Geomorphology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Geomorphology

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

Underground riparian wood: Buried stem and coarse root structures of Black Poplar (*Populus nigra* L.)

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ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form 31 July 2016
Accepted 2 August 2016
Available online xxxx

Keywords:
Populus nigra
Underground wood
Buried stems
Adventitious roots
Root system architecture
Structure-from-motion

ABSTRACT

Despite the potential importance of tree species in influencing the processes of wood recruitment, transport, retention, and decay that control river wood budgets, focus has been relatively limited on this theme within fluvial wood research. Furthermore, one of the least investigated topics is the belowground living wood component of riparian trees.

This paper presents observations of the morphology and age of buried stem and coarse root structures of eight *Populus nigra* individuals located in the riparian woodland of two sites on the middle to lower Tagliamento River, Italy. This species was selected because of its wide distribution along European rivers and its frequent dominance of riparian woodland.

Each tree was excavated by hand to expose a minimum of half of the root system with complete exposure of the main axis. Smaller roots were then removed and larger protruding roots cut back to permit access to the main axis. The excavated structures were photographed from multiple angles for photogrammetric modelling; the structure and character of the exposed sediments around the tree's main axis were recorded; and wood samples were taken from the main aboveground stem(s), sections of the main buried axis, and major roots for dendrochronological analysis. Results from these field observations and laboratory dating of the wood samples were combined to describe the belowground morphology of each tree and to draw inferences concerning the impact of fluvial disturbances.

Common features of these excavated structures included: (i) rooting depths to below the bar surface where the original tree established, with many young roots also existing at depth; (ii) translocation of the main buried axis in a downstream direction; (iii) a main buried axis comprised mainly of stems that have become buried and then generated new shoots, including multistem patches, and adventitious roots; (iv) the presence of steps and bends in the main buried axis associated with the generation of coarse lateral roots, that reflect the sedimentary structure of the surrounding aggraded bank sediments; and (v) grafting of roots within and between some sampled trees.

Overall, the sampled trees possessed extremely complex three-dimensional buried wood structures that permeate bank sediments and tie the tree and aggraded bank sediments to basal gravels. These properties and the considerable amount of underground wood that is present have great significance for anchoring trees and giving uprooted trees and root wads a propensity to snag once they enter the fluvial system. Furthermore, the ability of this underground biomass to sprout suggests that uprooted and remaining components of root networks following tree uprooting may resprout, generating new vegetation canopies that can trap mobile wood. Overall, this underground wood offers many traits that may tighten wood budgets, and it is likely that other riparian Salicaceae species with similar traits may have similar wood budget impacts.

1. Introduction

To date, most fluvial wood research has focused on the characteristics of large wood pieces and accumulations retained within river systems and set in the context of large wood dynamics and budgets at catchment to reach scales (Benda and Sias, 2003; Wohl, 2013; Ruiz-Villanueva et al., in press). Despite the potentially enormous importance of tree species in influencing all of these processes, there has been a more limited focus on how species may differentially influence the processes of wood recruitment, transport, retention, and decay that control river wood budgets (Gurnell, 2003, 2012). Nevertheless,

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http://dx.doi.org/10.1016/j.geomorph.2016.08.002
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since 2000, researchers have started to look in more detail at the characteristics of the trees from which large wood is recruited (Wohl, 2013; Ruiz-Villanueva et al., in press), and the fundamental importance of species for fluvial wood properties and dynamics is becoming increasingly clear. For example, a 'large wood cycle' dominated by large, slow-decaying coniferous species, has been proposed (Collins et al., 2012). This concept, based on observations in the Pacific Northwest of the USA, emphasises the crucial importance of large, slow-decaying wood pieces that accumulate into jams that eventually form hard points within the alluvial deposits of the floodplain. Seedlings germinate and grow to maturity on these stable hard points, eventually providing further very large wood pieces to the fluvial system. Thus the age structure and rates of turnover of the riparian forest are strongly controlled by buried wood hard points. Furthermore, although most research has focussed on dead pieces of large wood, research concerning riparian tree species that are able to sprout following uprooting, transport, and deposition has also demonstrated the crucial importance of the species of riparian tree delivering wood to the fluvial system (Gurnell, 2013, 2016). This latter research has demonstrated how such species can act as river physical ecosystem engineers by forming vigorous vegetated patches from deposited 'living' wood that are anchored to river bar surfaces by their root systems. These patches grow rapidly, forming a second type of hard point that strongly influences the extent and turnover of riparian woodland and thus the recruitment of wood (Zanoni et al., 2008) and also the morphology of the entire active river channel (Bertoldi et al., 2011). Moreover, such resprouting species frequently dominate the riparian tree communities of temperate river systems (Karrenberg et al., 2002).

Since 2000, a rapidly increasing body of international research has indicated the importance of tree species in determining wood behaviour. This research has investigated key tree properties for river wood dynamics, including the density and decay resistance of the large wood produced by different tree species (e.g., Bilby, 2003; Tabacchi and Planty-Tabacchi, 2003; Scherer, 2004; Mäkipää and Linkosalo, 2011; Ruiz-Villanueva et al., 2014; Lawson et al., 2015); aboveground tree architecture, flow resistance, strength, and biomass (e.g., Baptist et al., 2007; Aberle and Järvelä, 2013; Bendix and Stella, 2013; Camporeale et al., 2013; Jalonen and Järvelä, 2014); and the ability of trees and wood to interact with sediment erosion, deposition, and retention processes (e.g., Gurnell et al., 2001, 2008; Pollen-Bankhead and Simon, 2010; Manners et al., 2015), but much remains to be investigated.

