The key role of pioneer woody vegetation in mid-channel bar metamorphosis to island: case study from the River Loire (France)

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1. Introduction

In the middle reaches of the Loire River, human activities have accelerated the incision process which caused severe morphological evolution of the river (e.g. disconnection of adjacent floodplain areas and alluvial bars). As a consequence, bars can be affected by a strong development of woody pioneers trees which trigger sediment accretion and fixing.

The conceptual model of alluvial island's proposed by Gurnell et al. (2001), highlights the key role played by vegetation in this process; nevertheless the vertical sediment deposition rates affecting islands during their first stage of development remains unknown. In other words, investigations detailing the first stage of development and involving woody pioneer trees are missing. This issue, which concerns initial island growth and rhythm of sediment archiving involving vegetation, is of key importance for fundamental aspects in both modern and ancient fluvial systems (Gibling and Davies, 2012). From an applied point of view, such studies are of interest for fluvial management, providing information on the intervention time scales and practices, especially in the management of flood water level.

The study site of Mareau-aux-Prés (France), located 10 km close to the city of Orléans, is an island and bar network developed downstream of a natural limestone riffle. The presence of this natural riffle is explained by intense sediment mining in this area which stopped in years 1990's. Downstream of the riffle, a 20 000 m² sandy-gravelly bar developed between 2003 and 2005; this bar was rapidly colonized by woody pioneer vegetation, mainly *Populus nigra* L. This paper will focus on the control exerted by the vegetation during the first stage of development of this bar.

2. Materials and methods

2.1 Morphological and sedimentological surveys

The topography of the bar was surveyed together with scour-fill processes on annual basis by measurements performed since 2007 to 2012.
Detailed topography was recorded according to10 m spaced cross sections using a DGPS and enriched with a set of spatial points, characterizing slope break. Data were integrated in a GIS software (ArcGIS 9) and 1 m mesh digital elevation models were created using the spatial analyst extension of ArcGis.
Scour chains were inserted into the river bed to measure the active layer of sediments stored on the bar.
Annual bulk samples were taken at each scour chain location. Grain size analyses were performed using dry sieving in order to quantify the critical shear stresses on the bar.

2.2 Physical parameters and mapping of vegetation

Density, maximal and minimal height and diameters were surveyed on 2 x 2 m plots centered on each scour chain location. Diameter for the smallest was measured on 0.1 m whereas for the largest, measure was Diameter Breast Height (DBH).
The Manning-Strickler roughness coefficient (n_{veg}) was calculated using the Petryk and Bosmajian (1975) equation for non-submerged vegetation:

$$n_{veg} = Rh^{2/3}\sqrt{\frac{C_d + \sum A_i}{2gAL}} \qquad (1)$$

where n_{veg} vegetation roughness, R_h hydraulic section assimilated to depth (m), C_d drag coefficient (equal to 1), $\sum A_i$ sum of areas of trees projected onto the wet section, g gravity ($m.s^{-2}$), A wetted section (m²), L unit length of the study reach (m).

Cartography of *P. nigra*, based on dominance-abundance coefficient of Braun-Blanquet and evaluated with the percentage of recovery (Combroux *et al*, 2002), was realized with GPS and integer on GIS.

2.3 Hydrology and hydraulic parameters

Flood intensity, duration and frequency as well as submersion periods of the bar were evaluated using the data of the gauging station of Orleans located 10 km upstream. Water surface elevations, measured by DREAL Centre, allowed us to calculate depth of flow on the bar.

3. Results

3.1 Morphological evolution

Between 2007 to 2012, vertical accretion was observed on three morphological units with more than 1 m in some areas. These units were also characterized by lateral expansion. Different sediment deposition rates in a same morphological unit were recorded and shown to vary from simple to double.
Slopes, delimiting these units, are increasing from upstream to downstream while the top of these units tend to flatten out.
Formation of three islands, separated by a perennial sub-channel with initial bar elevation, is identified.

3.2 Sediment budget during floods

Since 2007, on the bar studied, about 7000 m^3 deposit of sediments occurred while 3000 m^3 were eroded. Areas with univocal process, fill (2000 m^3) or scour (40 m^3), were clearly identified and associated with the vegetated areas for deposition and sub-channel.

Scour chain results present some areas with no erosion whereas critical shear stress calculated with D_{90} was lower than shear stress during flood events. These are observed on vegetated area and sub-channel.

Areas of major sediment deposition varied from one year to the other.

3.3 Temporal grain size evolution and critical threshold for sediment motion

Spatial grain size distribution is organized according to a downstream and vertical fining which increased with time. D_{90} of sediments present in the vegetated areas and in the sub-channel were clearly different but they both have decreasing values with time..

3.4 Flow resistance induced by vegetation

For n_{veg} values < 0.017, resistance to the flow exerted by vegetation is correlated to diameters; while for n_{veg} values up to 0.03, density is the most important parameter.

4. Discussion and conclusions

The aim of this study was to understand the first stage of island edification and transformation time from an alluvial bar. Four morphologic units were identified: 3 vegetated islands and a sub-channel.

The three vegetated islands result of a combination of processes. On one hand, the morphology of the study reach contributes to sediment deposition since these units are located downstream a natural riffle (lee effect). This is also favourable for seed deposition and for sprouting of black poplars. According to the engineer species concept (Corenblit et al., 2011) pioneer woody vegetation participates to sedimentological processes and improves environmental conditions for their survival.

This concept is translated as a positive feed-back on sediment deposition rates observed in this study. More specifically, vegetation creates obstacles marks (Euler and Herget, 2011) which widen, grow and finally merge (Rodrigues *et al.*, 2007). Vegetation roughness induces a decrease in sediment transport capacity which contributes to rapid vertical accretion, and fining of trapped sediments (quantity of bedload sediment decreases relatively to suspended sediments). Moreover, vegetation increases threshold of sediment motion as a protection against erosion (McKenney et al., 1995).

Nevertheless, direct link between vegetation roughness and sediment deposition rates was not shown. We assume that the sediment supply coming from the main channel is of key importance to explain the sediment trapping by the vegetated filters. Further investigations, namely bathymetrical and flow dynamics surveys, will be carried out in this sense on the study site in the future.

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