Forest Ecology and Management 372 (2016) 247–257

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Effects of riparian buffer width on wood loading in headwater streams after repeated forest thinning

Julia I. Burton [a,*], Deanna H. Olson [b], Klaus J. Puettmann [a]

[a] Department of Forest Ecosystems and Society, Oregon State University, 321 Richardson Hall, Corvallis, OR 97331, United States
[b] U.S. Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331, United States

ARTICLE INFO

Article history:
Received 6 January 2016
Received in revised form 23 March 2016
Accepted 26 March 2016
Available online 19 April 2016

Keywords:
Best management practices
Coarse woody debris
Density management
Forest management
Pacific Northwest
Stream management zone

ABSTRACT

Forested riparian buffer zones are used in conjunction with upland forest management, in part, to provide for the recruitment for large wood to streams. Small headwater streams account for the majority of stream networks in many forested regions. Yet, our understanding of how riparian buffer width influences wood dynamics in headwater streams is relatively less developed compared to larger fish-bearing streams. The effects of riparian buffer width on instream wood loading after thinning can be difficult to discern due to the influence of basin characteristics and reach-scale geomorphology on wood recruitment, breakage and redistribution. We assessed the relationships between instream wood loading, geomorphology and riparian buffer width in small headwater streams after upland thinning. Then we examined the distances between pieces of stream wood and their sources, or the distance from which wood volumes were recruited to these streams. Data were collected along 34 stream reaches at six different sites in a replicated field experiment, comparing three no-harvest streamside buffer treatments (~6-m, 15-m minimum, and ~70-m widths). At each site, second-growth forests were thinned first to 200 trees per ha [tph] and ~10 years later to 85 tph, alongside an unthinned reference unit (~400 tph). We measured wood loading ($m^3/100$ m) four times: (1) prior to thinning; (2) year 5 post-1st thinning; (3) immediately prior to the 2nd thinning; and (4) year 1 post-2nd thinning. The majority of wood volume was in late stages of decay, most likely biological legacies from the previous forest stand, and distributed along the streambank. Surprisingly, wood volume in early stages of decay was higher in stream reaches with a narrow 6-m buffer than in stream reaches with larger 15- and 70-m buffers and the unthinned reference units. Additionally, wood volume increased with drainage basin area. Only 45% of wood in late stages of decay could be associated with a particular source. Yet, 82% and 85% of sourced wood in early and late stages of decay, respectively, originated from within 15 m of streams. Expected continue low rates will likely result in declining volumes of wood in late stages of decay. Thinning and directional felling of logs into to streams could be used to augment wood volumes in the near term, and accelerate the development of large-diameter logs for future inputs. However, the relationship between instream wood loading and basin area suggests that instream wood loading depends on management across the entire watershed.

1. Introduction

In the mountainous forested landscapes of the US Pacific Northwest, headwater streams encompass as much as 80% of the length of stream networks (Gomi et al., 2002; Schumm, 1956; Shreve, 1969). The majority of forests in these watersheds are managed, often for timber production on private land and multiple values on public land. Over time, forest regulations have strengthened the requirement that management plans consider the cumulative effects of management activities on the conservation of aquatic ecosystems (e.g., USDA and USDI, 1994), including headwater streams. This has raised concerns about the effects of forest management practices on stream wood dynamics in forested headwaters (Benda et al., 2015; Czarnomski et al., 2008; Harmon et al., 1986; Montgomery et al., 1996; Pollock and Beechie, 2014).

Large wood is a functionally important component of forested streams, as it moderates streamflow and influences channel morphology, sediment and organic matter transport and storage (Bilby and Bisson, 1998; Bilby and Ward, 1991; Keller and Swanson, 1979; Montgomery et al., 1995, 1996). It is generally

---

* Corresponding author.
E-mail addresses: julia.burton@oregonstate.edu (J.I. Burton), dedeolson@fs.fed.us (D.H. Olson).

http://dx.doi.org/10.1016/j.foreco.2016.03.053

more abundant in small headwater streams than larger streams as a result of lower current forces and smaller channel areas to distribute debris downstream (Bilby and Ward, 1989; Keller and Swanson, 1979; Wohl and Jaeger, 2009). Here, wood plays a disproportionate role in structuring the channel morphology because any given volume of wood will cover a greater proportion of the channel (Swanson and Lienkaemper, 1978; Triska et al., 1982). Additionally, wood contributes to forest biodiversity by providing habitat for numerous plant, fungi, and animal species (e.g., Harmon et al., 1986; Wondzell and Bisson, 2003) including macroinvertebrates, fish (e.g., Bilby and Bisson, 1998; Bisson et al., 1987) and amphibians (Olson and Burton, 2014; Olson and Weaver, 2007).

