Forest Ecology and Management 258 (2009) 804–813

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Dynamics of wood recruitment in streams of the northeastern US

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ARTICLE INFO

Article history:
Received 5 March 2009
Received in revised form 18 May 2009
Accepted 19 May 2009

Keywords:
Large woody debris
LWD
Riparian forest
Wood recruitment
Wood dynamics
Stream restoration
Debris dam
Northeastern US

ABSTRACT

Wood is an important component of forested stream ecosystems, and stream restoration efforts often incorporate large wood. In most cases, however, stream restoration projects are implemented without information regarding the amount of wood that historically occurred or the natural rates of wood recruitment. This study uses a space-for-time analysis to quantify large wood loading to 28 streams in the northeastern US with a range of in-stream and riparian forest characteristics. We document the current volume and frequency of occurrence of large wood in streams with riparian forests varying in their stage of stand development as well as stream size and gradient. Linear models relating stream wood characteristics to stream geomorphic and forest characteristics were compared using Akaike's Information Criterion (AIC) model selection. The AIC analysis indicated that the volume and frequency of large wood and wood accumulations (wood jams) in streams was most closely associated with the age of the dominant canopy trees in the riparian forest (best models: $\log_{10}$(large wood volume (m^3 100 m^{-1})) = (0.0036 × stand age) − 0.2281, $p < 0.001$, $r^2 = 0.80$; and large wood frequency (number per 100 m) = (0.1326 × stand age) + 7.3952, $p < 001$, $r^2 = 0.63$). Bankfull width was an important factor accounting for wood volume per unit area (m^3 ha^{-1}) but not the volume of wood per length of stream (100 m^{-1}). The empirical models developed in this study were unsuccessful in predicting wood loading in other regions, most likely due to difference in forest characteristics and the legacy of forest disturbance. However, these models may be applicable in other streams in the northeastern US or in streams with comparable riparian forests, underlying geology, and disturbance regimes—factors that could alter long-term wood loading dynamics. Our results highlight the importance of understanding region-specific processes when planning stream restoration and stream management projects.

1. Introduction

Large wood and accumulations of large wood (wood jams) are widely recognized as important features in forested stream ecosystems. Large wood is important in stream pool formation (Montgomery et al., 1995), in sediment and organic matter retention (Bilby and Likens, 1980; Diez et al., 2000), and in creating fish and invertebrate habitat (Flebbe and Dolloff, 1995; Riley and Fausch, 1995; Wallace et al., 1995). Recent studies have also linked increased wood volume to greater nutrient cycling in headwater streams (Steinhart et al., 2000; Valett et al., 2002; Bernhardt et al., 2003; Warren et al., 2007). Given the importance of wood to stream ecosystems, the volume, abundance, characteristics, and function of wood in streams is of interest to both researchers and managers (Bisson et al., 2003; Bernhardt et al., 2005), and a number of studies have documented standing stocks and wood loading rates for streams in many regions of the country and the world (Richmond and Fausch, 1995; Meleason et al., 2005; Chen et al., 2006; Young et al., 2006). Few studies have evaluated the dynamics of wood in northeastern US stream ecosystems, leaving those engaged in stream research and management with little guidance regarding historic conditions and future changes in loading and abundance of large wood. In this study, we surveyed 28 streams across the northeastern US, and quantified wood, stream, and riparian forest metrics at each site. From these data we (1) evaluated stream wood dynamics in the northeastern US relative to other regions; (2) quantified temporal trends in wood loading to streams in mixed northern hardwood forests; (3) identified factors that best accounted for variability in the amount of wood in these study streams of mixed northern hardwood forests; and (4) developed empirical models to predict current and future wood loading in the northeastern US and other regions with comparable forest type, geologic conditions, and disturbance histories.

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doi:10.1016/j.foreco.2009.05.020

Wood recruitment into streams occurs either as a result of individual tree mortality or as a consequence of fine to coarse scale disturbances affecting multiple trees in the riparian forest. Secondary forests that developed following clear-cutting or land abandonment (old-field succession) currently dominate much of the landscape in the northeastern US (Foster, 1992). In the absence of anthropogenic influences, natural disturbance regimes interact with successional processes in shaping forest structure (Lorimer, 1977; Bormann and Likens, 1979; Runkle, 1982; Frelich and Graumlich, 1994; Keeton et al., 2007). Within the northeastern US, forest development following a stand-replacing disturbance (natural or anthropogenic) begins with a single cohort of trees that persists as an even-aged stand for up to 150 years (Bormann and Likens, 1979). During this stage of stand development high tree densities and competition for resources (e.g. light, nutrients, and water) lead to high density-dependent tree mortality and thereby a high potential for wood input to streams (Franklin et al., 2002). Density-dependent mortality naturally thins stands of weaker, less competitive trees. These trees are often smaller in size, limiting their effectiveness in stream geomorphological functions, such as debris jam formation and bank stabilization. Wood function is likely to increase later in stand development as dominant canopy trees achieve diameters of 30 cm or more (Keeton et al., 2007).

