THE ROLE OF HYDROLOGIC DISTURBANCES ON BIOMASS EROSION DYNAMICS: FIRST RESULTS FROM RIVERINE EXPERIMENTS

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P. Perona(1), P. Molnar(1), J. Jiang(1), C. Camporeale(2), E. Perucca(2),
R. Francis(3), A. Gurnell(4)

(1) ETH Zurich, Switzerland, E-mail: paolo.perona@ifu.baug.ethz.ch
(2) Politecnico di Torino , Italy, E-mail: carlo.camporeale@polito.it
(3) King's College London, United Kingdom, E-mail: robert.francis@kcl.ac.uk
(4) Queen Mary, University of London, United Kingdom

This paper presents an overview of RIVERINE project (RIver-VEgetation interactions and Reproduction of Island Nuclei formation and Evolution) preliminary results. We show some exemplary statistics of the both eroded and non-eroded material as resulting from a competitive dynamics between vegetation growth time scale and interarrival time of disturbances with constant magnitude. Two experiments, that is within channels with either regular geometry (parallel walls) or converging walls are discussed. Results show coherency of the results between the two geometries as far as the selective erosion mechanism of riparian vegetation is concerned. The experiment with convergent walls also conjectures that island formation is limited by the stream power associated to the local specific discharge.

1. INTRODUCTION

Recent experimental studies in flumes have focussed on the active role that riparian vegetation plays in the morphological evolution of meandering and braided rivers (Gran & Paola, 2001; Coulthard, 2005; Tal & Paola, 2007; Braudrick et al., 2009). The development of bars and islands in braided rivers and their stabilization is fundamental for the establishment of pioneering vegetation and for riparian vegetation distribution in general. However, it is not only flood magnitude that has an effect on island pattern formation in natural rivers. For example, in the Tagliamento River (Italy) Gurnell & Petts (2006) found that islands develop within thresholds defined by stream power, rates of vegetation growth and rates of sedimentation, and that different growth trajectories can be assumed depending on vegetation type and the time to germination of large woody debris deposited after floods.

Physical experiments are important tools to create controlled conditions within a reasonable timescale in order to understand cause and effects relationships between plants and channel morphology (Gran & Paola 2001; Coulthard 2005; Braudrick et al. 2009). Such experiments however did not address the issue of timescales in the feedback between vegetation growths and flow variability. The first experiments to investigate unsteady conditions in a consistent manner were those of Tal & Paola (2007). However, the interarrival times of the disturbances were rather large compared to the growth rates of vegetation (alfalfa), and no differentiation between the time required to germinate was made because plants were continuously reseeded after each flood. These aspects seem to be critical since the resistance of the root system to erosion is clearly a function of time as the plants grow and (some) get eroded depending on the frequency and magnitude of the flood disturbance.

Building on the knowledge gained in previous studies, the RIVERINE experiment intended to explore the competing timescales of vegetation growth and flooding frequency. The novel aspects in relation to the previous experiments are: (a) flooding frequencies are comparable with plant root germination and growth rates so that vegetation and floods are in direct competition; (b) changes in the detailed morphology of the channel bed surface were measured by laser scanning; (c) data were collected on both eroded and growing plants (e.g. number of seeds, plants, stem and root lengths, etc.) and eroded sediment after each flood; and (d) the effect of floodplain boundaries was examined by running the experiments in a straight and convergent channel.

Overall and compatibly with the limited time at our disposal for running such type of experiments, first analyses seem to provide promising results which would fully support the mainly explorative scope of RIVERINE and indicate future direction for repeating and improving the experiments.

2. METHODOLOGY

Experiments were conducted at the Total Environmental Simulator of the University of Hull and located at "The Deep", Hull, UK. The Hydralab III access time (i.e., 35 working days) was entirely used to setup and run the foreseen experiments, but it did not allow to a certain extent to repeat and adequately refine the controlling variables. Figure 1 below shows the flumes with parallel and with

