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# Does reintroducing large wood influence the hydraulic landscape of a lowland river system?

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ABSTRACT

Our understanding of the effectiveness of reintroduced large wood for restoration is largely based on studies from high energy river systems. By contrast, few studies of the effectiveness of reintroducing large wood have been undertaken on large, low energy, lowland river systems: river systems where large wood is a significant physical feature on the in-channel environment. This study investigated the effect of reintroduced large wood on the hydraulic landscape of the Barwon-Darling River, Australia, at low flows. To achieve this, the study compared three hydraulic landscapes of replicated reference (naturally wooded), control (unwooded,) and managed (wood reintroduced) treatments on three low flow periods. These time periods were prior to the reintroduction of large wood to managed reaches; several months after the reintroduction of large wood into the managed reaches; and then more than four years after wood reintroduction following several large flood events. Hydraulic landscapes of reaches were characterised using a range of spatial measures calculated from velocity measurements taken with a boat-mounted Acoustic Doppler Profiler. We hypothesised that reintroduced large wood would increase the diversity of the hydraulic landscape at low flows and that managed reaches would be more similar to the reference reaches. Our results suggest that the reintroduction of large wood did not significantly change the character of the hydraulic landscape at the reach scale after several months ($p = 0.16$) or several years ($p = 0.29$). Overall, the character of the hydraulic landscape in the managed reaches was more similar to the hydraulic landscape of the control reaches than the hydraulic landscape of the reference reaches, at low flows. Some variability in the hydraulic landscapes was detected over time, and this may reflect reworking of riverbed sediments and sensitivity to variation in discharge. The lack of a response in the low flow hydraulic landscape to the reintroduction of large wood is inferred because the character (the size and complexity of individual pieces) and positioning of large wood in managed reaches did not mimic that of reference reaches effectively despite the abundance of wood pieces being similar in the reference and managed reaches. The results of this study highlight the importance of understanding the natural character and distribution of large wood on hydraulic landscapes in large low energy lowland river systems, especially when reintroducing large wood for river management purposes.

## 1. Introduction

Large wood is reintroduced into river channels to enhance physical and functional habitat for aquatic communities (Gerhard and Reich, 2000; Abbe et al., 2003) as well as to alleviate bed and bank erosion (Brooks et al., 2001; Shields et al., 2006). It has become a common river restoration strategy in many regions including North America (Cederholm et al., 1997; Pess et al., 2012), Europe (Kail and Hering, 2005; Kail et al., 2007), and Asia (Nagayama and Nakamura, 2010). The National USA River Restoration Science Synthesis database, for example, records an exponential increase in river restoration projects in the United States between 1970 and 2011, with an increasing use of large wood as the primary mechanism for restoring river channels (Bernhardt et al., 2005).

Despite the growing popularity of wood reintroduction as a restoration approach, our understanding and ability to predict the effectiveness of the approach is limited by two key and related factors. First, assessments of effectiveness generally occurs at the scale of individual pieces or piles of wood (Shirvell, 1990; Rosi-Marshall et al., 2006) with few studies examining how wood reintroduction alters patterns of wood abundance and distribution and hydraulic conditions at reach or larger scales (> 100 m) and how biota respond to these altered patterns. Second, most studies of wood reintroduction have taken place in high energy river systems in the Northern Hemi-

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sphere (Roni et al., 2002, 2008). This focus on high energy river systems is important because wood distribution is likely to vary based on stream energy because high energy streams have a greater capacity to redistribute wood at reach and larger scales (Wohl, 2016).

Adding wood to river channels has an important local effect (< 10 m), with individual pieces or piles of wood providing physical habitat and changing local hydraulic conditions. Biota also respond to habitat availability and hydraulic conditions at larger scales (> 100 m; Fausch et al., 2002). Studies that focus on site-scaled restoration attempts may be subject to type 1 error, that is, detecting an effect from the river restoration approach that is not there. Researchers have shown that biota can initially respond to the restoration approach but can determine a noneffect over larger scales. Brooks et al. (2006), as an example, found that an initial response from fish within 12 months was not significant after four years. In this study, larger scale fish assemblages did not change, but rather the fish response was to congregate around the newly formed habitats. Increasingly, evidence is recognising the importance of reach-scale habitats (< 100 m) or the diversity of habitat landscapes as being critically important for aquatic biota, especially fish (Fausch et al., 2002; Boys and Thoms, 2006). Different fish species can display preferences for a range of habitats including large wood at reach scales (Boys, 2007). This is because fish require different habitats at different life stages so as to complete life cycles, and the range of habitats are likely to be distributed at reach or greater spatial scales (Fausch et al., 2002). There is currently a disjunct between research undertaken at site scales and the understanding that biota respond to reach or larger scale habitat (Wohl et al., 2005, 2015). This situation has important implications for river restoration.

As noted above, most studies of the effectiveness of wood reintroduction have taken place in high energy systems. Indeed, according to recent reviews, < 5% of large wood restoration projects ($n$ = 137) have been carried out on low energy systems (see reviews by Kail et al., 2007; Burnett et al., 2008; Lester and Boulton, 2008; Roni et al., 2008; Miller et al., 2010; Nagayama and Nakamura, 2010). The relative lack of focus on low energy systems is particularly important when it comes to understanding and predicting the effects of wood addition on habitat and conditions at reach and larger scales because energy is critical to the distribution of wood in streams (Hughes and Thoms, 2002; Wohl, 2016).

