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Spatially-explicit reconstruction of 100 years of forest land use and disturbance on a coastal British Columbia Douglas-fir-dominated landscape: Implications for future watershed-scale carbon stock recovery

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ABSTRACT

Reservoir creation, a prevalent mechanism for deforestation, coupled with persistent harvest activity, can significantly affect the carbon (C) budget of a landscape. The objective of this study was to assess the impact of successive reservoir expansion and forest harvest events over a 100-year period on a watershed-scale terrestrial C budget. Using a spatially-explicit version the Carbon Budget Model of the Canadian Forest Sector 3 (CBM-CFS3), and a compiled forest cover disturbance geodatabase, C stocks and stock changes were analysed for the Sooke Lake watershed near Victoria, British Columbia, Canada. Over the study period, of the 7943 ha of forest modeled, 2430 ha was cut and replanted and 640 ha deforested. In 1910 the watershed was dominated by mature/old Douglas-fir forests with average aboveground biomass of 258 Mg C ha^{-1} across the watershed. Deforestation occurred as a result of reservoir expansion between 1911 and 1915. The effect of deforestation as well as fires and localized, intensive harvest from 1920 to 1940 on what were private forestlands in the north and south east of the watershed, reduced aboveground biomass to an average of 189 Mg C ha^{-1}. Distributed harvesting between 1954 and 1998 and two additional reservoir expansions resulted in a study-period minimum aboveground biomass value of 148.7 Mg C ha^{-1} in 1991. By 2012 aboveground biomass had begun to recover (177.9 Mg C ha^{-1}). Even though land clearing for reservoir expansion had occurred again in 2002, cessation of logging activities since the mid-1990s has resulted in a recovery of aboveground C stocks. Yet, total ecosystem C stocks will not reach pre-disturbance levels until 2074 given current management practices. This research highlights the long-term implications of past management practices on future C stock recovery. Conclusions drawn from the retrospective C budget could apply to other landscapes that have undergone similar recursive deforestation events paralleled by forest harvest disturbances.

1. Introduction

Northern forest ecosystems play an important role in global carbon (C) cycling and are considered to be a net C sink for atmospheric C (IPCC, 2007), storing more carbon than they emit to the atmosphere. Although dependent on the spatial and temporal scale of analysis, the sink strength of a forest area (and potential shift to a C source) is mainly determined by processes that drive biomass production (i.e. photosynthesis, moisture regime, ambient temperature and geological parent material), forest decay, and the frequency, intensity and permanence of disturbances such as fire, harvest, insect and disease outbreaks, or deforestation due to urbanization, agriculture, mining or reservoir creation. As well, lateral transfers of C into, or out of, a forest ecosystem through aquatic systems can also impact the ecosystem C balance (Cole et al., 2007). While naturally variable, the C sequestration potential of forests can be optimized by forest management practices (Man, Lyons, Nelson, & Bull, 2013). Increasing a forest landscape's C sink strength can improve the likelihood of reaching global carbon dioxide (CO_2)

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stabilization targets IPCC (2007b). Understanding the net C balance of forest lands by monitoring C sinks and sources and modelling past and future C budgets can assist forest managers, allowing them to adjust forest management plans in an effort to mitigate climate change.