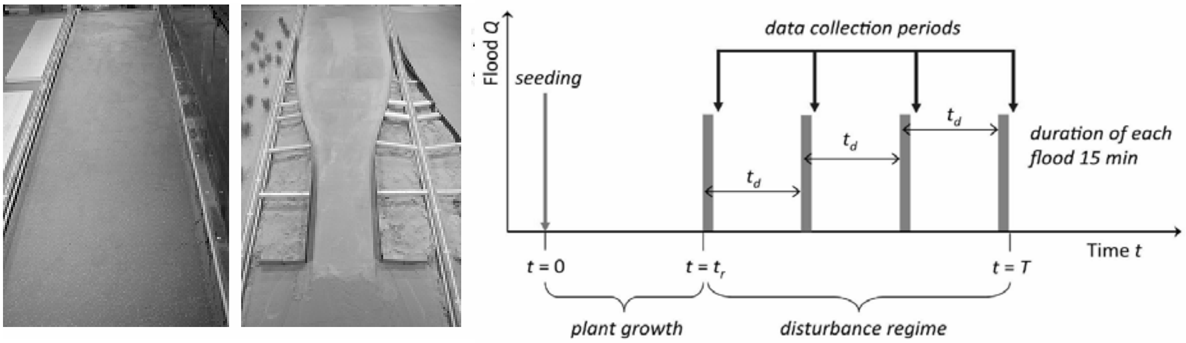

Figure 1. The two geometries explored in these experiments and the adopted disturbance regime

convergent walls, as well as the general scheme that was adopted to perform the experiments. Whilst in the following only some technical aspects of the experimental procedure are recalled, major details of the facility setup can be found elsewhere (Perona et al., in preparation). Initially, two flume channels with parallel walls where setup and run simultaneously with two different disturbance magnitudes (i.e., 3 and 5 l/s) for 15 min. After stopping the flow, the eroded material was collected downstream, and a sample of non eroded plants was carefully extracted at the end of the channel. A number of 4 disturbances where run at daily interval t_d; then the experiment was interrupted, the grass and the roots completely removed, the bed re-levelled and re-seeded for repeating the experiment by eventually changing the intertime t_r between the seeding and the first disturbance. Then, convergent walls made of plastic material with surface roughness similar to that of the bed sand were mounted and the whole procedure above described was repeated again. For all experiments vegetation was seeded at an initial density of of about 2300 seeds/m^2. The d_{50} of the sediment was 0.48 mm.

3. RESULTS AND CONCLUSIONS

The analysis of the eroded sediment for all experiments clearly reflects the role of growing vegetation, which reduces the erosion of the bed material in successive runs (Figure 2). Soil without roots is noncohesive; by growing the plant roots add tensile strength and elasticity, which enhance the bulk shear strength of the soil and reduces the erosion potential. However, two additional processes could have act on the flume bed, limiting the erosion capacity after each run. These are the gradual

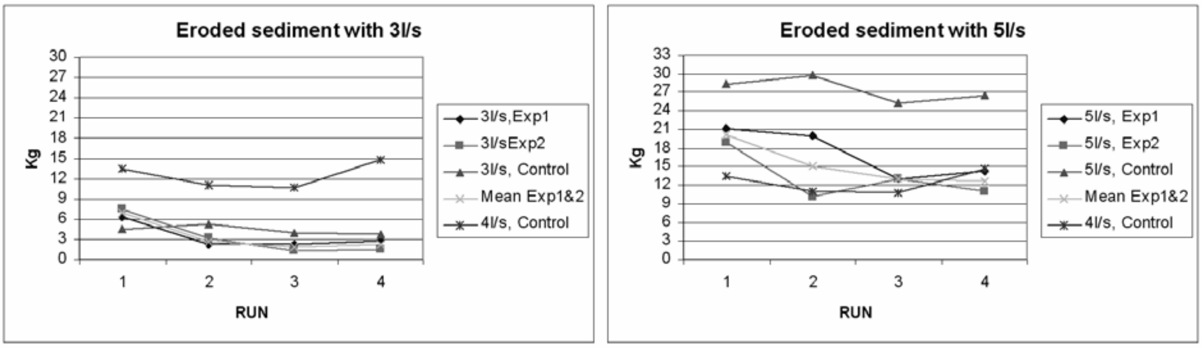

Figure 2. Erosion of the sediment in the flume with parallel walls for both experiments with 3 and 5 l/s for 15 min in the presence of vegetation growth and for the control runs without vegetation.

adjustment of the slope to its statistical equilibrium value with related reduction of the sediment transport capacity, and the reinforcement of the cohesion effect of the soil by means of water infiltration, which might have induced a better spatial distribution and compaction of the grains. Whilst the second effect is probably negligible as the river bed saturated practically immediately at the beginning of the first run, the first effect was controlled by running a identical experiments without vegetation that could serve as control. The control run with the same flow rate, duration, and without vegetation, actually show that erosion in successive runs becomes approximately constant after a short transitory, but the amount of eroded material is considerably higher than that in the presence of vegetation. Such results basically confirm the reliability of our experimental procedure of supplying the sediment after each run by simply re-filling the uppermost part of the channel.

