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An objective classification of largewood in streams

Mohammad M. Bataineh [*], Lori D. Daniels

University of British Columbia, 2424 West Mall, Vancouver, BC V6T 1Z4, Canada

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ABSTRACT

Traditional, stage-based, classification systems provide a qualitative measure of decay and have been widely used to monitor and model terrestrial coarsewood and aquatic largewood dynamics. These systems are limited by subjective assignment of wood to classes, lack of measurements relating wood morphology with decay classes, and poor estimates of elapsed time-since-death within and between decay classes. To overcome these limitations, we used quantitative methods to develop a new classification system for in-stream largewood based on morphological attributes that are (1) easily measured in the field and (2) relate to the time-since-death of individual logs. Using principal components and cluster analyses, we developed a three-class system for largewood based on log length, branch order, and cover (quartile classes) of bark, vegetation, and soil. Thresholds for each attribute provided criteria that we organized in a dichotomous key that can be used to objectively and consistently assign individual pieces of largewood into mutually exclusive classes. Using time-since-death determined using dendrochronology, we verified that successive classes in our model-based decay classification represent progressive largewood decomposition through time. This model-based classification system provides an improved framework for developing management plans and modeling dynamics of in-stream largewood.

1. Introduction

Dead wood, including standing snags and fallen trees and logs, provides vital structural components that affect the ecological function of many terrestrial and aquatic ecosystems (Harmon et al., 1986). In terrestrial ecosystems, "coarsewood" provides habitat for many organisms (Ucitel et al., 2003; Lee, 2004) and serves as substrates for nonvascular plants (Crites and Dale, 1998). Coarsewood also affects ecosystem processes such as countering the effects of acidic deposition on soils (Kappes et al., 2007), nutrient dynamics (Ausmus, 1977; but see Laiho and Prescott, 2004) and carbon storage (Bradford et al., 2009; Olajuyigbe et al., 2011). In riparian ecosystems, "largewood" regulates sediment storage, dissipates energy to influence sediment transport and forms fish habitat (Harmon et al., 1986; Richmond and Fausch, 1995; May and Gresswell, 2003). Within ecosystems, physical and biological processes continually alter the amount, size, distribution, and physical and chemical properties of coarsewood and largewood. Stand age, composition, and structure, as well as disturbance regime, site quality, and decomposition rates are among the factors that influence temporal and spatial patterns of wood quantity and quality (Harmon et al., 1986; Sturtevant et al., 1997; Laiho and Prescott, 2004).

The challenge of managing a dynamic forest resource, such as coarsewood or largewood, lies in quantifying rates of input and output within an ecosystem. Quantifying wood input and output requires observations over long temporal and wide spatial scales (Harmon et al., 1986). Such observations are ideally attained from networks of permanent sample plots. However, existing networks were seldom designed to quantify wood dynamics (Chojnacky and Heath, 2002) and establishment of new networks is limited by monetary and logistical constraints. Furthermore, data from newly established networks span short-term periods of one or three decades (e.g., Harmon, 1992; Laiho and Prescott, 1999).

Dendrochronological methods offer an alternative, relatively rapid, approach to quantifying coarsewood and largewood dynamics, with the added benefit of providing longer periods of observation through long-term reconstructions. Although these methods provide indirect estimates of decomposition rate (Laiho and Prescott, 1999) and may underestimate those rates because of a higher probability of sampling slow decaying wood (Kruys et al., 2002), these estimates provide crucial information for management and conservation guidelines in the absence of direct estimates of decomposition rates (Laiho and Prescott, 1999). Dendrochronological methods also circumvent chronosequence methods, which inherently assume all factors other than time are comparable among study sites, and were customarily employed to provide invaluable insights into wood dynamics (Means et al., 1992; Daniels et al., 1997; Kruys et al., 2002).

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[*] Corresponding author. Current address: University of Maine, 5755 Nutting Hall, Orono, ME 04469-5755, USA. Tel.: +1 207 581 2856; fax: +1 207 581 2875.

E-mail addresses: mbbataineh@gmail.com, mohammad.albataineh@maine.edu (M.M. Bataineh), lori.daniels@ubc.ca (L.D. Daniels).

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Stage-based classification systems provide a qualitative measure of decay. In stage-based classifications, wood is assigned a decay class that reflects its morphology and wood integrity. The wood is assumed to change through time in predictable ways and transition from one decay class to the next at relatively constant rates (Maser et al., 1979; Pyle and Brown, 1998). Simplicity and ease-of-use have contributed to the common application of these systems for assessing wildlife habitat value (Bowman et al., 2000), log merchantability (Thomas et al., 1979), and carbon budgets (Chojnacky and Heath, 2002; Iwashita et al., 2013). Thus, a wide range of decay classification systems have been developed and applied (Maser et al., 1979; Thomas et al., 1979; Pyle and Brown, 1998; Kruys et al., 2002; Zielonka, 2006).

Models of wood dynamics often rely on stage-based classification systems (Kruys et al., 2002; Vanderwel et al., 2006), but are limited by the qualitative nature of the classes. Common limitations of these classification systems include: (1) subjectivity in assigning individual pieces of wood to prospective classes (Vanderwel et al., 2006; Larjavaara and Muller-Landau, 2010); (2) lack of measure of the strength of the relationship between wood morphology or decay processes with decay classes (Newberry et al., 2004; Eaton and Sanchez, 2009); and (3) lack of time measurements associated with decay classes, which may be most important for modeling. The first limitation results from differences in the assignment of wood to prospective classes among observers, which highlights the inherent bias of those classification systems (Vanderwel et al., 2006; Larjavaara and Muller-Landau, 2010). Second, refining decay classes requires improved understanding of the relationships between decay and morphology (Eaton and Sanchez, 2009). However, different quantitative measures of decay such as loss of needles, bark or branches or decreases in wood mass or density provide variable estimates of the strength of relationships with decay classes (Newberry et al., 2004; Eaton and Sanchez, 2009).

