of Mongolia and China. This biome actually represents a number of ecoclimatic zones that support coniferous or mixed conifer-hardwood forests. Most boreal regions experience large annual changes in solar input, short growing seasons (3–4 months), and extremely cold winter temperatures (Eugster et al. 2000). Low precipitation and temperatures may limit plant productivity in boreal ecosystems (Baldocchi et al. 2000). However, throughout the Holocene, soils in boreal regions have served as an important reservoir for terrestrial carbon (C) (Harden et al. 1992). Today, boreal forests contain approximately 27% of the world's vegetative C and between 25% and 30% of the world's soil C, approaching 500 Gt C (Gorham 1991; Dixon et al. 1994). Carbon sinks in the boreal forest are relatively small, averaging between 0.3 and 0.5 Pg ($=10^{15}$g) C yr^{-1}, and the size of this sink varies spatially and temporally (Apps et al. 1993; Goodale et al. 2002). Thus, C sequestration in boreal regions is dictated by the small difference between larger C inputs and outputs, which makes it difficult to assess spatial or temporal controls on C balance. We argue that soil C storage is a long-term (decadal and longer) proxy for net ecosystem production (NEP; total ecosystem C storage) that integrates annual variation in processes such as net primary productivity (NPP) and decomposition (Randerson et al. 2002) and thus is useful for assessing spatial or temporal controls on NEP.

Identifying spatial controls on ecosystem-level processes is important for scaling current ecosystem dynamics and planning future responses to global change. An approach based in landscape ecology, or the study of how pattern effects process (Turner 1989), can help to identify the controls of landscape structure on ecosystem processes. However, a landscape approach requires an integrated investigation of patterns and processes at varying spatial and/or temporal scales. For example, large-scale patterns of deglaciation and sediment deposition exert major controls on hydrology and ecosystem development in boreal regions. Glacial till of varying thickness overlies bedrock across much of interior and eastern Canada, increasing in thickness to 20 m in low-lying areas. Glacial movement across Canada created relatively flat lake and outwash plains in the west and moraines in central Canada. Peatlands occur extensively across glacial plains in western and central Canada because of poor drainage. Rocky outcrops with increasing elevation are found farther east. Across Alaska and Siberia, large regions repeatedly have been covered by windblown loess (largely silt or finer particles) derived from river floodplains and glacial outwash plains (Pewe 1958; Van Cleve et al. 1993). Silt is transported to lowlands, mixed with organic debris, and incorporated into permafrost layers (see the section "Discontinuous Permafrost" below). Loess deposits generally are less well drained than other glacial deposits and thereby influence heterogeneity in surface hydrology.