Influence of migrating bars on dune geometry

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ABSTRACT: Authors investigate the effect of migrating bars on dune geometry in a sandy gravel bed river (Loire River, France). Bathymetric survey were carried out in order to determine dune geometry. Preliminary results show that superimposed dunes geometry is not only governing by water depth. Bars could provide enough sediment to the development of dunes on their stoss sides despite decreasing water depth.

1 INTRODUCTION

Bedforms are commonly superimposed in river channels (Figure 5). Many authors have described this phenomenon in both, field and flume studies (McCabe & Jones 1977, Carling et al. 2000, Parson et al. 2005, Villard & Church 2005, Fernandez et al. 2006, Rodrigues et al. 2015, Wintenberger et al. 2015). However, there is a gap in the understanding of interactions between two scales of superimposed bedforms, specifically between bars (macroforms sensu Jackson 1975) and dunes (mesoforms sensu Jackson 1975).

Bars induce spatial forcing of flow depth, velocity and direction (Claude et al. 2014) that impact superimposed dunes geometry, celerity and sediment transport. Bars also influence sediment supply locally by defining the thickness of the active layer (Carling et al. 2000, Kleinhans et al. 2002, Tuijnder et al. 2009). Dunes located on bars influence time and spatial variation of flow resistance (roughness) and sediment supply that feedback on migration rates of the bars. One point specifically needs attention: how bar and dune configuration influence sediment transport and how they interact? This paper, is focused on the first type of interactions mentioned above.

Figure 5. Bar front and superimposed dunes in the Loire River (near Saint-Mathurin-sur-Loire-, Source: J. Le Guern).

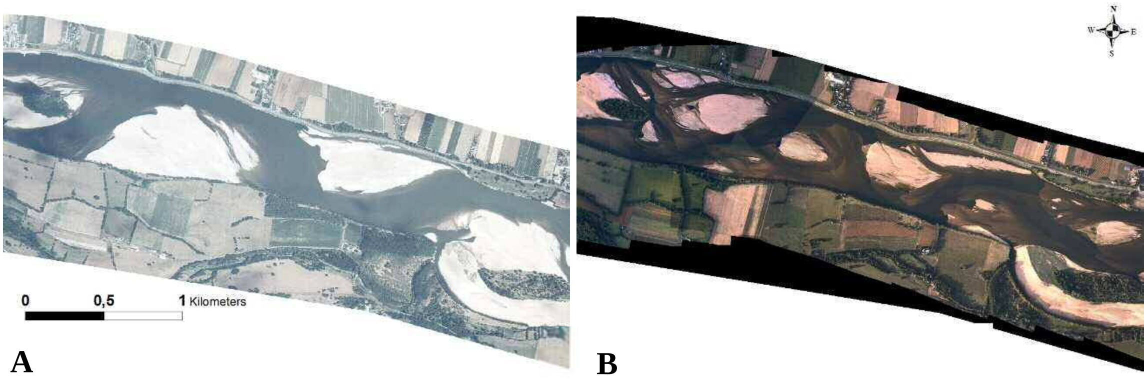

Figure 6. Aerial photographs of the study reach. A. July 2002 Q=200 $m^3.s^{-1}$, alternate bars (m=1). B. September 2017 Q=160 $m^3.s^{-1}$, multiple bars (1.5<m<2.5).

2 STUDY SITE

The study site is located near Saint-Mathurin-sur-Loire, in the downstream part of the Loire River (France), about 150 km upstream of the estuary. The study reach is 2.5 km long and nearly straight with a bed slope of 0.0002 m m^{-1}. The aspect ratio β, which is the width to depth ratio of the channel, ranges between 120 and 750 and decreases with discharge. This large variation of the aspect ratio with hydrological conditions lead to a reach with different bar modes: multiple bars (Figure 2, study site in 2017) with one to two bars per cross section; and alternate bars (Figure 2, study site 2002) with one bar per cross section (respectively m=1.5 to 2.5 and m=1, Crosato & Mosselman 2009). From a theoretical point of view, alternate bars cannot occur for such high β ratio values. When the bar mode of the reach is greater than one, it is difficult to determine bar wavelength but height is about 1.5 m. When bars are alternate, the wavelength is about 1.3 km.

