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Carbon sequestration and the optimal forest harvest decision: A dynamic programming approach considering biomass and dead organic matter

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ABSTRACT

Carbon sequestration in forests is being considered as a mechanism to slow or reverse the trend of increasing concentrations of carbon dioxide in the atmosphere. We present results from a dynamic programming model used to determine the optimal harvest decision for a forest stand in the boreal forest of western Canada that provides both timber harvest volume and carbon sequestration services. The state of the system at any point in time is described by stand age and the amount of carbon in the dead organic matter pool. Merchantable timber volume and biomass are predicted as a function of stand age. Carbon stocks in the dead organic matter pool changes as a result of decomposition and litterfall.

The results of the study indicate that while optimal harvest age is relatively insensitive to carbon stocks in dead organic matter, initial carbon stock levels significantly affect economic returns to carbon management.

Introduction

In response to global concern about climate change, policy makers and scientists are searching for ways to slow or reverse the trend of increasing concentrations of greenhouse gases, especially carbon dioxide (CO_2), in the atmosphere. Forests are viewed as potential carbon sinks. As trees grow,

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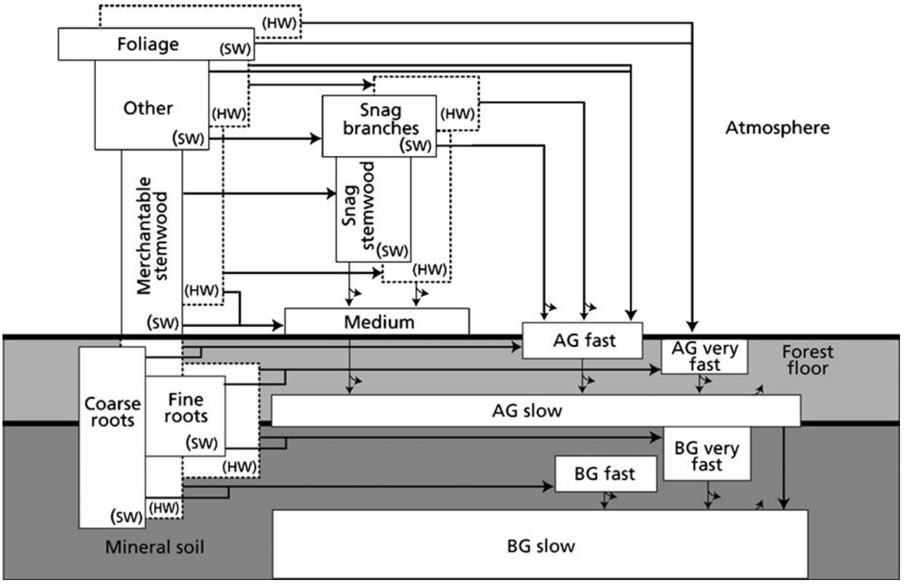

Fig. 1. The carbon pool structure of the CBM-CFS3. Very fast, fast, medium, and slow refer to relative decomposition rates for pools. Curved arrows represent transfers of carbon to the atmosphere, and straight arrows represent transfers from one pools to another. SW is softwood, HW is hardwood, AG is above ground, and BG is below ground. Illustration courtesy of the Canadian Forest Service, reproduced with permission from Kull et al. (2007, Fig. 1-1).

photosynthesis converts CO_2 into cellulose and other plant material, temporarily removing it from the atmosphere. In addition, a substantial amount of carbon is stored in forests as dead organic matter (DOM) in standing snags, on the forest floor, and in the soil until the process of decomposition releases it back to the atmosphere.

The Intergovernmental Panel on Climate Change (IPCC) provides guidelines for the calculation and reporting of changes in stocks of forest carbon (IPCC, 2006) as it relates to national greenhouse gas inventories. The IPCC identifies three tiers for reporting changes in stocks of forest carbon. These tiers reflect the relative importance of forest carbon stocks to greenhouse gas inventories and the sophistication of the data collection and monitoring infrastructure of countries.

Canada has elected to use tier 3 methodologies (with the most detailed reporting requirements) for reporting changes to carbon stocks on managed forest lands. The IPCC specifies five carbon pools that must be accounted for: above-ground biomass, below-ground biomass, dead wood, litter, and soil carbon. The Canadian Forest Service developed the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) to track and report changes in forest carbon stocks (Kull et al., 2007). CBM-CFS3 is a detailed model that recognizes more than 20 different carbon pools within a forest stand and tracks the transfer of carbon between these pools and the atmosphere (Fig. 1).

The classic problem in forest economics is the determination of the harvest age for an even-aged forest stand which maximizes the net present value of an infinite series of timber regeneration, growth, and harvest cycles. Faustmann (1849) is usually attributed with the first correct solution to this problem when only timber values are considered. Samuelson (1976) provides a more formal mathematical specification of the problem. Hartman (1976) extends the model to include values associated with standing trees (e.g. wildlife habitat) as well as the extractive value of timber harvest.

In the forest economics literature, most of the analysis of carbon sequestration has focused on the carbon pools in living biomass. However, the DOM carbon pool can represent a substantial proportion of the total carbon stored in forest stands and management decisions such as harvest age can have a substantial effect on soil carbon stocks (Aber et al., 1978; Kaipainen et al., 2004). Covington (1981) found that forest floor mass declines sharply following harvest, with about half of forest floor organic matter lost in the first 20 years. DOM may increase immediately following harvest as a result of slash