Net Ecosystem Productivity (NEP), determined by the difference between forest biomass production, defined as Net Primary Production (NPP), and decomposition, defined as Heterotrophic Respiration (Rh) (Chapin et al., 2006), represent the carbon balance of a forest. These forest dynamics are affected by attributes such as forest age, site productivity and species composition. Relative to a natural, unmanaged forest, these attributes are further influenced by forest management activities related to harvest, wood-based bioenergy, or fire and insect suppression (Stinson et al., 2011) as well as natural disturbance events. Net biome production (NBP) integrates C flux changes associated with disturbance (Kurz et al., 2009), depicting how events like reservoir creation, fire and forest harvest impact C emissions across a landscape. Specifically, reservoir creation, whether for water supply, flood control or hydro-electricity, can have pronounced effect on the terrestrial C budget of a forested watershed. While the initial impacts of establishing a reservoir are analogous to other disturbances, such as fire or harvest, the resulting permanent deforestation can have long term implications for the balance of landscape C with the atmosphere (Schlesinger & Bernhardt, 2013). The Carbon Budget Model of the Canadian Forest Sector 3 (CBM-CFS3) is a landscape-level, annual time-step model for forest ecosystem C dynamics that uses data commonly collected by forest managers including forest inventory, growth and yield (G&Y) curves, natural and human-induced disturbance and land use change information, as inputs to simulate forest C dynamics (Kull et al., 2014). G&Y curves that describe forest growth (in merchantable volume) are converted to aboveground stand-level biomass (Boudewyn, Song, Magnussen, & Gillis, 2007) and belowground biomass by component (Li, Kurz, Apps, & Beukema, 2003) using allometric equations. The C pool structure of CBM-CFS3 includes both live biomass C (e.g. live stemwood and foliage) and DOM (e.g. coarse woody debris, snags, soil C) (Fig. 1) (see Supplementary Material Table S1 for description of common pools and fluxes); transfers between these pools occur at varying rates depending on what forest constituents are represented within the pool. CBM-CFS3 cannot explicitly model mixed-age or mixed species stands; to reflect these stand attributes, G&Y curves that exhibit these qualities are used instead (Kull et al., 2014). The model allows for C transfers out of the forest ecosystem to the atmosphere through decay, disturbance or export (e.g. Harvested Wood Products (HWP)). Decay dynamics are determined through a temperature dependent decay rate (Kurz et al., 2009) calibrated against a Canada-wide decomposition experiment (Trofymow & CIDET Working Group, 1998; Smyth, Trofymow, Kurz., CIDET Working Group. 2009). CBM-CFS3 has been widely used to model annual C uptake and emissions at the landscape, regional and national level for international C reporting by governments and operational C budgets by forest companies (Kull et al., 2014), and has been evaluated against Canada's National Forest Inventory ground plot database (Shaw et al., 2014). Also, the model has been applied retrospectively to reconstruct past C budgets of diverse landscapes (Bernier, Guindon, Kurz, & Stinson, 2010; Trofymow, Stinson, & Kurz, 2008).

Using newly developed tools for the CBM-CFS3 that allow for spatially-explicit input/output, a baseline retrospective C budget was developed for the Sooke Lake Watershed within the Greater Victoria Water Supply Area (Fig. 2), capturing 100 years (1911–2012) of anthropogenic disturbance. The objectives of this research were to: 1) Construct a spatially-explicit forest cover/disturbance geodatabase for the period of known anthropogenic disturbance with accompanying accurate and current growth and yield information; 2) Investigate the impact of deforestation through reservoir creation and sustained yield forestry activity on the landscape level forest C budget; and 3) based on a business-as-usual case where there is no change in forest growth, decay or disturbance patterns as a result of climate change or forest management priorities, make projections of the length of time required for total ecosystem C stocks to recover to pre-disturbance levels. As well, two of primary sources of model error will be investigated

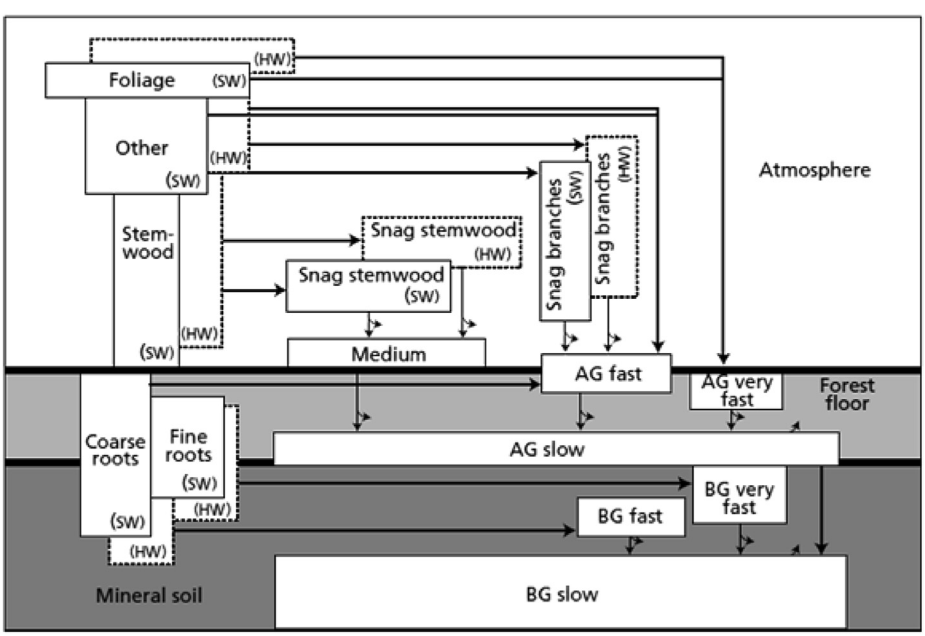

Fig. 1. CBM-CFS3 internal carbon pool and flux structure. “Very fast”, “fast”, “medium”, and “slow” refer to the relative decay rates of the pools. Curved arrows represent transfers of carbon to the atmosphere, and straight arrows represent transfers from one pool to another. SW = softwood, HW = hardwood, AG = aboveground, BG = belowground. Reprinted from Kull et al. (2014).