Superimposed dunes are about 4 m long and 0.2 m height. They migrate with a mean celerity of 30 meter per day during flood events. The bed is composed of sands and gravels with a mean diameter of 0.8 mm.

3 METHODS

To assess the effect of bars on dunes, 12 single-beam bathymetric surveys were carried out along the reach for different discharge conditions (Figure 4). Geometry of dunes have been extracted from three longitudinal bed elevation profiles (BEP, see Figures 3 and 4) with the Matlab code Bedform Tracking Tools (van der Mark et al. 2008).

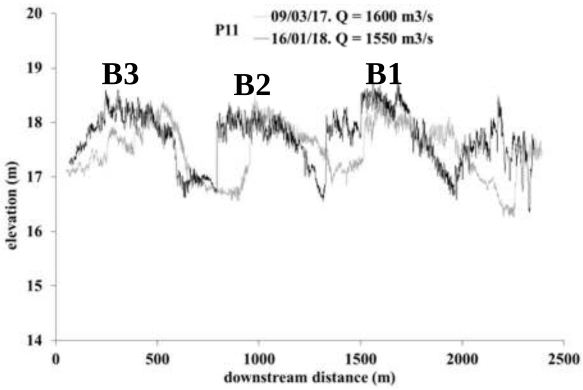

Figure 3. Examples of BEP surveyed in March 2017 and January 2018. Note the presence of dunes on bars stoss side and migration of bars.

The geometry of each dune, determined by the program with a zero crossing method, was extracted from the stoss side of each bar present on the site. Stoss side of bars were intentionally delimited using the lowest water level surveyed to exclude the lower parts of the channel that are subject to transverse sediment reworking at low flows.

