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Introduction to the Wood in World Rivers special issue

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Large wood has gradually come to be recognized as a critical component of process and form in river corridors, reflecting increasing recognition of the complex interactions among water, sediment, living vegetation, and wood in forested regions (Gurnell, 2013; Montgomery et al., 2003; Ruiz-Villanueva et al., 2016b; Wohl, 2017). Downed, dead wood pieces larger than 10 cm in diameter and 1 m in length have been described as the third leg of the tripod of physical fluxes (Wohl et al., 2019), along with water (Poff et al., 1997) and sediment (Wohl et al., 2015), in natural river regimes. Large wood is also recognized as part of a continuum of interactions among river process and form and both living and dead vegetation (e.g., Gurnell et al., 2016; Gurnell & Grabowski, 2016; Hawley & MacMannis, 2019; Opperman et al., 2008).

Research on the geomorphic and ecological effects of large wood was initially largely confined to the Pacific Northwest region of the United States as part of an increasing focus on old-growth forest ecosystems (e.g., Keller & Swanson, 1979; Swanson et al., 1976), although important precursors of this work were pioneering studies of interactions between forest and river dynamics (Hack & Goodlett, 1960) and the influence of vegetation on channel forms in small streams (Zimmerman et al., 1967). Simultaneous with the work in the Pacific Northwest, ecologists started to emphasize the role of large wood in creating structure, habitat diversity, and transient storage in smaller streams in the eastern United States (e.g., Bilby & Likens, 1980).

The long history of deforestation and wood removal from river corridors in most of the world (Erskine & Webb, 2003; Harmon et al., 1986; Montgomery et al., 2003; Wohl, 2014) initially limited recognition of the historical importance of large wood in rivers. Over the past five decades, however, a rapidly growing body of field-based case studies (e.g., Ruiz-Villanueva et al., 2016b; Swanson et al., 2021) has documented the ubiquity of large wood influences, from headwaters to inland and coastal deltas and estuarine areas of large rivers (Hinwood & McLean, 2017; Kramer et al., 2017; Phillips, 2012), and on to coastal regions (Dugan & Hubbard, 2010; Gheskiere et al., 2005; Kennedy & Woods, 2012; Kramer & Wohl, 2015), the open ocean (Rama et al., 2014, 2016), and abyssal plains (Amon et al., 2017; Schwabe et al., 2015). Increased documentation of the geomorphic and ecological importance of large wood has led to increased emphasis on retaining and restoring large wood to river corridors (BoR, 2015; Grabowski et al., 2019; Roni et al., 2015).

The first Wood in World Rivers Conference was held in October 2000 at Oregon State University (USA), with the stated intent of (i) synthesizing knowledge of the physical dynamics and ecological interactions of large wood in rivers and streams of different geographical regions, (ii) creating a framework for interpreting and applying the results of research at diverse sites, (iii) identifying management systems for wood in rivers, (iv) assessing physical and biological responses of large wood in stream restoration, and (v) exploring links between primary information on the physical and ecological dynamics of large, resource management, and the communities and cultures in which such management is applied (Gregory et al., 2003). This conference resulted in an edited volume published in 2003 and this volume remains a comprehensive and valuable source of understanding for diverse aspects of wood in rivers.

The second Wood in World Rivers Conference took place in August 2006 at the University of Stirling in Scotland. Eleven papers resulting from this conference were published in an *Earth Surface Processes and Landforms* special issue in 2007 (Gurnell, 2007). The third conference was held in Padova, Italy in July 2015, with 15 papers published in a 2017 special issue in *Geomorphology* (Picco et al., 2017). The fourth conference, held in Valdivia, Chile in January 2019, is the primary source for papers in this special issue, although we have also brought in relevant papers published independently of the conference.

