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Physical modelling of the combined effect of vegetation and wood on river morphology

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A B S T R A C T

The research reported in this paper employs flume experiments to investigate the potential effects of living vegetation and large wood on river morphology, specifically aiming to explore how different wood input and vegetation scenarios impact channel patterns and dynamics. We used a mobile bed laboratory flume, divided into three parallel channels (1.7 m wide, 10 m long) and filled with uniform sand to reproduce braided networks subject to a series of cycles of flooding, wood input, and vegetation growth. Temporal evolution of river configuration (in terms of the braiding index), vegetation establishment and erosion, and wood deposition amount and pattern was recorded in a series of vertical images. The experiments reproduced many forms and processes that have been observed in the field, from scattered logs in unvegetated, dynamic braided channels to large wood jams associated with river bars and bends in vegetated, stable, single-thread rivers. Results showed that the inclusion of vegetation in the experiments changes wood dynamics, in terms of the quantity that is stored and the depositional patterns that develop. Vegetated banks increased channel stability, reducing lateral erosion and the number of active channels. This promoted the formation of stable wood jams, where logs accumulated continuously at the same locations during subsequent floods, reinforcing their effect on river morphology. The feasibility of studying these processes in a controlled environment opens new possibilities for disentangling the complex linkages in the biogeomorphological evolution of the fluvial system and thus for promoting improved scientific understanding.

1. Introduction

The importance of vegetation and wood for river morphology has been recognized only quite recently (for reviews see Gurnell, 2013, 2014). Initially, this recognition developed from field observations, but over the last two decades vegetation has increasingly been incorporated into numerical models (Camporeale et al., 2013; Ruiz Villanueva et al., 2014), and some physical modelling has also started to investigate how wood and plants interact with fluvial processes. However, in previous physical modelling studies the influence of large wood and riparian vegetation has been studied separately, whereas in this paper, we focus on physical modelling incorporating both living vegetation and wood.

Traditionally, physical modelling has been used largely to investigate interactions between water and sediment, reproducing forms and processes in an effective way (Paola et al., 2009). Where vegetation has been incorporated, the focus has been largely on aquatic vegetation and, particularly, on the ways in which it affects the flow field (e.g., Folkard, 2009; Nikora, 2010; Nepf, 2012) and associated sediment dynamics. Riparian vegetation has also been incorporated into flume experiments, for example, illustrating how it is a crucial ingredient for reproducing single-thread/meandering rivers (Gran and Paola, 2001; Tal and Paola, 2007, 2010; Braudrick et al., 2009; van Dijk et al., 2013).

Inclusion of biotic (i.e., living) elements in physical models is challenging, not only because the experimental setup has to support vegetation growth and survival, but more crucially because it poses scaling problems (Thomas et al., 2014). However, if the experiments are used to investigate processes rather than to reproduce field prototypes, fast-growing plant species such as alfalfa (*Medicago sativa*) provide the possibility of exploring a range of influences of aboveground and belowground vegetation biomass on river processes and morphology (Clarke, 2014). For example, vegetation impacts can be investigated at fine scales, such as the contribution of root reinforcement to bank cohesion, and at coarser scales, such as the retention of sediment by vegetation to build islands (e.g., Gran and Paola, 2001; Perona et al., 2012).

Large (dead) wood has also been studied in the laboratory, mostly to investigate its effect on the flow field and to assess the conditions under which wood can be mobilised and transported (Braudrick et al., 1997;

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Braudrick and Grant, 2001; Bocchiola et al., 2006; Welber et al., 2013). The interaction between wood and bridges during floods has also been investigated (Schmocker and Weitbrecht, 2013). Only recently have laboratory experiments been used to investigate the interaction between large wood and river morphology, relating bedforms and sediment dynamics with wood dispersal (Welber et al., 2013; Bertoldi et al., 2014).

Despite the fact that living vegetation and dead wood are closely related in nature (Moulin and Piégay, 2004; Gurnell et al., 2005; Collins et al., 2012), to date no experiments have been conducted to investigate their joint influence on river morphology. In this paper, we demonstrate that flume experiments can be an effective tool for investigating the variables controlling the morphological evolution of rivers bordered by riparian woodland and thus affected by the occurrence of large wood deposits. The experiments also allowed us to explore the coupled role of riparian vegetation and large wood on river channel forms and dynamics, particularly on the landforms created by their interaction.

2. Methods

The following experiments were conducted within the 'Total Environmental Simulator' facility, located at the University of Hull, UK.

2.1. Experimental setup and network development

Three 1.7-m-wide, 10-m-long flumes were built within the Total Environmental Simulator. Each had an initial slope of 1.3% and was filled with well-sorted sand (median grain size 0.73 mm). Water and sediment inputs to the flumes were set to 1.26 l/s and 1.9 g/s, respectively, to simulate high flow conditions. Flow and sediment inputs were provided using submerged pumps and automatic sediment feeders.

