Geomorphology 279 (2017) 3–26

Contents lists available at ScienceDirect

Geomorphology

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

Bridging the gaps: An overview of wood across time and space in diverse rivers

Ellen Wohl

Department of Geosciences, Colorado State University, Fort Collins, CO 80523-1482, USA

ARTICLE INFO

Article history:
Received 14 October 2015
Received in revised form 7 April 2016
Accepted 18 April 2016
Available online 30 April 2016

Keywords:
Instream wood
Large wood
Rivers
Hydraulics
Sediment
Channel morphology
Management

ABSTRACT

Nearly 50 years of research focused on large wood (LW) in rivers provide a basis for understanding how wood enters rivers; how wood decays, breaks, and is transported downstream; and how at least temporarily stable wood influences channel geometry, fluxes of water, sediment, and organic matter, and the abundance and diversity of aquatic and riparian organisms. Field-based studies have led to qualitative conceptual models and to numerical stimulations of river processes involving wood. Numerous important gaps remain, however, in our understanding of wood dynamics. The majority of research on wood in rivers focuses on small- to medium-sized rivers, defined using the ratio of wood piece size to channel width as channels narrower than the locally typical wood-piece length (small) and slightly narrower than the longer wood pieces present (medium). Although diverse geographic regions and biomes are represented by one or a few studies in each region, the majority of research comes from perennial rivers draining temperate conifer forests. Regional syntheses most commonly focus on the Pacific Northwest region of North America where most of these studies originate. Consequently, significant gaps in our understanding include lack of knowledge of wood-related processes in large rivers, dryland rivers, and rivers of the high and low latitudes. Using a wood budget as an organizing framework, this paper identifies other gaps related to wood recruitment, transport, storage, and how beavers influence LW dynamics. With respect to wood recruitment, we lack information on the relative importance of mass tree mortality and transport of buried or surficial downed wood from the floodplain into the channel in diverse settings. Knowledge gaps related to wood transport include transport distances of LW and thresholds for LW mobility in small to medium rivers. With respect to wood storage, we have limited data on longitudinal trends in LW loads within unaltered large and great rivers and on fluctuations in LW load over time intervals greater than a few years. Other knowledge gaps relate to physical and ecological effects of wood, including the magnitude of flow resistance caused by LW; patterns of wood-related sediment storage for diverse river sizes and channel geometry; quantification of channel-floodplain-LW interactions; and potential threshold effects of LW in relation to physical processes and biotic communities. Finally, knowledge gaps are related to management of large wood and river corridors, including understanding the consequences of enormous historical reductions in LW load in rivers through the forested portions of the temperate zone; and how to effectively reintroduce and manage existing LW in river corridors, which includes enhancing public understanding of the importance of LW. Addressing these knowledge gaps requires more case studies from diverse rivers, as well as more syntheses and metadata analyses.

1. Introduction

Nearly half a century after wood in rivers became a topic of research in fluvial geomorphology and ecology (e.g., Zimmerman et al., 1967; Swanson et al., 1976; Keller and Swanson, 1979), we now have an extensive body of relevant literature on which to draw in seeking to understand how downed, dead wood influences process and form within river corridors (e.g., Gregory et al., 2000; Le Lay et al., 2013). Substantial gaps remain in our understanding, however, and in our ability to quantitatively predict interactions among wood, fluxes of water, sediment, and solutes within rivers, river geometry, and river biotic communities. The primary objective of this paper is to provide a brief overview of existing knowledge of wood in river corridors and to identify important knowledge gaps. This paper focuses on large wood (LW), defined here as pieces of wood exceeding 10 cm in diameter and 1 m in length, within the river corridor, which includes the active channel and floodplain. I define the active channel as the area within the low-flow channel that has unvegetated gravel bars (Arnaud et al., 2015). In the context of LW-river interactions, a small river is narrower than the locally typical wood-piece length, a medium river is slightly narrower than the longer wood pieces present, and a large river is wider than the length of all wood pieces delivered to the river (Gurnell, 2003). I also add the category of great river, after Kramer and Wohl (in press), to designate rivers draining areas $\geq 10^6$ km^2 and with mean annual discharge $> 10^3$ m^3/s.

E-mail address: Ellen.wohl@colostate.edu.

http://dx.doi.org/10.1016/j.geomorph.2016.04.014

Approximately 20 rivers fall into this category globally. Even very large wood pieces can be only a fraction of the average channel width of rivers that are hundreds of meters to kilometers in width, and LW dynamics in these rivers may have distinctive characteristics. Large wood dynamics refers to recruitment, transport, storage, and breakdown (abrasion, breakage, decay) of wood.

One way to think about existing knowledge of wood is to imagine a scenario in which an investigator familiar with previous research on LW could choose a river segment anywhere in the world and quantitatively predict (i) all aspects of a wood budget, including inputs, storage, and outputs, and fluctuations through time and space in variables influencing the wood budget; and (ii) the geomorphic and ecological effects of LW on the river segment. In this context, a segment refers to any length of river with consistent channel geometry that extends for at least several times average bankfull width. The length of the segment would thus scale with channel size but typically would lie within the range of 10^1–10^3 m. For river segments in most regions of the world, we are unable to quantitatively predict the characteristics listed above. This paper explores the knowledge gaps that prevent such predictions, starting with a discussion of wood budgets, including fluctuations in the variables influencing the budget, and then exploring geomorphic and ecological effects of LW and management of LW and river corridors.

