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Invited review

Large wood recruitment and transport during large floods: A review

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ABSTRACT

Large wood (LW) elements transported during large floods are long known to have the capacity to induce dangerous obstructions along the channel network, mostly at bridges and at hydraulic structures such as weirs. However, our current knowledge of wood transport dynamics during high-magnitude flood events is still very scarce, mostly because these are (locally) rare and thus unlikely to be directly monitored. Therefore, post-event surveys are invaluable ways to get insights (although indirectly) on LW recruitment processes, transport distance, and factors inducing LW deposition — all aspects that are crucial for the proper management of river basins related to flood hazard mitigation. This paper presents a review of the (quite limited) literature available on LW transport during large floods, drawing extensively on the authors' own experience in mountain and piedmont rivers, published and unpublished. The overall picture emerging from these studies points to a high, catchment-specific variability in all the different processes affecting LW dynamics during floods. Specifically, in the LW recruitment phase, the relative floodplain (bank erosion) vs. hillslope (landslide and debris flows) contribution in mountain rivers varies substantially, as it relates to the extent of channel widening (which depends on many variables itself) but also to the hillslope-channel connectivity of LW mobilized on the slopes. As to the LW transport phase within the channel network, it appears to be widely characterized by supply-limited conditions; whereby LW transport rates (and thus volumes) are ultimately constrained by the amount of LW that is made available to the flow. Indeed, LW deposition during floods was mostly (in terms of volume) observed at artificial structures (bridges) in all the documented events. This implies that the estimation of LW recruitment and the assessment of clogging probabilities for each structure (for a flood event of given magnitude) are the most important aspects for the prediction of LW transport magnitude at any cross section along the river network. Finally, the review discusses the optimal strategies to manage LW-related hazard, which should consider riparian vegetation and in-channel dead wood as key components of river ecosystems and thus should interfere with LW (as well as with sediment) transport dynamics only for limited spatial and temporal scales.

Contents

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1. Introduction

Since the 1980s, in-channel wood has been recognized to play a major role in forested river basins, and nowadays there is quite a large body of literature on the important ecological and morphological effects of wood elements (Fig. 1A) within streams and rivers (Montgomery et al., 2003; Collins et al., 2012; Gurnell, 2012; Wohl, 2013). However, most of the research has been carried out in a few areas of the world, with a relevant bias toward near-natural, poorly inhabited areas (i.e., Pacific Northwest and Rocky Mountains in northern USA) where wood abundance in the channel network was and still is massive. In the more densely populated regions of Europe and Japan, researchers started to investigate wood dynamics in river basins in the 1980s with a radically different perspective, that of natural hazards mitigation. Indeed, large wood elements transported during floods and debris flows were long known to have the capacity to induce dangerous obstructions (Fig. 1B) during flood events, especially at bridges and at hydraulic structures, present in large numbers in these long-populated areas; and as a consequence, large wood is often cleared from channels. Also, dense and mature riparian vegetation brings about additional flow resistance (Hession and Curran, 2013), which may contribute to more frequent flooding in case of insufficient channel sections; and periodic vegetation cuts are thus the norm in heavily populated regions. In addition, in rural societies where domestic heating is strongly dependent on local biomass fuel, riparian vegetation and dead wood can be a relevant source. For example, riparian areas along European rivers were heavily utilized for animal grazing and woody biomass collection until the economic growth following the World War II (Comiti, 2012).

Despite the increasing number of studies on the role and benefits of wood for stream morphology and ecosystems functioning, two contrasting views still exist within the scientific and technical ‘river community’: one belonging to the fluvial geomorphologists/ecologists (dominant in the American continent) and one of the civil/forest engineers (prevalent in Europe and Japan). Not surprisingly, such different attitudes toward wood in rivers are present (and probably in a more pronounced way) in the respective populations (Piégay et al., 2005; Mutz et al., 2006; Chin et al., 2008; Collins et al., 2012; Hession and Curran, 2013; Wohl, 2015). Indeed, the main theme in newspapers, TV, and social networks after most flood events that occurred in Europe over the last decades was about the (allegedly obvious) causal role of vegetation and woody ‘debris’ to flood damages, despite the fact that actual evidence of such links are often missing.