One of the least investigated topics is the belowground component of riparian trees. While research on buried dead wood is scarce, research on the impact of buried living wood on the large wood cycle is particularly limited. In general, root systems provide anchorage for a tree and ensure water and nutrient supply. Rooting depth, density, root size, and root strength all contribute to tree anchorage and resistance to uprooting (Burylo et al., 2009) and so are all relevant to the wood cycle. Early successional species (e.g., pioneer riparian species) tend to have a significantly greater proportion of roots at depth than late successional species (Gale and Grigal, 1987), and species adapted to dry climates generally have deeper root systems than those adapted to moister conditions (Brunner et al., 2015). Furthermore, the root systems of woody plants comprise a wide range of different root sizes: coarse roots provide perennial structures that anchor trees, transport water and nutrients, and store nutrients and carbohydrates; fine roots are more ephemeral and forage for resources (Comas et al., 2013). Root properties vary between and within species, particularly in relation to tree age and physical, chemical, and biological environmental conditions (Brassard et al., 2009; Pasquale et al., 2012; Bardgett et al., 2014).

Despite such general knowledge regarding tree root systems, little is known about rooting depth, strength, and architecture among riparian tree species or how these vary under different environmental conditions, although root strength has been shown to vary with root diameter as well as between species (Simon and Collison, 2002; Pollen et al., 2004; Pollen-Bankhead and Simon, 2010). These properties strongly affect the ability of trees to avoid uprooting and to reinforce sediments (e.g., Docker and Hubble, 2008) and thus to influence the wood cycle.

This paper focuses on one species of riparian Salicaceae. The Salicaceae dominate riparian woodland across the northern temperate zone (Karrenberg et al., 2002). These poplar and willow species are typified by high growth rates and the ability to propagate from vegetative fragments, even when these are very small. These characteristics appear to have evolved in response to the particular selection pressures experienced in riparian zones (Eckenwalder, 1996). The high root growth rate of seedlings permits establishment on newly deposited fluvial sediments with rapidly declining water tables (Mahoney and Rood, 1992; Barsoum and Hughes, 1998; Guilloy-Froget et al., 2002); high stem elongation rates in established plants confer tolerance to burial by flood-deposited sediment; and the propensity for vegetative reproduction from fragments permits survival of destructive flow events (Barsoum et al., 2004). Furthermore, these species often produce vast networks of adventitious roots that give rise to new stems by suckering. Consequently, natural riparian stands of these species frequently consist of genetically uniform patches of clonal stems, often with a large, shared root network. This vast underground biomass, which is particularly significant in younger trees (Shepperd and Smith, 1993), constitutes a large store of readily mobilised carbohydrate (Nguyen et al., 1990; Pregitzer and Friend, 1996) that can support replacement of stems destroyed by major disturbances as well as rapid colonisation of newly deposited fine sediments and the exploitation of their nutrient and moisture storage resources.

The species on which we focus is *Populus nigra* L., a tree that often dominates the riparian margins of European rivers and whose role as a river physical ecosystem engineer has been recently reviewed (Corenblit et al., 2014). Corenblit et al. (2014) considered the performance of this species through the four phases of the fluvial biogeomorphic succession (Corenblit et al., 2007), highlighting (among other things) the way in which its root systems may develop with tree age according to environmental factors such as moisture availability and sediment retention. However, remarkably little is known about the depth, longevity, and growth of buried stems and associated roots of this species, which have such major implications for landform stability and turnover. Its role in driving vegetation and landform development along river margins dictates that it naturally grows in a highly disturbed environment where floods and associated erosion and deposition of sediment are common events. Thus we can assume that its belowground complexes of buried stems and roots not only resist such processes but also respond to them. As part of a larger study of the character and controls on the root systems of *Populus nigra*, in this paper we investigate the morphology and age of the main buried axis and largest roots of eight case study trees and their sedimentary environment within two reaches of the braided, gravel-bed Tagliamento River in northeast Italy. The aim of this research is to highlight the characteristics of this underground large wood component of *Populus nigra*, which is a source of large quantities of wood to the Tagliamento River (e.g., Gurnell et al., 2001, 2005), and is crucial to the trees' ability to resist displacement in erosive flood events. We also infer the history of the formation of this underground large wood component from this morphological and dendrochronological information. A complementary process history, constructed from historical sources including flow records and aerial imagery, is presented in Holloway et al. (2016-in this issue), which confirms or develops the interpretations presented in this paper, which are based entirely on the characteristics of the underground roots and their sedimentary environment.

2. Study area

The Tagliamento River is located in northeast Italy where its main stem rises in the southern fringe of the European Alps and flows ~170 km to the Adriatic Sea. The river spans a climatic gradient from

Please cite this article as: Holloway, J.V., et al., Underground riparian wood: Buried stem and coarse root structures of Black Poplar (*Populus nigra* L.), Geomorphology (2016), http://dx.doi.org/10.1016/j.geomorph.2016.08.002