Modelling feedbacks between plant morphology and hydrodynamics

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1. Introduction:

Plants divert flow and suspended sediments due to their above ground structure and hence shape coastal landscapes and riparian floodplains through biogeomorphic feedbacks (Schwarz *et al.* 2014; Corenblit *et al.* 2015). Balke et al., (2012) have shown that the outcome of such feedback mechanisms is highly conditional as vegetation presence may lead to local scour under high energy conditions whereas an increase in sedimentation only occurs during low energy conditions. Moreover flume studies have highlighted the dependence of biogeomorphic feedbacks on plant traits (e.g. rigidity and height of vegetation (Bouma *et al.* 2005; Schwarz *et al.* 2015)). Plant traits may not only vary across species but also within species due to thigmomorphogenesis. That is plant morphology adapts to increased mechanical stress, usually with increased stem diameter, reduced height and altered stiffness. This has been previously shown for trees exposed to strong winds (Braam 2004) and freshwater aquatic vegetation (Schoelynck *et al.* 2015).

2. Growth Experiments:

With the help of MASTS we have experimentally tested the effect of mechanic bending on plant growth and morphology of *Bolboschoenus maritimus*, a typical marsh pioneer in the Clyde estuary. This was achieved with a mechanical apparatus (Fig. 1) that mechanically bends the individual plants at different angles (0°,25°,30°,35°), simulating mechanical disturbance by water without affecting environmental factors. The plants were then harvested and plant traits were measured.

Fig. 1 Bending machine operated by a timer

Approximately 25cm tall Individuals of *Bolboschoenus maritimus* were collected in the field and transplanted to the greenhouse on 23.05.17. They were placed in PVC piping which would bend the plant for 3 hours at the defined angle followed by 3 hours in upright position.

Temperature and plant height were recorded throughout the growth experiment. The plants were harvested on July 5th 2017. Above ground dry weight and length of longest shoot showed significant differences between the control treatment (0°) and 30° bending angle (ANOVA, $P<0.05$) (Fig. 2).

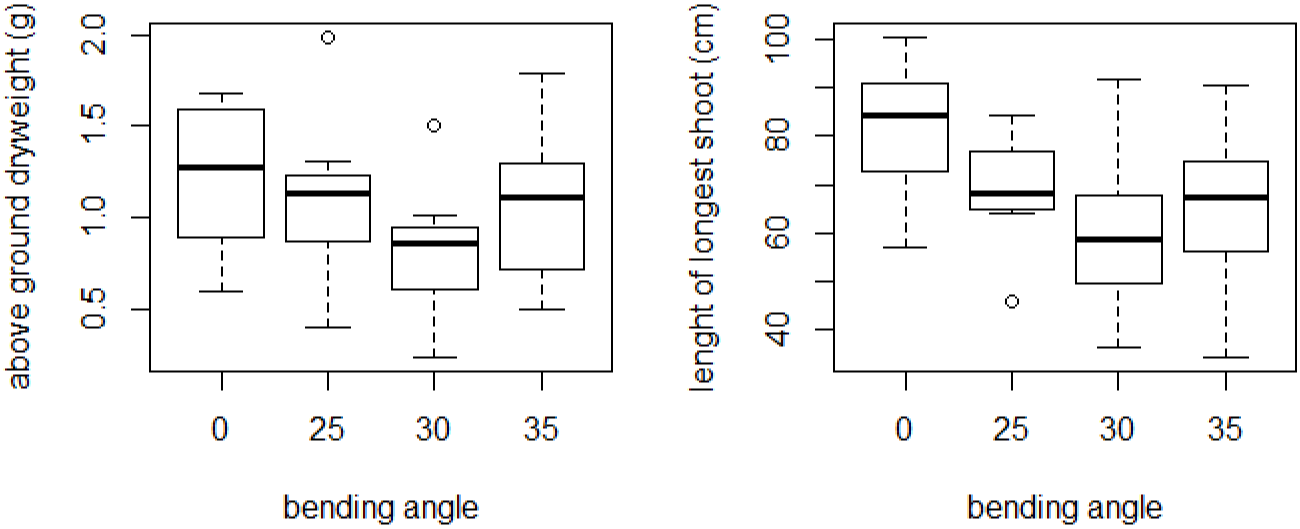


Fig. 2 Plant traits of *Bolboschoenus maritimus* at the end of the growth experiment

3. Flume Experiment:

Individuals of contrasting morphology were collected from the field to study their effects on current velocities. The flume has been separated into two parts with the aim to study the preferred flow routing. Individuals collected from the seaward edge of the marsh (right hand side of flume Fig. 3) were generally shorter and had greater shoot diameter compared to individuals collected at higher elevations (left hand side of flume Fig. 3). The growth experiments confirmed that at least the height differences can be partially explained by increased mechanical stress at the seaward edge. The flume data (Fig. 3) showed that, with a water depth of 21 cm, the shorter but thicker individuals collected from the marsh edge had a greater effect on flow reduction, especially at the upper part of the profile where the dense canopy reduced current velocities. Further flume experiments are needed to test the effect of different flow velocities on bending angle of the plants where it is expected that the plants with smaller diameter would bend more easily. The maximum water depth of the flume was reached and hence fully submerged flow conditions were not tested.

