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Tamm Review

Quantifying carbon stores and decomposition in dead wood: A review

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ABSTRACT

The amount and dynamics of forest dead wood (both standing and downed) has been quantified by a variety of approaches throughout the forest science and ecology literature. Differences in the sampling and quantification of dead wood can lead to differences in our understanding of forests and their role in the sequestration and emissions of CO_2, as well as in developing appropriate strategies for achieving dead wood-related objectives, including biodiversity protection, and procurement of forest bioenergy feedstocks. A thorough understanding of the various methods available for quantifying dead wood stores and decomposition is critical for comparing studies and drawing valid conclusions. General assessments of forest dead wood are conducted by numerous countries as a part of their national forest inventories, while detailed experiments that employ field-based and modeling methods to understand woody debris patterns and processes have greatly advanced our understanding of dead wood dynamics. We review methods for quantifying dead wood in forest ecosystems, with an emphasis on biomass and carbon attributes. These methods encompass various sampling protocols for inventorying standing dead trees and downed woody debris, and an assortment of approaches for forecasting wood decomposition through time. Recent research has provided insight on dead wood attributes related to biomass and carbon content, through the use of structural reduction factors and robust modeling approaches, both of which have improved our understanding of dead wood dynamics. Our review, while emphasizing temperate forests, identifies key research needs and knowledge which at present impede our ability to accurately characterize dead wood populations. In sum, we synthesize the current literature on the measurement and dynamics of forest dead wood carbon stores and decomposition as a baseline for researchers and natural resource managers concerned about forest dead wood patterns and processes.

Contents

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1. Introduction

Forest ecosystem management has become an important global strategy for mitigating future climate change effects (Ryan et al., 2010; Malmsheimer et al., 2011; McKinley et al., 2011). Societal demands and trends in land use, in combination with future global change scenarios, may reduce the amount of carbon (C) stored in forests and associated wood products (Joyce et al., 2014). However, substantial knowledge gaps exist regarding the C implications of various forest management activities, given the complex interplay between C emissions and sequestration in forest ecosystems (Malmsheimer et al., 2011; McKinley et al., 2011). Further complicating the assessment of forest ecosystem C stores and fluxes is the diversity of constituent pools, ranging from standing live trees to soil organic C. Tree mortality, canopy damage, and pruning create woody detritus, a critical component of natural forests. We focus here on detritus in the form of aboveground coarse woody debris (Harmon et al., 1986) because it represents a critical stage in the C cycle as live biomass transitions to other pools, such as to the atmosphere or soil organic material, through the process of decomposition.

Aboveground coarse woody debris includes standing dead trees (SDTs), downed woody debris (DWD), and stumps (Fig. 1), forming an important C pool with varying turnover rates. Less is known about the amount of downed dead wood that is buried, but this population can accumulate over centuries given the reduced decomposition when wood is found belowground (Moroni et al., 2015). The DWD pool alone accounts for approximately 20% of total ecosystem C in old-growth (Harmon et al., 1990) and secondary (Bradford et al., 2009) forests, and it is increasingly being considered for use in bioenergy production (Schlamadinger et al., 1995; Sathre and Gustavsson, 2011; Zanchi et al., 2012). At local scales, forest management guidelines and forest certification programs may require maintaining or increasing the abundance of woody debris (e.g., Sustainable Forestry Initiative, 2015). From a global perspective, estimates of woody debris biomass and C are needed for countries that report greenhouse gas emissions from land use, land-use change, and forestry sectors to the United Nations Framework Convention on Climate Change (e.g., Woodall et al., 2012a). In addition to being a dynamic C pool, woody debris is a determinant of fire behavior (Arno, 2000), a component of biodiversity (Martinuzzi et al., 2009; Stokland et al., 2012), and an important substrate for regeneration of many tree species (Bolton and D'Amato, 2011). Thus, quantifying and forecasting the amount and characteristics of woody debris is important to determining current and future forest structure, function, and composition. Accordingly, the annual number of scientific publications on woody debris has numbered around 200 in recent years compared to less than 20 publications per year in the mid-1980s and early 1990s (Fig. 2).

Our review provides a synopsis of the available methods for quantifying woody debris C stores and decomposition and for forecasting dead wood attributes as a part of model simulations. While we focus on methods for quantifying dead wood as a part of national forest inventories (NFIs) from primarily temperate forests, we also emphasize how experiments have furthered the scientific development of dead wood modeling efforts. Common abbreviations used throughout the text may be found in Table 1. With an emphasis on C stores and fluxes, two main sections are presented. The first discusses common sampling techniques for inventorying