A diversity of wood recruitment, decomposition, and redistribution processes interact with geomorphic conditions to control the spatial and temporal variability of wood in streams (Fig. 1). Hillslope processes, or mass wasting events, such as landslides, debris flows and forest disturbances can introduce large quantities of wood to streams (Keller and Swanson, 1979; May, 2002; Reeves et al., 2003). Between these infrequent events, smaller volumes of wood are recruited chronically from local tree falls, with the probability of a tree landing in a stream being a function of slope distance (i.e., the distance from the stream along the riparian hillslope) from the stream in relation to tree height (McDade et al., 1990; USDA and USDI, 1993; Van Sickle and Gregory, 1990). Large wood also can be recruited gradually with streambank erosion and undercutting streamside trees, and hillslope creep (e.g., Bisson et al., 1987; Hassan et al., 2005). Once recruited, wood redistribution in headwater streams generally proceeds slowly as wood decays (Nakamura and Swanson, 1993), although floods can periodically redistribute larger quantities of wood downstream. Headwater streams may serve as important sources of large wood sources, with extreme flood events and periodic slope failures delivering large wood volumes downstream. Wood redistribution downstream is especially important for the maintenance and restoration of habitat conditions for different assemblages of wood-associated species in larger streams, including several sensitive salmonid species (e.g., Naiman et al., 1992).

Wood recruitment and redistribution processes can vary spatially with geomorphic conditions (Czarnomski et al., 2008; Spies et al., 1988; Wohl and Cadol, 2011). For example, unstable, steep slopes that constrain streams may increase recruitment of large wood to narrow colluvial stream channels resulting from a higher density of trees within the fall zone (i.e., one tree-height distance) of the stream, compared to larger alluvial channels (May and Gresswell, 2003). In narrow, highly constrained streams, fallen logs can be suspended above the channel and eventually fall into the wet and dry zones of the bankfull channel or be redistributed downstream with breakage and decomposition (Nakamura and Swanson, 1993; Robison and Beschta, 1990; Wohl and Goode, 2008). Fluvial redistribution of wood depends not only on the size of the wood relative to the stream but is also influenced by morphological characteristics such as stream width relative to depth, and gradient (e.g., Bilby and Ward, 1989; Lienkaemper and Swanson, 1987; Wohl and Goode, 2008). Thus, efforts to understand and predict effects of forest management practices on wood in streams (e.g., Bragg, 2000; Czarnomski et al., 2008; Davidson and Eaton, 2015; Martin and Benda, 2001; Meleason et al., 2002; Pollock and Beechie, 2014; Van Sickle and Gregory, 1990; NetMap Riparian Management: http://www.terrainworks.com/riparian-management, accessed 22 April 2015) may be improved by accounting for basin characteristics and reach-scale geomorphology (Fig. 1).

Large wood dynamics relative to stand development have been documented in upland forests (Duvall and Grigal, 1999; Spies et al., 1988) and similar trends apply to forested riparian areas (Keeton et al., 2007; May, 2002). During early developmental stages of forest stands, recruitment of wood is limited to small trees undergoing density-dependent mortality. High volumes of large wood, or "legacy wood", reflect the previous rather than the current stand and the associated history of disturbance or harvesting (Duvall and Grigal, 1999; May, 2002; Spies et al., 1988). As trees grow and legacy wood decays, wood volumes are predicted to decline during the stem-exclusion phase (i.e., stage of stand development characterized by high levels of density-dependent mortality as trees compete for resources, grow in height and stratify their canopies into exposed and suppressed crown classes; Oliver and Larson, 1996). Increased inputs of larger trees in later stages of stand development result a U-shaped distribution of large wood volume over time (Duvall and Grigal, 1999; Harmon et al., 1986; Spies et al., 1988).

In managed forest landscapes, stands are typically harvested before they reach later stages of development, resulting in a landscape that is dominated by early stages of stand development (e.g., Nyland, 2002) where large wood recruitment is limited in amount (e.g., volume or biomass) and piece size. For example, industrial management practices in western Washington and Oregon typically result in clearcut-harvest rotation ages of around 50 years (Briggs and Trobaugh, 2001). Thus, forests in this region contain a greater proportion of young to middle-aged stands in the "stem-exclusion phase" (∼71%) than were present historically (Ohmann et al., 2007; Wimberly and Ohmann, 2004). Landowners who plan for longer rotation ages typically implement thinning operations to bring merchantable timber to markets and increase

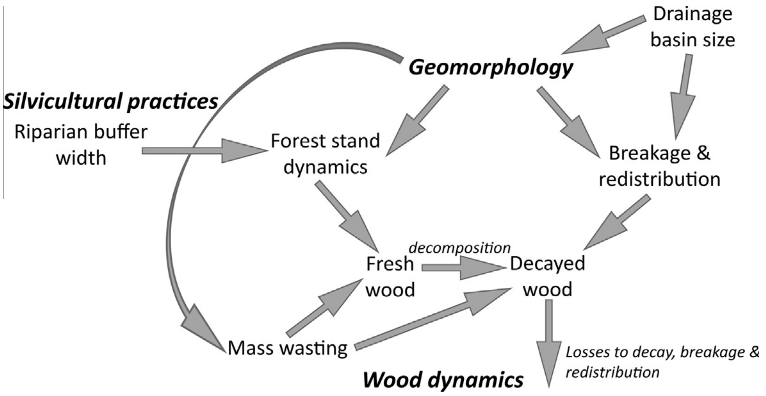

Fig. 1. Conceptual model placing streamside riparian buffers with upland forest thinning into a general ecological context for wood dynamics in headwater streams.