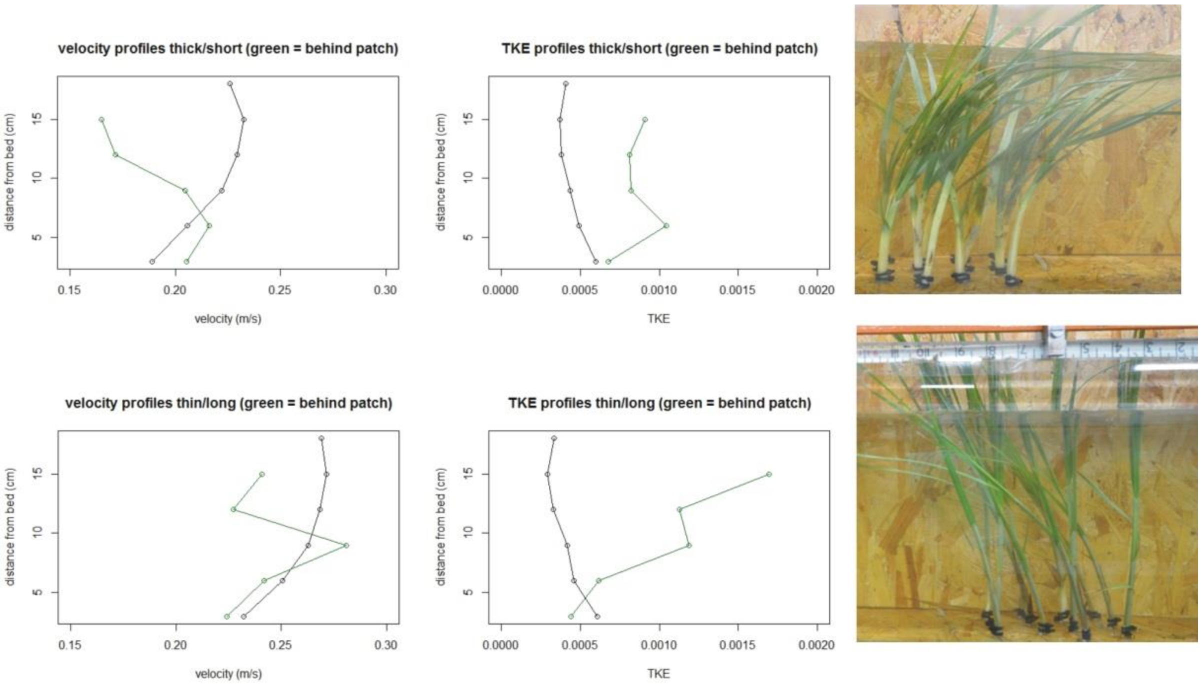


Fig. 3 Flume experiments with contrasting plant morphology (thin and long vs. thick and short). Velocity profiles were measured in front of and behind the vegetation patch.

4. Numerical Modelling:

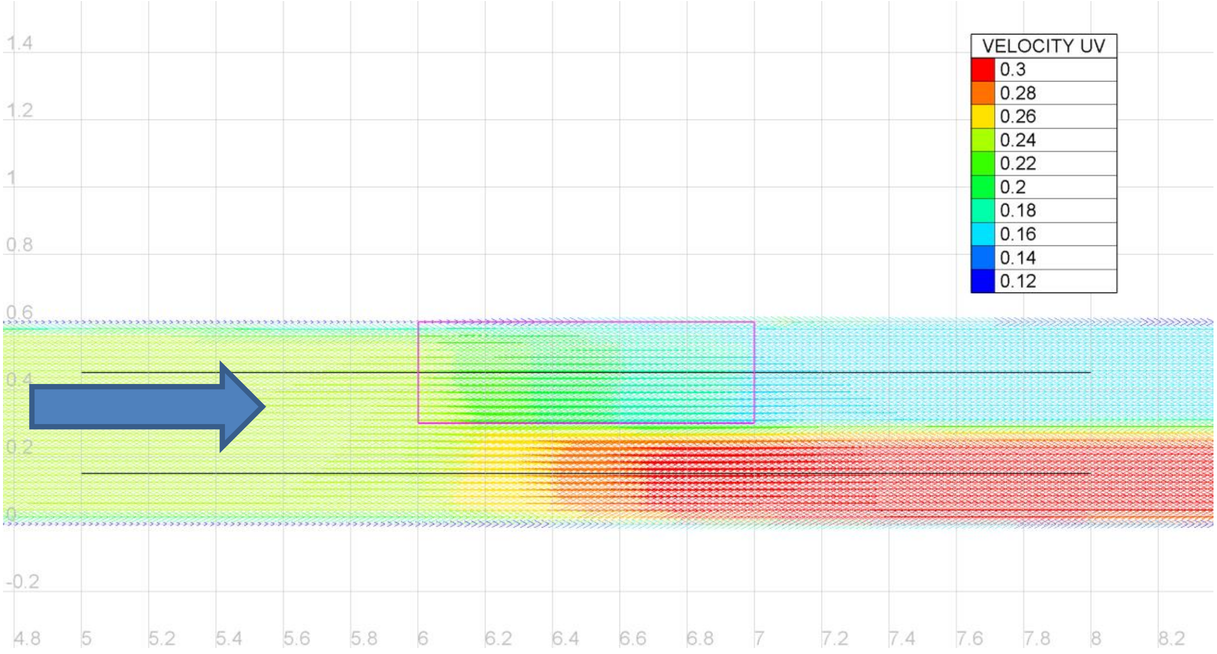
We used the flow module TELEMAC2D to investigate the effect of thigmomorphogenetic adaptation on flow routing during a flume experiment with unidirectional flow. The model solves the 2D depth-averaged equations for momentum and continuity for unsteady incompressible turbulent flow (shallow water equations) on an unstructured grid using finite element spatial discretization (Hervouet, 2007; Villaret et al., 2013). The effect of aboveground plant structures on flow was incorporated by following the approach of (Baptist et al., 2007). This method treats vegetation stems as uniformly spaced rigid vertical cylinders, where flow velocity through the stems is assumed to be uniform within the vegetation after passing the vegetated-unvegetated boundary. The effect of vegetation is parameterized through the flow resistance, with separate expressions for flow resistance due to sub-merged and non-submerged vegetation. The extra drag force exerted by vegetation results in momentum loss, which subsequently leads to flow deviation around vegetated areas.

