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An integrated model for snag and downed woody debris decay class transitions

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Abstract

In order to project the long-term implications of forest management for coarse woody debris (CWD) and its habitat-related ecological functions, the time frame of snag and downed woody debris (DWD) decomposition needs to be quantified. In the present study, we parameterized models of CWD decay class transitions that explicitly represent decomposition-related changes in white and red pine (*Pinus strobus*, *P. resinosa*) snags and DWD over time. Remeasurements of permanent sample plots in Ontario, Canada, were used to derive models of a tree's condition at death (standing or fallen), snag fall rates, transitions among snag decay classes, and the entry of fallen snags into DWD decay classes. DWD decay class transitions were modelled from the condition of harvest residues across a 27-year chronosequence of shelterwood-harvested stands in central Ontario, and on the quasi-equilibrium decay class distribution of DWD in a series of relatively undisturbed sites. By combining these various model components, an integrated model of CWD decay class transitions was developed to project the condition of snags and DWD pieces over time. Projections showed that white and red pine snags had median fall times of 15–20 and 30 years, respectively. DWD from trees that fell at death was projected to advance through four decay classes over a 55–60-year period, whereas DWD originating from snags was modelled to persist for up to 90 years after tree death because of slower decomposition while standing. For both snags and DWD, decay classes I and II were short–lived relative to later classes. Diameter was found to have a significant effect on DWD transitions into decay classes II and IV but not III, with projections accordingly showing smaller-sized DWD to be less abundant in class III than larger material. Incorporating CWD dynamics such as those modelled here into stand growth and mortality models would enable managers to simulate long-term changes in the quality and quantity of snags and DWD under various forest management regimes, and to evaluate the degree to which CWD-associated habitat features may be maintained over time.

Keywords: Coarse woody debris; Pine; Snags; Downed woody debris; Decomposition; Decay classes; Forest management; Shelterwood; Transition model

1. Introduction

Coarse woody debris (CWD), which consists of both standing dead trees (snags) and material that has fallen to the ground (downed woody debris, DWD), is a dynamic resource in forest ecosystems. Decomposition processes continually alter the physical and chemical structure of CWD, and as a result numerous elements of the forest biota are affected not only by the total amount of CWD, but also by its distribution across different stages of decomposition (Nordyke and Buskirk, 1991; Bader et al., 1995; Simila et al., 2003; Morneault et al., 2004). Accordingly, models of CWD inputs and decomposition are needed to assess the long-term dynamics of snags and DWD under different forest management systems, including accumulations in various decay classes over time and consequent implications for future habitat supply (Lofroth, 1998; Harmon, 2001; Jonsson and Kruys, 2001). Before such models can be developed though, a sound quantitative understanding of the temporal progression of CWD through various stages of decomposition is required.

Research on CWD decomposition has traditionally employed separate approaches for snags and downed woody debris. Studies of snag dynamics have tended to focus on fall rates and the factors affecting them (e.g., Cline et al., 1980; Lee, 1998; Huggard, 1999; Garber et al., 2005); some also have quantified rates of snag breakage (Landram et al., 2002) or progression through a series of decay classes (Raphael and Morrison, 1987; Morrison and Raphael, 1993). These analyses treat snags as discrete units whose condition can be expressed as a function of time standing. In contrast, most studies of the decomposition of downed woody debris have been based on Olson's (1963) model of plant litter decomposition, which uses an exponential decay function to

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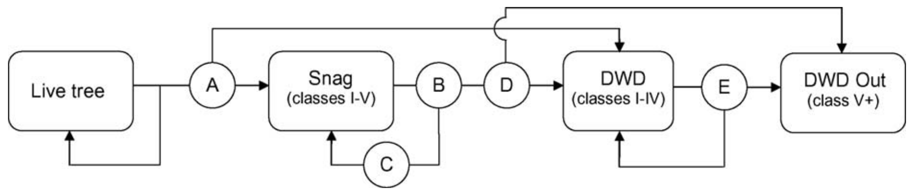

Fig. 1. Schematic illustration of the relationships among model components in the present study. Over a given time interval, trees that die are probabilistically distributed among snag decay classes and downed woody debris (A). Snags may remain standing or fall (B), and conditionally either undergo transitions among snag decay classes (C) or are distributed among DWD decay classes upon falling (D). Downed woody debris progresses through a series of decay classes (E), and here is considered to leave the system upon exiting class IV.