Density independent factors, such as local disturbance events, have a stronger influence on stand structure in later stages of stand development (Frelich and Graumlich, 1994; Lorimer and White, 2003). Although mass wasting and fire have controlling effects on wood inputs in some regions (Chen et al., 2006; Young et al., 2006), these processes are uncommon found in northeastern US hardwood-conifer forests. High intensity, stand replacing disturbances are infrequent in inland north temperate hardwood forests across the upper mid-west and northeastern US. In coastal New England, stand-replacing wind events (e.g. hurricanes) occur relatively frequently, with a return interval of only about 100 years. However, in forests of inland New England and upstate New York, return intervals for hurricanes and comparable stand-replacing wind events are much longer (350 years or more; Boose et al., 2001). Average return intervals for stand replacing fires in this region often exceed 1000 years (Fahey and Reiners, 1981; McGee et al., 1999; Seymour et al., 2002; Lorimer and White, 2003). Frequent small-scale disturbance events dominate forest dynamics in old-growth hardwood forests in the northeastern US and upper mid-west, and these disturbances may ultimately be more important to long-term wood accumulation in both forests and streams (Frelich and Graumlich, 1994; Ziegler, 2002). Disease has also been highlighted as a factor that may be increasingly associated with coarse wood on forest floors in northern hardwood forests (McGee, 2000).

Wood export from streams occurs as a result of decay, physical abrasion/breakdown, and fluvial transport. In-stream wood experiences frequent drying and wetting that increases decay rates. As a rule, conifers generally decay more slowly than hardwoods in streams (Melillo et al., 1983; Bilby et al., 1999; Spanhoff and Meyer, 2004), but some hardwoods, such as oaks (*Quercus* spp.), also decay slowly. Species that decay more slowly will remain in the stream longer and will therefore have a longer term impact on standing stocks of large wood. Physical breakdown of wood is influenced by the species and the decay stage of the wood interacting with the energy of the stream and the presence of objects, such as bedload or ice that actively abrades wood. Wood mobility is strongly influenced by wood length relative to bankfull width (Lienkaemper and Swanson, 1987; Young, 1994; Gurnell et al., 2002; Warren and Kraft, 2008), particularly in the constrained stream channels common in the northeastern US. Large pieces of wood exceeding the width of the bankfull channel are more likely to remain stable and act as a trap for smaller pieces of wood, resulting in reduced large wood export. Similarly, mobility of large wood is reduced in small streams with narrow channels, and export via fluvial transport is more limited. We therefore expect stand age and stream size interaction to influence wood loading and accumulation in northeastern streams (Likens and Bilby, 1982).

We used a suite of commonly measured stream and riparian forest characteristics and assessed their relationship to stream large wood characteristics. Akaike's Information Criterion (AIC; Burnham and Anderson, 2004) model comparison techniques were used to test an a priori set of linear models for each response variable. The current study complements earlier research that focused more specifically on riparian zones in the Adirondack Mountains of New York alone and suggested the potential for a strong relationship between in-stream wood volume and stand age in those riparian forests (Keeton et al., 2007). The current study encompasses a broader regional scope and focuses on predicting the dynamics of in-stream wood for future management and research. We hypothesized that the age of dominant canopy trees in the riparian area and stream bankfull width together would be the factors most closely associated with the amount of large wood in streams and with the frequency and size of wood accumulations.

2. Study site

This study included a total of 28 streams surveyed in summer or early fall across northern New York and New Hampshire (Fig. 1). Riparian forests for all streams were classified as mixed northern hardwood forests, a forest community that includes both hardwoods and conifers. The dominant riparian trees included: white pine (*Pinus strobus*), red spruce (*Picea rubra*), eastern hemlock (*Tsuga canadensis*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), ash (*Fraxinus* spp.), and American beech (*Fagus grandifolia*). No large-scale forest disturbances were documented at any study sites during the study. Stream gradient ranged from ~1% to ~24% and mean bankfull widths ranged from 1.4 to 15.1 m (see Table 1 for a summary of stream characteristics at each site). The age of the dominant canopy trees in the riparian forest ranged from approximately 20 to 370 years (Table 1). The mean age of the dominant canopy trees was highly variable, especially in older uneven-aged stands (see below for stand age estimate methods and associated references).

This study was conducted in two mountain regions in the northeastern US. Eighteen streams were surveyed in the Adirondack Mountains region of New York from 2003 to 2006, and ten streams were surveyed in the White Mountain region of New Hampshire from 2004 to 2007. Most of the White Mountain sites were located in the Hubbard Brook Experimental Forest (HBEF) (Bormann and Likens, 1979; Likens and Bormann, 1995). Ten of the Adirondack streams were surveyed as part of an earlier study on forest–stream interactions (Keeton et al., 2007), and some of the data from that study were included here. The large wood censuses conducted for the current study were completed separately from estimates conducted by Keeton et al. (2007), but occurred along the same stream reaches (Warren et al., 2008). Stream survey data from four streams at HBEF (Watersheds 2, 3, 5, and 6) are reported in Warren et al. (2007), though riparian forest surveys at these sites were conducted for the current study alone and have not been reported elsewhere. All additional data (six sites in NY and six sites in NH) are unique to this study.

Logging and subsequent fires fueled by logging debris contributed to the substantial loss of primary forests in much of the Adirondack Mountain region of New York during the 1800s and early 1900s (McMartin, 1994). Yet a number of areas in the interior and western portions of the Adirondacks were unaffected by