The third limitation common to stage-based classification systems can be overcome by including a measure of time-since-death for individual pieces of wood (Daniels et al., 1997). Several studies have used dendrochronology to determine time-since-death of terrestrial coarsewood and relate them to decay classes (e.g., Mast and Veblen, 1994; Daniels et al., 1997; Storaunet and Rolstad, 2002; Storaunet, 2004 in Scandinavia; Newberry et al., 2004 in western Canada; Campbell and Laroque, 2007 in eastern Canada). In general, these studies show that time-since-death increases with decay class, as expected. However, they also show significant variation within decay classes and among species and environments (Mast and Veblen, 1994; Daniels et al., 1997; Delong et al., 2008), emphasizing the need for ecosystem-specific measures of coarsewood decay.

Ecosystem-specific variation in wood decay implies a fourth limitation of existing classification systems, particularly for research on wood in aquatic ecosystems. Most decay classification systems were developed for terrestrial coarsewood, but are also applied to aquatic largewood (Robison and Beschta, 1990; Dahlström et al., 2005; Powell et al., 2009). In aquatic systems, anaerobic conditions affect decomposition rates and processes (Guyette and Cole, 1999; Guyette et al., 2002; Arseneault et al., 2007) and may result in morphological traits that differ from terrestrial coarsewood. We know of no research that has assessed the applicability of standard terrestrial coarsewood classification systems, such as the widely spread classification developed in Douglas-fir-dominated forests of the Pacific Northwest, USA (Maser et al., 1979; Thomas et al., 1979), to aquatic largewood.

In this study, our goal was to use quantitative methods to develop a new classification system for in-stream largewood based on morphological attributes that are: (1) easily measured in the field; and (2) relate to the time-since-death of individual logs. This study is part of a broader research project that aims to quantify and, ultimately, model the temporal dynamics of terrestrial coarsewood and aquatic largewood in riparian ecosystems of the Alberta Foothills. In previous work, we determined the abundance and function of largewood in headwater streams (Jones et al., 2010) and assessed the effects of fire and post-fire stand dynamics on in-stream largewood dynamics (Jones and Daniels, 2008; Powell et al., 2009). Building on this research, we used our novel dataset that includes >500 in-stream logs for which morphological traits had been recorded and year of death had been estimated using dendrochronology. We addressed two inter-related questions: How does a statistically-derived classification of the decay of in-stream largewood differ from existing classification systems for terrestrial coarsewood? Does time-since-death differ among the model-based decay classes, indicating improved representation of in-stream largewood decay and function?

2. Materials and methods

2.1. Study area

This research was conducted in the Athabasca and North Saskatchewan River watersheds of the Foothills Research Institute land base, which is in the upper portions of the Rocky Mountains Foothills of Alberta, Canada. The area is part of the Upper Foothills Natural Subregion (Natural Regions Committee, 2006), which is characterized by strongly rolling to steep terrain with an elevation range of 1430–1931 m above sea level (Beckingham et al., 1996). The climate is continental, with mean annual temperature and mean annual precipitation of 1.3 °C and 588 mm, respectively (Natural Regions Committee, 2006). Brunisols and gray luvisols dominate soil pedons, whereas organic soils and gleysols occur in depressions and poorly drained areas (Beckingham et al., 1996; Natural Regions Committee, 2006). Forests dominate the landscape, with lodgepole pine (*Pinus contorta* Dougl. ex Loud.), white spruce (*Picea glauca* (Moench) Voss), and black spruce (*Picea mariana* (P. Mill.) B.S.P.) as the main species both on upland sites and in riparian zones. The disturbance regime is commonly characterized as stand-replacing forest fires, with a mean return interval of 100 years (Beckingham et al., 1996); however, evidence of historical stand-maintaining fires has been reported recently (Amoroso et al., 2011).

2.2. Sampling and data collection

Our data on in-stream largewood is from 26 headwater streams that were sampled between 2002 and 2009. Headwater streams, defined as first to third order streams with bankfull width< 3.5 m and <2.3° slope (McCleary and Hassan, 2008), were sampled to quantify the links between natural disturbances in riparian areas and temporal dynamics of largewood. Consequently, the sampled streams represented a gradient of riparian forest conditions, from recently disturbed (2001 Dogrib fire) to mature (age > 100 years) riparian forests. Five headwater streams surrounded by recently disturbed riparian forests were selected according to the following criteria (Jones and Daniels, 2008): (1) upstream drainage area <200 ha; (2) the entire reach had burned during the Dogrib fire with 100% canopy tree mortality; (3) no harvesting occurred before or after the fire; and (4) no evidence of recent or historic landslides. The remaining 21 streams were selected according to the following criteria (Powell et al., 2009; Jones et al., 2010): (1) stream drainage basin <10 km^2; (2) riparian forests were dominated by lodgepole pine, white spruce or a mixture of white and black spruce; (3) no evidence of partial harvesting within 30 m of the stream; (4) no evidence of wood transport ability; and (5) not confined by hillslopes. Spatially referenced data of forest cover and stream