describe change in density over time. Extending this concept to decaying wood, many researchers have modelled the dynamics of DWD in terms of a gradual loss of density (e.g., Lambert et al., 1980; Means et al., 1985; Harmon et al., 1987; MacMillan, 1988). Some studies have also used the exponential decay model to represent the loss of volume through fragmentation (Lambert et al., 1980) or the decrease in relict CWD volume during stand development (Duvall and Grigal, 1999). Recently, Kruys et al. (2002) employed a stage-structured matrix model as an alternative framework for modelling CWD decomposition. Their approach tracks the amount of coarse woody debris within individual decay classes, and can thereby be linked with habitat studies that have long used decay classes as a measure of the changing quality of CWD (Maser et al., 1979). Kruys et al.'s (2002) approach also brings the analysis of DWD dynamics more in line with that of snags by formulating the decomposition process as a series of transitions through discrete states over time.

In the present study we analyzed the temporal progression of white and red pine (*Pinus strobus*, *P. resinosa*) CWD through different stages of decomposition, including transitions to snags and DWD following tree death, from snags to DWD, and among both snag and DWD decay classes. These components were linked together to produce a probabilistic model that describes the position (standing or downed) and condition (decay class) of individual pieces of CWD over time (Fig. 1). For snags, we modelled breakdown from the time of tree death until fall based on remeasurement data from a network of permanent sample plots in central Ontario, Canada. Although permanent plots have been used to investigate snag fall rates elsewhere (e.g., Lee, 1998), the present study is unique in presenting a detailed analysis of snag dynamics, including rates of fall, transitions among decay classes, and decay class distributions at death and at fall. For downed woody debris, decay class transitions were modelled from a 27-year chronosequence of shelterwood-harvested stands in Algonquin Provincial Park, Ontario. Several studies have previously used logging residues to quantify rates of CWD decomposition (Foster and Lang, 1982; Fahey, 1983; Erickson et al., 1985; Frangi et al., 1997), but ours is the first to apply this approach to transitions through a sequence of decay classes. Our ultimate objective in carrying out these analyses of snag and downed woody debris dynamics was to develop an integrated model that describes the progression of CWD pieces through a series of decay classes from tree death until the late stages of log decomposition.

2. Methods

2.1. Snags

2.1.1. Data

Snag data were obtained from 55 permanent sample plots in central Ontario (Fig. 2) that were established by the Ontario Ministry of Natural Resources from 1992 to 1995. These plots were remeasured once between 1997 and 2003, and were selected from among 62 remeasured plots in site regions 4E and 5E (Hills, 1959) that contained white or red pines (7 plots had no dead trees of these species and therefore contributed no snag data). Although most of the plots (43 of 55) were remeasured after 5 or 6 years, some were remeasured at 4-, 7-, or 9-year intervals.

Plots were generally dominated by white and/or red pine, with red oak (*Quercus rubra*), white birch (*Betula papyrifera*), spruce (*Picea glauca*, *P. mariana*), balsam fir (*Abies balsamea*),

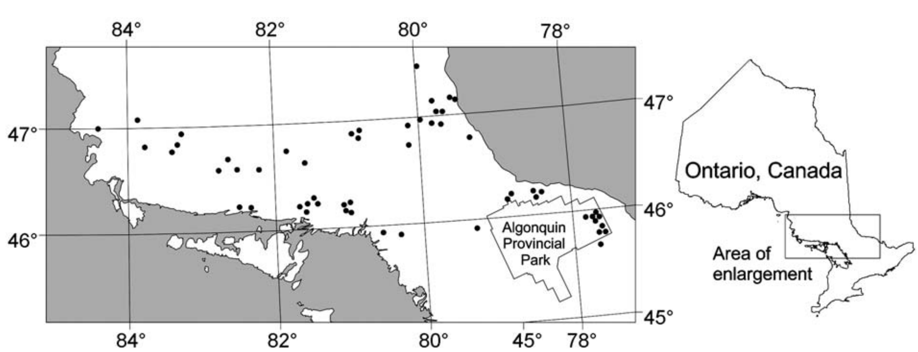

Fig. 2. Locations within central Ontario of 55 permanent sample plots used to model white and red pine snag dynamics. Actual plot positions may not be exactly as shown as some points were shifted slightly to keep symbols from overlapping.