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A model for the investigation of long-term carbon dynamics in boreal forests of western Canada I. Model development and validation

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Abstract

To interpret field studies of forest floor dynamics in the continental boreal forest of western Canada and identify areas for future research, we developed a boreal forest carbon dynamics model based on the decay algorithms of the CENTURY model. Forest floor and mineral soil carbon pools were separately represented. We quantified detrital inputs for nine separate components of live vegetation using published data to relate litterfall to biomass and regression models to relate biomass of each component to stand age and other significant variables. The regression models were developed from observed C stocks of each component using data from 80 forest stands forming six chronosequences. The six chronosequences were for two of the principal species in this region, *Pinus banksiana* and *Populus tremuloides*, in each of three distinct climatic areas (approximately represented by the BOREAS SSA, BOREAS NSA and Wood Buffalo National Park). We carried out extensive sensitivity testing and validation tests against a wide range of data, including forest floor carbon stocks measured in the six chronosequences. The validation tests highlighted the need for better data in several areas, particularly root litter, woody detritus dynamics, coniferous foliage litter and nitrogen budgets. Nevertheless, the model performed well against the available data and was judged adequate for its purposes.

Keywords: Boreal forest; Canada; Validation; CENTURY; Model; Forest floor; Carbon dynamics

1. Introduction

Northern ecosystems are increasingly recognised as playing an important role in climate change (Woodwell et al., 1998; Chapin et al., 2000). Boreal forests may form an important biotic feedback because they store large amounts of carbon (Apps et al., 1993), which can be sensitive to climate, particularly temperature (Kauppi et al., 1997; Liski and Westman, 1997) and temperature increases in boreal regions are likely to be relatively large, according to projections of general circulation models (GCMs) (Kattenberg et al., 1996). The potential for feedbacks is clear; however, their magnitude and sign remain uncertain.

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In upland forests, the forest floor is a substantial pool of carbon which is likely to be sensitive to climate change (Nalder and Wein, 1999). It also acts as an important control on many key processes such as nutrient cycling. These processes may be more important than aboveground processes in determining long-term productivity responses to increasing temperature and CO_2 (Medlyn et al., 2000). Consequently, it is important to be able to predict how the forest floor changes throughout the life of a stand to assess the impacts of climate change. These dynamics, however, have been little studied, particularly over the long-term (decades to centuries).

Because of the long timescales involved with climate change, experimental data are difficult to acquire and assessments of impacts often rely on computer models. No suitable models exist, however, for the western Canadian boreal forest. The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS) (Kurz et al., 1992) has been widely used to study carbon stocks and dynamics of Canadian forests (e.g., Kurz and Apps, 1999), but it does not explicitly represent the forest floor. Patch models, also termed gap dynamics models, have been frequently used for climate change studies in boreal forests but can give unreliable predictions outside their region of parameterisation (Bugmann et al., 2001). Also many of these models do not explicitly represent the forest floor (e.g., Burton and Cumming, 1995; Price et al., 1999). Of those that do, decay is generally represented as a first-order process based on short-term decay studies (e.g., Bonan, 1990b; Post and Pastor, 1996; Makipaa et al., 1999), but there is mounting evidence that this is not appropriate for the longer term (e.g., Parton et al., 1987, 1988; Berg and Ekbohm, 1991; Trumbore, 1993; Townsend et al., 1995; Liski et al., 1998; Giardina and Ryan, 2000).

The CENTURY model (Parton et al., 1987, 1993) provides an alternative model of soil organic matter decomposition based on concepts from agricultural systems. It is well validated and has proved robust in predicting mineral soil C across a range of ecosystems (Parton et al., 1988, 1989, 1993; Ojima et al., 1993; Trumbore, 1993; Parton and Rasmussen, 1994; Vitousek et al., 1994; Yarie et al., 1995; Smith et al., 1997). It has successfully been applied to predict mineral soil C at several sites in the continental boreal forest of western Canada (Peng et al., 1998). However, CENTURY has a number of limitations. First, it does not explicitly represent the forest floor as a separate soil layer, a limitation previously noted for forest applications (Kelly et al., 1997). Second, the tree growth routines and parameters are not species-specific. Third, CENTURY does not represent other vegetation such as shrubs and moss which can be important components (Nalder and Wein, 1999). Fourth, the abiotic multipliers were developed for U.S. grasslands and there are significant concerns, addressed further in Section 2, about their applicability to boreal forests.

Here we develop a new model to simulate forest floor carbon dynamics. This is a carbon dynamics model based on the CENTURY decay routines but with new input and abiotic multiplier routines to address the above limitations. The model is part of a wider study into forest floor dynamics which focuses on upland forests in the Boreal West Ecoclimatic Province of Canada (Ecoregions Working Group of Canada, 1989; Siltanen et al., 1997). This region will be referred to as the western boreal. It is formed by a 1000 km wide arc of continental boreal forest that stretches from the Ontario/Manitoba border west and north to the base of the western mountain chain in Alberta and the Northwest Territories. It is of particular interest because it appears particularly sensitive to climate change: it has undergone 1.3–1.7 °C warming over the last century (Environment Canada, 1992) and GCM projections indicate it will undergo greenhouse warming much greater than the global average in the future (Kattenberg et al., 1996).

Our objective is to develop and validate a simple but realistic model of forest floor dynamics which will be suitable for interpreting the results of previous field studies, particularly to explain the effect of age, species and climate on forest floor carbon, and for identifying critical areas for further research. The applicability of the model is limited to upland stands dominated by *Populus tremuloides* Michx. (trembling aspen) and *Pinus banksiana* Lamb. (jack pine). These species together account for 50% of timber volume in the western boreal upland.

2. Methods

2.1. General description of model

The boreal forest carbon dynamics model (BFCDM) described here simulates carbon flows through the for-