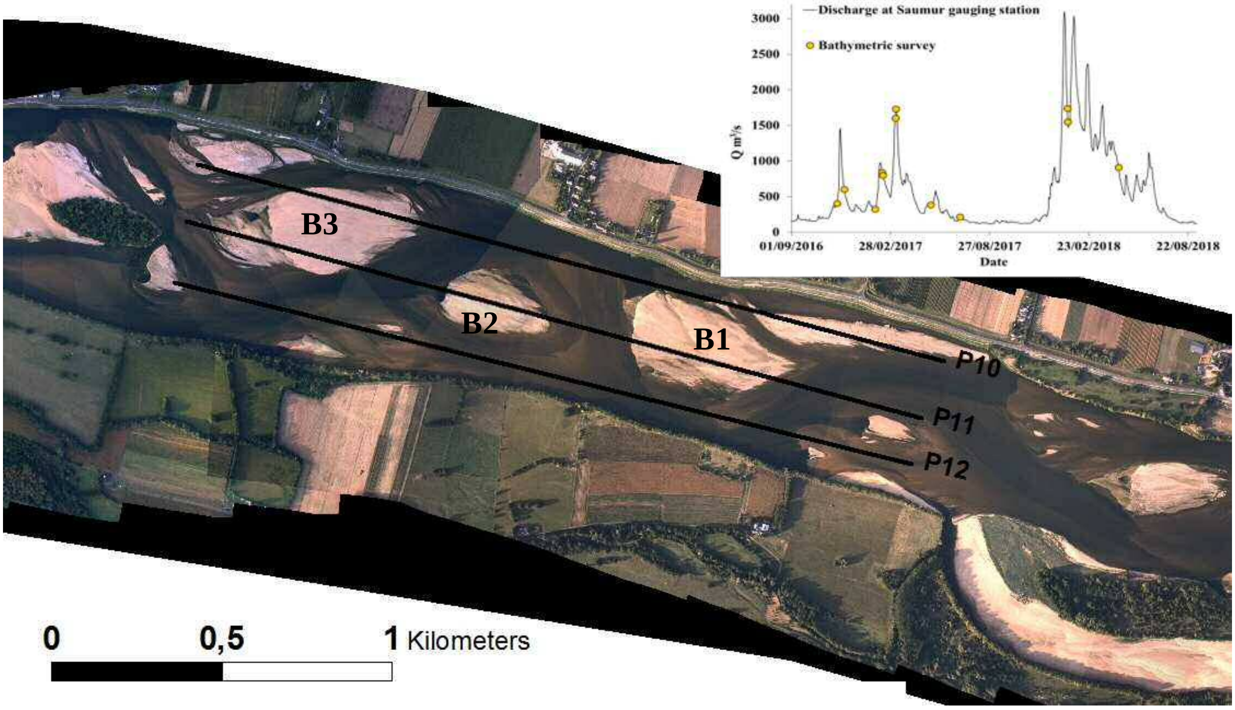

Figure 4. Study reach and profiles followed along the reach during bathymetric surveys and discharge of the Loire at Saumur gauging station (located about 30 km upstream, mean discharge = 680 $m^3.s^{-1}$) with bathymetric surveys.

4 RESULTS

During low flows, when present on stoss sides of bars, dunes are small (about 1.4 m long and 0.04 m height). During flood events, the height of dunes is about 0.2 m and the wavelength is about 4.4 m. Mean parameters on each bar stoss side show that dune height and length increase with the water depth (Figure 5). Mean water depth gradually decrease from banks to the center of the channel. Consequently, height of dunes follows the same evolution even if bedforms appears to be more asymmetric where mean depth is higher (left bank). These observations are in line with predictive models of dune height based on water depth (e.g. Yalin 1964) even if those models overestimate the height of dunes (Figure 5).

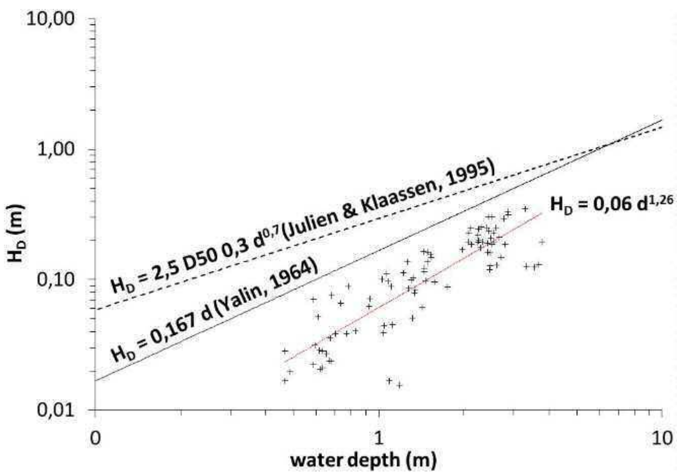

Figure 5. Relationship between mean flow depth and mean dune height for each bar. Comparison models by Yalin (1964) and Julien & Klaassen (1995).