Papers from the first Wood in World Rivers Conference emphasized the much greater historical abundance of large wood in most river corridors of the temperate latitudes (Montgomery et al., 2003). Subsequent geologic research indicated how the evolution of land plants and then woody plants influenced river channels and floodplains as the root systems of vascular plants helped to increase bank resistance and the development of logjams influenced channel avulsion and planforms (e.g., Gibling & Davies, 2012). For many years following the initiation of riverine large wood research in the Pacific Northwest, however, few riverine scientists conceptualized large wood as an inherent part of river corridors, with the exception of work in southern England (e.g., Gregory et al., 1985). The geographic scope of riverine large wood research has grown tremendously since circa 2000, thanks in part to the first Wood in World Rivers (WWR) conference. The geographic diversity of the four WWR conferences reflects the spread of studies on wood in rivers and the growth from a niche topic in the Pacific Northwest to a topic of global relevance in riverine science. Despite the geographic spread of field studies, however, the boreal and tropical latitudes remain underrepresented in studies of wood in river corridors published in English-language journals (Wohl, 2017; Wohl et al., 2017).

The first WWR conference focused on field studies, physical-biotic interactions, and numerical modeling of wood recruitment to channels. These remain focal topics of riverine science research that explicitly includes the role of large wood, as illustrated by papers in this special issue examining controls on wood load and spatial distribution of wood in diverse field settings (Galia et al., 2020; Iroumé et al., 2020; Máčka et al., 2020; Picco et al., 2021; Rossetti de Paula et al., 2020) and on the geomorphic (Booth et al., 2020; Gurnell et al., 2019; Hinshaw et al., 2020; Iroumé et al., 2020; Zhang & Rutherfurd, 2020) and ecological (Ader et al., 2021; Shirey et al., 2020) effects of large wood.

With time, areas of emphasis in research on large wood in river corridors have grown to include:

- influences of coupled upland–channel and floodplain–channel interactions on wood dynamics in river corridors (Booth et al., 2020; Hassan et al., 2019; Lininger et al., 2017; Wohl, 2020; Wohl et al., 2018);
- quantification of the distribution of large wood within a river network with respect to reach-scale longitudinal variations in wood load (Matheson & Thoms, 2018; Pfeiffer & Wohl, 2018; Picco et al., 2021; Ruiz-Villanueva et al., 2016a; Scott & Wohl, 2018; Tonon et al., 2017; Wohl & Cadol, 2011) and aggregation of wood into jams (Wohl & Scamardo, 2021);
- quantitative characterization and classification of large wood pieces and accumulations (Dixon, 2016; Livers et al., 2020; Spreitzer et al., 2019);
- physical experiments on large wood transport, deposition, and geomorphic effects (e.g., Bertoldi et al., 2015; Davidson et al., 2015; Pagliara & Kurdistani, 2017; Ravazzolo et al., 2020; Zhang et al., 2020);
- transport dynamics of large wood in real rivers (Ghaffarian et al., 2020; Kramer & Wohl, 2017; Ruiz-Villanueva et al., 2019; Steeb et al., 2017);
- numerical modeling of large wood transport (e.g., Kang et al., 2020; Persi et al., 2018; Ruiz-Villanueva et al., 2014b; Zischg et al., 2018);
- the effects of large wood on organic carbon sequestration and stocks in river corridors (Beckman & Wohl, 2014; Lininger et al., 2017; Scott & Wohl, 2020; Sutfin et al., 2016; Wohl et al., 2012);
- the role of large wood in promoting transient storage (Ader et al., 2021), hyporheic exchange flows (Doughty et al., 2020; Sawyer et al., 2011), and associated effects on water quality; and
- explicit consideration of large wood in river restoration and management (e.g., Comiti et al., 2012; Conley & Kramer, 2020; Grabowski et al., 2019; Harvey et al., 2018; Matheson et al., 2017; Mazzorana et al., 2018; Roni et al., 2015; Schalko, 2020; Schalko et al., 2019).

The steadily increasing number of papers on large wood in rivers (Ruiz-Villanueva et al., 2016b; Swanson et al., 2021) reflects the growing maturity of this research topic, as does the continuing development of numerical (Kang et al., 2020; Mazzorana et al., 2018; Ruiz-Villanueva et al., 2014b), statistical (Scott et al., 2019), and conceptual (e.g., Collins et al., 2012; Comiti et al., 2016; Dixon, 2016; Kramer & Wohl, 2017; Livers et al., 2018; Wohl & Scott, 2017; Wohl, 2020) models of large wood dynamics, and the expansion of technology used to characterize wood process and form.