3.1 Parallel walls geometry: the erosion selective mechanism of flood disturbances

The statistics of the eroded and the non-eroded vegetation (No. of roots, main root and stem lengths) at each run reveal substantial differences among each others, which suggest that floods magnitude and duration would operate as selective mechanism for vegetation showing certain statistical features. Figure 3 shows the statistics for both the eroded and non-eroded material for both flowrates, which indicate that successive runs remove vegetation with similar histograms whilst the non-eroded vegetation keeps growing. This assertion cannot be fairly proven with the limited number of experiments we have done, nor a particular reason emerges at present to justify such a conclusion over the whole range of quantiles. However, a reasonable conclusion can be made at least about the mean of the statistics. In average, the balance between drag and resistance forces can be associated to the intrinsic erosive power of flow magnitude (drag action) and the related duration (sediment erosion action), and the root mechanical anchoring. Since disturbances have limited duration and there is an active morphodynamics, a single run is not enough to completely remove all the ”weak” vegetation. Moreover, erosion induces vegetation with longer roots (i.e., stronger anchoring) to eventually collapsing when for instance local nearby channels are strongly modified by the flow. This dynamic would explain the tail of the histogram distribution of the eroded material.

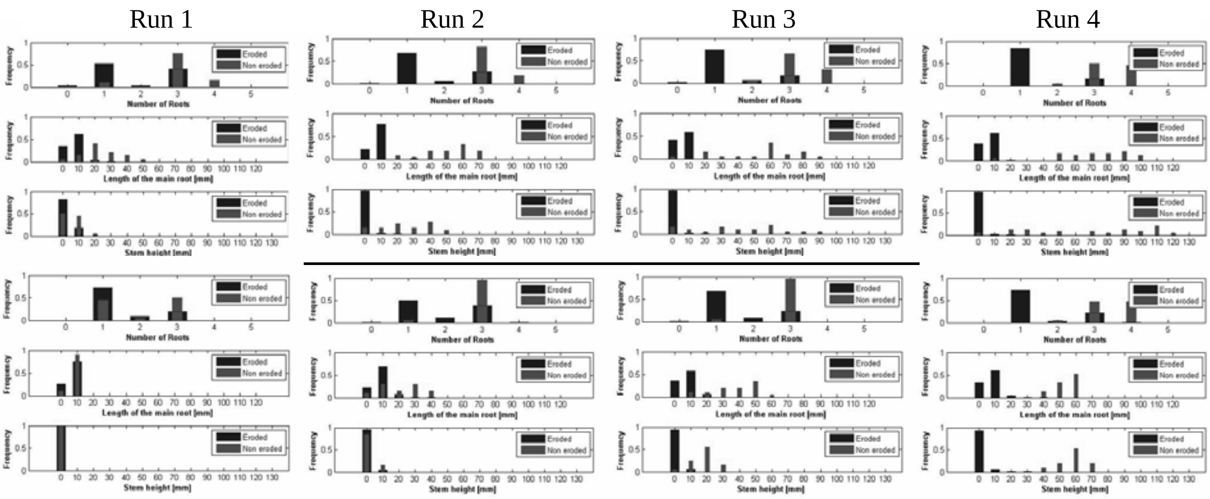

Figure 3. Histograms of the eroded and the non-eroded vegetation for one of the experiments with 3 l/s (upper panels) and 5 l/s (lower panels). Non-eroded material keeps growing in successive runs.