2. Wood budgets

A wood budget (Keller et al., 1995; Martin and Benda, 2001; Gurnell, 2013) represents an accounting of inputs, storage, and outputs of LW along a river segment of length x over time t, as expressed by Benda and Sias (2003):

$$\Delta S = \left[L_i - L_o + \frac{Q_i}{\Delta_x} - \frac{Q_o}{\Delta_x} - D\right]\Delta t \qquad (1)$$

in which ΔS is the change in storage, with S commonly expressed as volume of wood per surface area of channel or length of channel (e.g., m^3/ha or m^3/m); L_i is lateral inputs, and L_o represents lateral outputs to the floodplain; Q_i represents fluvial transport of LW into the river segment and Q_o fluvial transport out of the river segment; and D is decay, which here includes breakage and abrasion that reduce LW piece size and residence time within the river corridor. The variable L_i can be further conceptualized as resulting from several individual processes (Benda and Sias, 2003):

$$L_i = I_m + I_f + I_{be} + I_s + I_e + I_{bv} \qquad (2)$$

in which I_m is individual tree mortality, I_f is mass mortality, I_{be} represents LW recruitment via bank erosion that recruits living trees, I_s is recruitment via hillslope instability, and I_e describes LW recruitment of buried and downed, dead surface wood via floodplain erosion.

The I_{bv} term, which is not in the original equation of Benda and Sias (2003), represents beaver-recruited LW. Where beaver are present within rivers of the northern hemisphere, they constitute a distinctive influence on wood budgets because of their ability to selectively recruit and retain within their dams smaller pieces of wood that would otherwise likely remain mobile within a river. Although the role of beavers in actively recruiting and retaining wood within channels has not been examined explicitly, wood pieces < 10 cm in diameter and 1 m in length are commonly incorporated into beaver dams built on channels of< 6% gradient and < ~20 m in width (Baker and Hill, 2003; Johnston, 2012). The beaver dam as a structure creates effects similar to those of a channel-spanning logjam, including forming a backwater in which fine sediment and organic matter accumulate; enhancing overbank flow and the potential for channel avulsion and formation of secondary channels; and enhancing hyporheic exchange (Butler and Malanson, 1995; Lautz et al., 2006; Pollock et al., 2007; Westbrook et al., 2011, 2013; Wohl et al., 2012b; Polvi and Wohl, 2013).

2.1. Segment- to landscape-scale influences on wood budgets

The variables in Eqs. (1) and (2) reflect river-segment- to landscape-scale influences that cumulatively create an environmental context for LW budgets. These influences, as schematically illustrated in Fig. 1, include forest, hillslope, river network, valley bottom, and channel dynamics, and the activities of biota. Quantitatively predicting the components of Eqs. (1) and (2) at any point in time requires a detailed

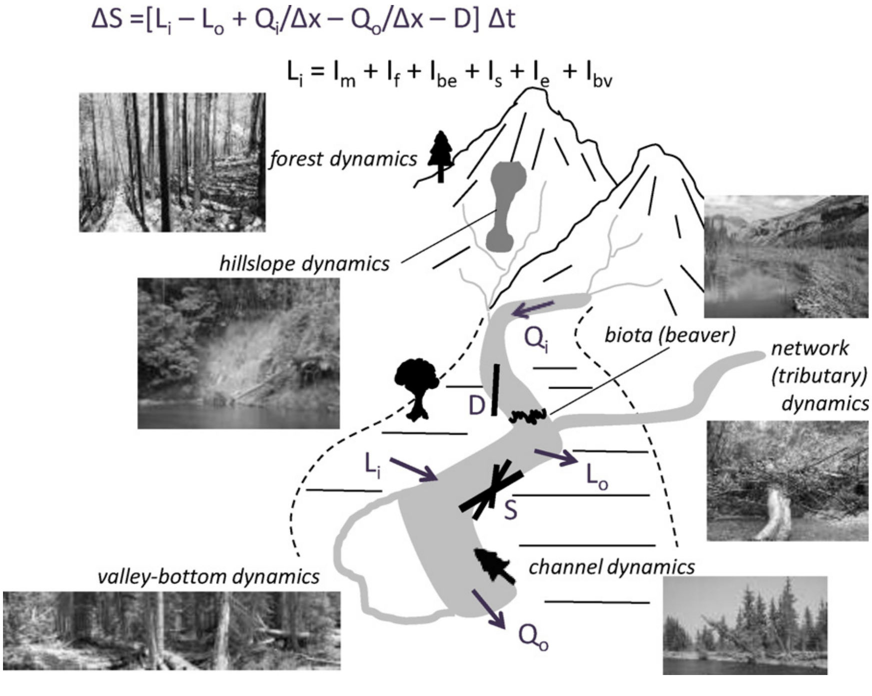

Fig. 1. Schematic illustration of physical and biotic factors influencing variables in a wood budget for a stream segment. Components of the geomorphic and biotic context within the watershed are italicized. Variables in the wood budget (upper equation) and the lateral inputs (lower equation) are defined in the text. Inset photographs (clockwise from upper left) illustrate a forest after wildfire, a landslide into a river, downed LW on a floodplain, trees undercut by bank erosion, a logjam at the mouth of a tributary, and a beaver dam.