Techniques applied to studying wood in river corridors within the past decade include use of:

- remote imagery, including drones and lidar (e.g., Abalharth et al., 2015; Atha & Dietrich, 2016; Lucía et al., 2018);
- ground-based video and time-interval photography (Boivin et al., 2017; Ghaffarian et al., 2020; Grabowski & Wohl, 2021; Kramer & Wohl, 2014; MacVicar & Piegay, 2012);
- structure from motion (Spreitzer et al., 2019);
- radio telemetry (e.g., MacVicar et al., 2009; Ruiz-Villanueva et al., 2016a; Schenk et al., 2014);
- dendrochemical signatures of wood geographic origin within a drainage basin (Piegay et al., 2017); and
- sensors that measure and record piece movement (Spreitzer et al., 2019).

As indirect methods of examining large wood dynamics provide new insights, however, there remains a need for basic, field-based measurements over diverse time and space scales. Such studies can address questions from how to estimate the porosity of a single logjam (Livers et al., 2020), to Lagrangian (tracking pieces of wood through time; Ravazzolo et al., 2015; Schenk et al., 2014) versus Eulerian (gross wood flux through an area; Tonon et al., 2018) perspectives on wood dynamics. Increasing ability to quantify wood budgets, wood regimes, and wood process domains in diverse portions of a river network and in diverse networks across the globe will inform both our understanding of wood dynamics and incorporation of this understanding in river management.

The use of large wood in river restoration is now routine in some regions, such as the US Pacific Northwest, and national syntheses (e.g., Cashman et al., 2019; Grabowski et al., 2019; Kail et al., 2007; Roni et al., 2015) and guidelines (BoR, 2015) exist for large wood management and restoration, but wood is still routinely removed from river corridors in many regions, regardless of whether the wood poses a threat to people or infrastructure (e.g., Ruiz-Villanueva et al., 2014a; Shirey et al., 2020). When wood is added back into river corridors as single pieces or engineered logjams, it is likely to be fixed in place or somehow stabilized (e.g., Nichols & Ketcheson, 2013), especially in moderate- to large-sized streams (Roni et al., 2015), rather than being allowed to adjust during flows of differing magnitude after emplacement. Artificial stabilization may limit the geomorphic and ecological functions of the large wood (e.g., Johnson et al., 2000; Wohl et al., 2019), but pioneering restoration experiments now underway in Oregon (Deer Creek story map, 2021) involve adding large quantities of unanchored wood to river corridors in an attempt to recreate the stage 0 conditions of the Cluer and Thorne (2014) river evolution model. Stage 0 conditions include anastomosing channel planform and production and retention of large wood. The Oregon river restoration experiments may create a new standard for management in river corridors with limited infrastructure and human population density.

For now, however, the widespread management and societal perception of river corridors is that they are an environment to be manipulated rather than an environment to which humans adjust.

Comparing the outdoor activities of mountain climbing versus river rafting illustrates this attitude: Mountain climbers pioneer new routes on rock faces and may leave hardware such as fixed bolts along climbing routes, but they do not blast off projections or undertake significant modifications of the topography of mountain faces. Cases of river rafters dynamiting dangerous boulders or cutting out large wood pieces and logjams with chainsaws either after a fatal accident or as a precautionary measure demonstrate a very different attitude toward the integrity of rivers and the human right to manipulate channel form. This dichotomy in attitudes has led to proposals to develop a river ethic, analogous to the land ethic proposed in Leopold (1949).

Both a river ethic and ongoing efforts to manage river corridors in more environmentally sustainable ways can be most effective if based on a holistic understanding of the dynamic adjustments continually occurring within natural rivers and the sources of river resilience to natural and human disturbances. Such understanding increasingly includes recognition of the central role of large wood in rivers. We are pleased to start this special issue with a State of the Science paper led by two of the founders of research on wood in rivers, Fred Swanson and Stan Gregory, and we look forward to the next Wood in World Rivers Conference.

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