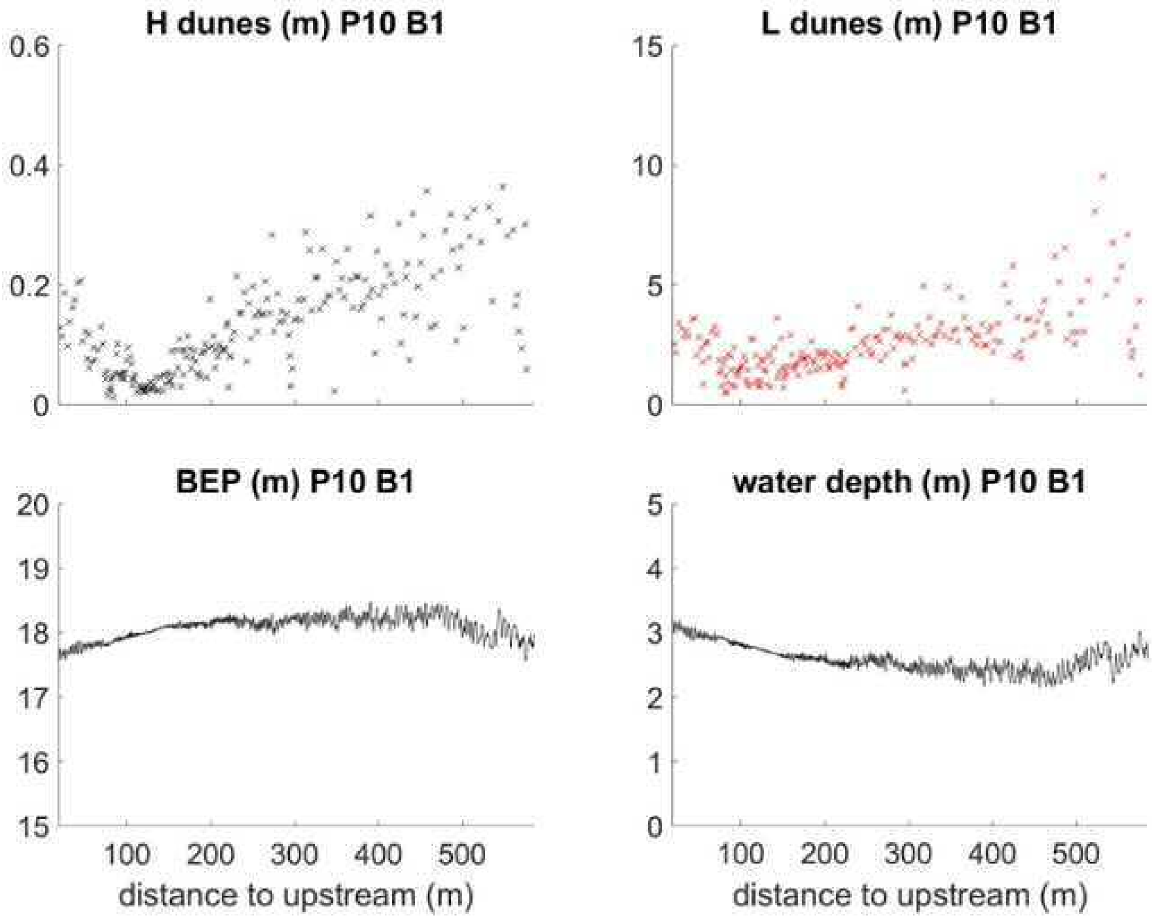

Figure 6. Evolution of dunes geometry along the stoss side of bar B1 on profile P10 (see figure 4) during the survey of 10/03/2017 (discharge at Saumur was 1740 $m^3.s^{-1}$).

By a closer look, we consider one survey during a flood event (Figure 4, 10/03/2017). During this survey, bar in the upstream part of P10 (B1) denote that sediment availability could control dune geometry because dunes height and wavelength increase when the water depth decrease (towards the crest of the bar, see Figure 6). These observations show that the increase of dune height is not necessarily linked to water depth and suggest that other parameters are involved. For instance, dune height can also be a function of sediment supply and availability (Tuijnder et al. 2009, Claude et al. 2014). The availability of sediment depends on the presence of bars that provide a sedimentary stock/active layer that allow the formation of larger dunes near the bar crest although water depth is shallower. The position of bars between them can also affect the development of dunes on bar located downstream by decreasing sediment supply or hydraulic constraints: lee side effect (Reesink et al. 2014). Upstream of B1, bars could affect hydraulic constraints and limit dune development immediately downstream.

5 CONCLUSION

Preliminary results of this study show different behavior of dunes geometry according to their location on the stoss side of bars. It is suggested that water depth is not always the governing parameter of superimposed dune height. It could be interesting to investigate effect on steepness, in order to better understand the impact of bar on dunes geometry. Moreover, we have to investigate evolution of dunes geometry for different flood stage (Reesink et al. 2018) and take into account history of floods on bars and superimposed dunes.

6 ACKNOWLEDGEMENT

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