As a result, the scientific research carried out by the morphoecologists has mostly dealt with ‘static wood’ (i.e., its habitat- and reach-scale interactions with sediment and biota, mostly at flows not able to entrain wood elements); whereas the engineers worked (especially through flume experiments) on ‘dynamic wood’ (i.e., transport and deposition patterns around structures at flood flows). However, notable exceptions to this over-simplified distinction are present, i.e., the theoretical analysis, experimental works and the long-term monitoring programs on wood transport carried out by several geomorphologists (see Section 5).

As a consequence, our current knowledge of wood transport dynamics during large floods is very scarce because (i) large floods by definition are (locally) rare, and thus the occasion to study them is very limited; (ii) geomorphologists and ecologists have been more interested in documenting the day-by-day wood-water-sediment-biota interactions, and large floods have been primarily of interest to geomorphologists in terms of sediment transport, erosion, and deposition; (iii) engineers have mainly focused on the local scale (bridge, check-dams) often using highly simplified assumptions (in terms of log geometry and transport modes/rates). Therefore, several questions remain unanswered, as described in the following sections, the most fundamental of all being: can we reliably and quantitatively predict wood recruitment, transport, and deposition (rates) within a given river basin, during a flood of an assigned magnitude/frequency? This paper intends to critically review the attempts made so far to shed light on the processes taking place during flood events (debris flows will be considered here only in terms of the associated wood delivery to higher order channels) that affect woody vegetation and wood transport, as well as on the reciprocal feedbacks involved.

2. Wood transport during large floods: a historical and geographical outline

The first scientific treatise on river hydraulics that we are aware of (Guglielmini, 1697) did not explicitly mention wood transport by fluvial flows, although sediment erosion and deposition problems as well as causes of flooding are discussed at length. Contemporary technical essays on river training (e.g., Viviani, 1688) also did not address wood transport, and most of the accent was placed on how to stop channel aggradation that was perceived as the most threatening process because of its progressive increase of flood hazard. One reason could be that these authors were familiar with lowland rivers in agricultural areas of northern and central Italy long deprived of riparian woodlands. Furthermore, at that time forest cover in the mountains was close to its historical minimum, which lasted at similar levels until approximately World War I (see Comiti, 2012).

However, the presence and role of large wood (hereafter LW, with the widely used definition of logs > 10 cm in diameter and >1 m in length) transport during large flood events has been recognized (at least in qualitative terms) at least since the late nineteenth century

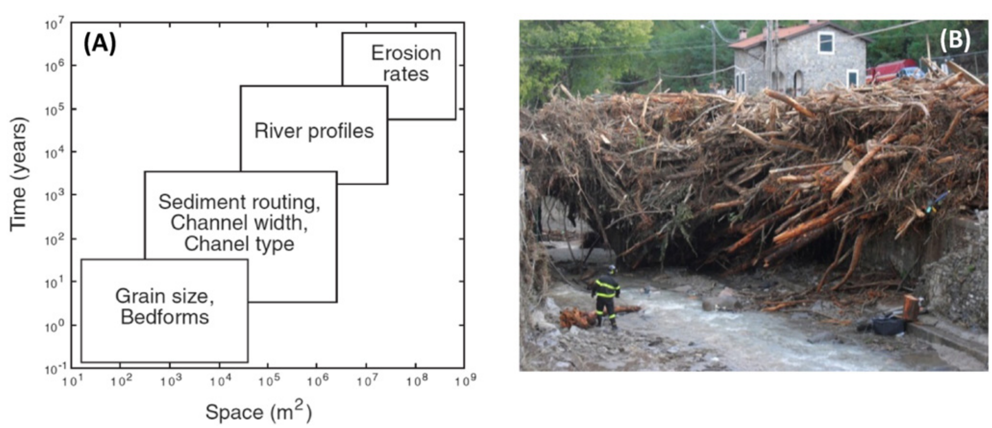

Fig. 1. The different types (at different scales) of geomorphic effects of wood in rivers (A, from Montgomery et al., 2003) have long been investigated by the geomorphological community; whereas the additional flood hazard induced by wood jams (B, a huge wood jam created by a bridge during a flood event in Italy, photo courtesy of the Province of La Spezia) has been dominant among hydraulic engineers in Europe and Japan.