Prior to the experiments, the flumes were run under steady high flow conditions for 21 h to obtain freely developed, steady-state, braided networks (for further details see Bertoldi et al., 2014). Experiments were then run, first to explore the dispersal and retention of wood through the flumes under different wood supply rates in the absence of any vegetation cover and then to explore wood dispersal and retention when vegetation was present.

2.2. Experiments without vegetation

A first set of experiments was conducted where wood was fed into the steady-state braided networks of the three unvegetated flumes to simulate the delivery of uprooted trees and very large logs to a 'large' braided river (i.e., a 'small' log length relative to the width of the anabranches; Gurnell et al., 2002).

Large wood was simulated using cylindrical wooden dowels (hereafter called 'logs'), some with and some without attached cross-shaped 'root wads'. The length of the logs was 8 cm, to represent 'large' river conditions, as defined above. The diameter of the logs was 3 mm, so that the length-to-diameter ratio was representative of data collected on the gravel-bed, braided Tagliamento River, northeastern Italy (Bertoldi et al., 2013). Log diameter was comparable to flow depth in many parts of the channel network. As a result, logs moved mostly by floating in the main anabranches and by rolling or sliding in the shallow areas on top of sediment bars. Sediment diameter was scaled to the median grain size of the same river. The logs were made of birch wood with a wet density of 0.67 kg/dm^3, which closely matches density values reported by Thévenet et al. (1998) for riparian species along the Drôme River, France, where the riparian woodland composition is typical of southern European rivers, including the Tagliamento. The logs were colour-coded to facilitate counting.

High flow conditions were maintained over 18 h as groups of logs were added to each flume at regular time intervals at a point immediately downstream of the flume inlet to sustain a 'low', 'medium' and 'high' wood input regime to flumes 1, 2, and 3, respectively (Table 1). Cohorts of logs were fed into each flume every 15 min. Individual logs within the same cohort were released at ~3-second intervals to ensure uncongested transport conditions, as defined by Braudrick et al. (1997). These inputs achieved a total input rate of 60, 120, and 180 logs/h in the first 6 h and 40, 80, 120 logs/h in the remaining 12 h of the experiment to flumes 1, 2, and 3, respectively (Table 1; for further information see Bertoldi et al., 2014).

Following the above experiments, the flumes were prepared for the experiments with vegetation by manually removing all logs from each flume and then running high flow conditions for 1 h to remove any imprint of the logs on the flume bed.

2.3. Experiments with vegetation

To explore interactions among wood and vegetation, the three flumes were prepared by broad-seeding them with alfalfa seeds at a density of 35 g/m^2 during low flow conditions (0.2 l/s). The flumes were then maintained under low flow conditions for four days while the seeds germinated and established. During this time, some hydrochorous reworking and dispersal of seeds was achieved through the channel network by the low flows. The low flow discharge was not sufficient to transport sediment, and no sediment was input to the flumes. Alfalfa seedlings had the twofold role of stabilising the sediments by root reinforcement and by interacting with flow and transported logs, reproducing the effect of flexible riparian vegetation in the forms of shrubs and young deciduous trees, as is typical of the Tagliamento River.

Following the vegetation establishment period, the three flumes were subjected to three different wood input regimes through four cycles of high flows interspersed with four days of vegetation regeneration under low flows. During these cycles no wood was input to flume 1, while flumes 2 and 3 were subject to 'low' and 'high' wood input regimes (Table 1), i.e., 60 and 180 logs/h during the first 2 h and thereafter 40 and 120 logs/h, respectively.

Table 1
Wood input regimes applied to the three flumes.

Vegetation wood input regime	Flume 1[a]		Flume 2		Flume 3		Flume 2		Flume 3	
	Experiments without vegetation						Experiments with vegetation			
	Low		Medium		High		Low		High	
	Hours	Hours	Hours	Hours	Hours	Hours	Hours	Hours	Hours	Hours
	0 ÷ 6	6 ÷ 18	0 ÷ 6	6 ÷ 18	6 ÷ 18	6 ÷ 18	0 ÷ 2	2 ÷ 16	0 ÷ 2	2 ÷ 16
Wood input rate [logs/h]	60	40	120	80	180	120	60	40	180	120
Input frequency [cohorts/h]	6	4	6	4	6	4	6	4	6	4
Cohort size [logs]	10	10	20	20	30	30	10	10	30	30
Logs with roots [% of total wood input]	60%	40%	60%	40%	60%	40%	40%	40%	40%	40%

[a] No wood was input to flume 1 during the experiments with vegetation.