3.2 Convergent walls geometry: influence of boundaries on complex island formation

As far as the experiments within the flume with convergent walls are concerned, the conclusions drawn for the eroded and non-eroded material within parallel walls seem still to hold. In addition, this experiment was useful to explore the conjecture proposed by Gurnell & Petts (2006). It would seem that building of complex islands is indeed controlled/limited by the floodplain lateral (rigid) boundaries. One of the experiments cannot be considered successful in this respect because an unexpected increase in plant growth rate over one of the weekends produced a completely vegetated channel. However, the other experiment was quite satisfactory. We observed the situation shown in Figure 4 where a clear limit in the presence of vegetation is evident downstream the “funnel” created by the convergent walls. In particular, such a limit band seems to depend on the flow magnitude and extends deeper inside the convergent for the experiment with the lower magnitude of the disturbance. By a rough computation we find that such a limit happens where the ratio between the channel width w and the upstream floodplain width B is $w/B=0.43 \div 0.55$ and for specific flowrates $q=Q/w= 3.7 \div 4.7$ l/s·m for the low and the high flow magnitude, respectively. The real situation in the Tagliamento River near Pinzano Gorge, would suggest a ratio $w/B \approx 0.51$ and a peak flood event in Froude similitude of about $4700 \div 7800$ m^3/s for a slope of 1%, whereas the local true slope is actually 1.6% and the daily mean of the historical largest event was about 3600 m^3/s. Such a value however is

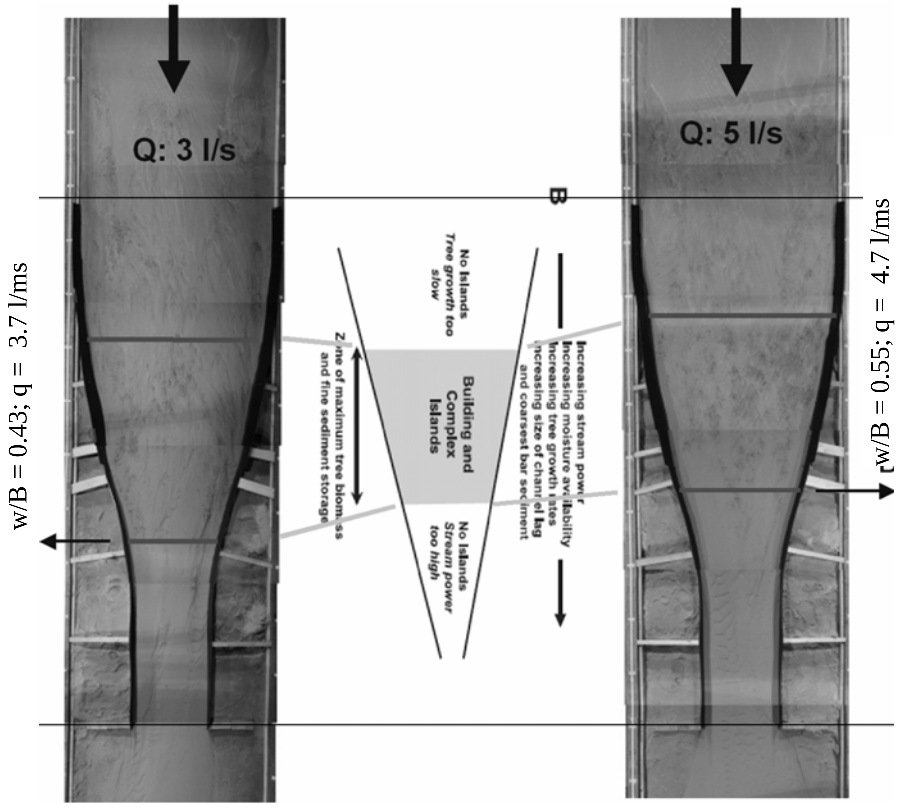

Figure 4. Planimetric view of the channels with convergent walls at the end of the experiment after the 4th run. The limit of vegetation growth within the convergent depends on disturbance magnitude, thus confirming the conceptual model of Gurnell & Petts (2006)

measured about 20 km upstream Pinzano and is missing a number of contributes including derivation for hydropower production and some affluent. However, an advanced analysis by using distorted scales is ongoing.

General conclusions can be drawn in relation to the preliminary analysis of the results. Our experiments started from an initially flat bed seeded at a uniform density in order to equal the probability of eroding the germinated plants. In this respect the morphologic evolution we observed is likely not mirroring the true process of island formation, which probably initiates from existing river morphology, the colonization by vegetation of which then starts the active interactions. Our strategy however allowed to shed light and to confirm the conjecture that floods would act as a selective mechanism for the riparian vegetation, thus “cleaning” the floodplain from debris and part of the germinated plants. Possibly, this would lead to a limiting time scales ratio t_g/t_d below which vegetation will likely not have a chance to colonize the river system. Finally, lateral boundaries seem important to determine the limiting zone where excessive stream power will dominate the recruitment and the colonization of available sediment sites.

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