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Modeling the effects of plant allometry on biogeomorphic feedbacks in gravel-bed rivers

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Riparian vegetation has been long recognized as key ecosystem engineers in rivers, able to actively modify flow and sediment transport processes through a series of so-called biogeomorphic feedbacks. Plant canopy is able to divert flow and change sediment transport patterns, whereas plant roots guarantee stability and resistance to scour and uprooting. These two-way interactions can profoundly influence the co-evolution of river morphology and vegetation determining rates of vegetation encroachment and shifts between alternate stable states. Yet, tools able to predict and quantify occurrence, rate, and timescales of the biogeomorphic feedbacks are limited.

The amount of resources allocated by the plant to its above- and below-ground structures, namely canopy and roots, represents a key adaptation strategy of several riparian species to cope with disturbed environments that, in turn, changes the relative effect of the biogeomorphic feedback. It has been hypothesized that plants allocate more biomass in structures that acquires the most limiting resources. For instance, water stressed conditions often found in down-welling zone in gravel-bed rivers should be associated to a greater biomass allocation to roots, whereas up-welling zones provides enough water to plants that grow faster and should invest more on above-ground structures.

To explore and quantify the importance of these inter-dependencies on river morphology, we developed a novel eco-morpohodynamic model that simulates river morphodynmic processes by using the numerical code BASEMENT and above and below-ground dynamics of vegetation and their related biogeomorphic feedbacks. We describe vegetation with a biomass density partitioned in above- and below-ground components. We adopt the model developed by Tron et al. (2014) for describing the plant root vertical distribution depending on water level fluctuations. We then link the amount of root biomass, which is used as a proxy of water resources availability, with plant growth and allocation. We assume that plant canopy changes roughness coefficient proportionally to the above-ground biomass and that plant root distribution determines the resistance of plants to uprooting.

We apply the model to a straight river channel with alternate bars, typical of many channelized European gravel-bed rivers. We investigate the co-evolution of vegetation and river morphology by varying flow regime and plant allometry and characteristics.

The results shows that the model can reproduce different spatial distributions of vegetation on bars depending on physically-based parameters related to water level fluctuations. Plant allometry differentiates along the bar mainly depending on the elevation above the mean water level. The system shows a threshold behavior, between vegetated and un-vegetated states, reflecting a distinct signature of vegetation dynamics driven by different flow regime and plant allometry, where uprooting has a primary role among the biogeomorphic feedbacks studied.

The proposed model is able to reproduce the main features of the co-evolution of vegetation and river morphology with alternate bars and paves the road for further applications and more detail investigations on the role played by plant allometry in shaping river morphology.