In high energy river systems where stream power exceeds 40 W m$^2$ (Erskine et al., 2012), pieces of wood are readily redistributed downstream. Moreover, the capacity of high energy streams to redistribute wood is further enhanced because the tree species that dominate riparian zones of high energy systems in the Northern Hemisphere tend to have relatively low air dry densities (Gurnell, 2003). For example, conifers such as cedar species have average air dry densities of 370 kg m$^{-3}$, Douglas fir species densities average 513 kg m$^{-3}$, while willows (*Salix* spp.) average 450 kg m$^{-3}$ (Wallis, 1970). The combination of high stream power and low density wood has ramifications for the sort of wood distributions that typically form in these systems and, by extension, the hydraulic landscape created in those systems.

For river systems in other parts of the world that do not have the same combination of high stream power and low density wood, the patterns of wood distribution and the resultant hydraulic landscapes that form are likely to differ. Australian rivers, for example, are typically low energy lowland rivers. These systems are characterised by bed slopes of $< 1 \times 10^{-4}$ with stream energy < 5 W m$^2$ (Thoms and Sheldon, 2002). Low energy lowland river systems account for 97% of Australia's total river length, and low flows defined as flows at the 95th percentile of the long-term daily duration curve persist for the majority of the time (Thoms and Sheldon, 2000a).

Along with differences in stream energy, the physical character of pieces of large wood in Australian low energy lowland river systems also differs from that of high energy rivers in the Northern Hemisphere. Most trees in the riparian zones of Australian rivers are hardwood species that have a high air dry density compared to the softwood species (~900 kg m$^{-3}$), are large in physical character, and the complexity of individual wood pieces is greater (Wallis, 1970; Capon et al., 2016). This combination of relatively lower stream power and higher air dry densities of large wood results in most pieces in these low energy lowland systems being recruited to the river channel and remaining where they fall even during large flow events (Gippel et al., 1996a; Webb and Erskine, 2003; Matheson and Thoms, 2017). Thus, the natural distribution of large wood in Australian low energy lowland river systems and the effect of this wood on the hydraulic landscape are likely to be fundamentally different to that of high energy Northern Hemisphere systems. A corollary of this argument is that the initial placement of reintroduced wood is likely to be more critical in low energy lowland systems where wood is less mobile than in high energy systems where wood is remobilised by flow. There is a need to understand wood distribution, the resultant hydraulic landscape, and the effect of wood addition in low energy lowland systems.

In response to the poor condition of river ecosystems within the Murray Darling Basin, Australia, and the significant decline of native fish communities (Gehrke et al., 1995), the Murray Darling Basin Authority developed and implemented the Native Fish Strategy (NFS; Murray-Darling Basin Authority, 2004). A key component of the NFS was the establishment of seven demonstration reaches and the reintroduction of large wood into river channels. This was based on the assumption that higher wood densities are beneficial to native fish through the provision of physical and hydraulic habitat (Boys et al., 2014). There has been no detailed monitoring and assessment of this restoration despite the expectation that increasing structural habitat in these low energy lowland river systems will have a beneficial functional ecohydraulic response for native fish.

The aim of this study is to assess the influence of reintroduced large wood on reach-scale hydraulic landscapes in a low energy lowland river system over time at low flows. To address this aim the following questions are asked: i) Does the reintroduction of large wood recreate 'natural' hydraulic landscapes? ii) Does the magnitude of any effect of reintroduced wood on the hydraulic landscape change over time, notably after a succession of high flow events?

## 2. Study area

This study was undertaken along a 210-km section of Barwon-Darling River between the townships of Bourke and Brewarrina, in the western regions of Murray-Darling Basin, SE Australia (Fig. 1). The Barwon-Darling River is a typical lowland semiarid system characterised by low bed gradients (average bed slope of $4.5 \times 10^{-5}$), a complex channel morphology, and an irregular flow regime (Thoms and Sheldon, 2000b). The flow regime of the Barwon-Darling River is one of the most variable in the world (Puckridge et al., 1998) with long-term coefficient of variation of annual flows ranging from 0.04% to 911% (Sheldon and Thoms, 2006). Extensive water resource development has significantly altered the flow regime of the river. Median annual runoff has been reduced by 42% since the 1960s following the construction of nine headwater dams and numerous weirs and the introduction of over 260 licenced water extractors (Thoms and Sheldon, 2000b). Small flood events (e.g., average recurrence interval of < 2 years) have been reduced in magnitude between 35 and 70% since the 1960s, and a significant increase in the duration of low flows – those flows associated with the 95th percentile on the low-term daily flow duration curve. At Bourke for example, the frequency of low flows has increased by 1.3 times; while overall flows show a marked increase in predictability and consistency and thus water level stability during extended periods of low periods along the entire river (Thoms and Sheldon, 2000b).

The in-channel environment is relatively depauperate in terms of the presence of physical habitat. The river bed substratum is dominated by a relatively uniform mixture of fine sand, silt, and clay particles with little variation along most of its length (Thoms and Olley, 2004). Large wood is the only hard substrate within the main channel of the Barwon