In a first step we show the effect of thigomorphogenetic adaptation by comparing plants with the same volume of biomass per square meter but different densities and different stem diameters. Previous studies on thigmomorphogenetic adaptations have shown that increased stress for instance at vegetation edges can lead to compacted growth forms with increased stem diameter, reduced density and potentially reduced plant height.

The following scenarios were compared:

Velo_1p: 1 Plant Species (sp1) in purple square

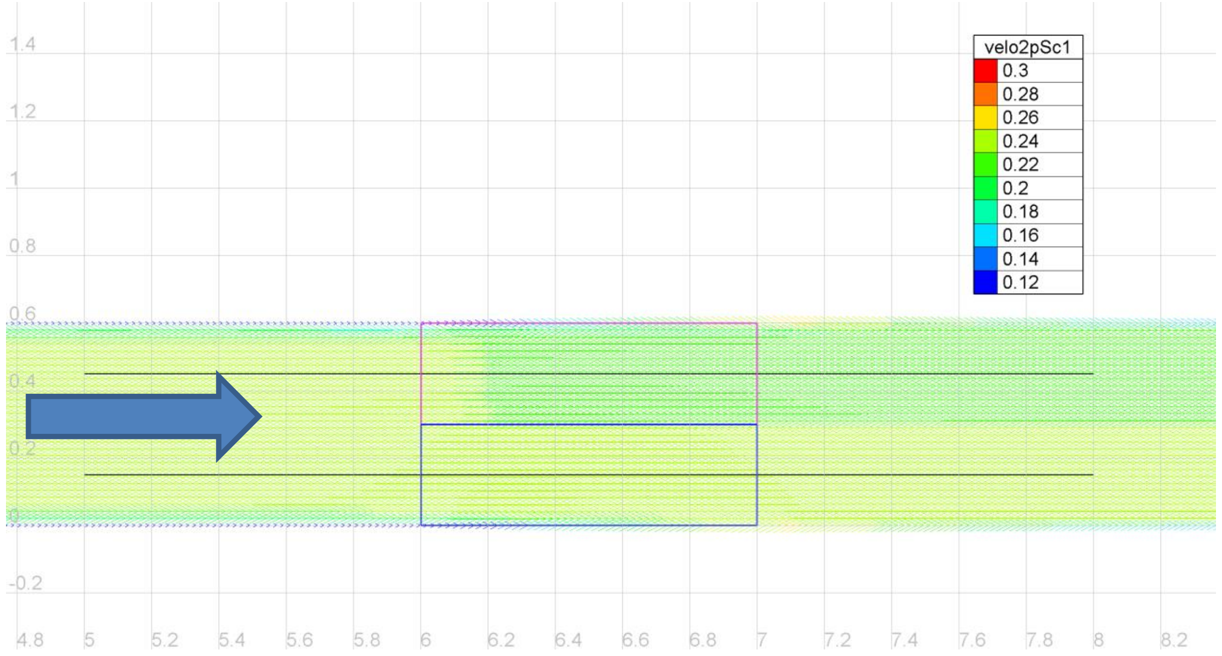
(sp1):400stems/m2; plant height 0.37m; Dragcoeff: 1.13; stem diameter:5 mm, , Volplant: 0.0026 m^3 stems/m^2



Velo2pSc1: 2 Plant Species (sp1) in purple square, (sp2) in dark blue square

(sp1):400stems/m2; plant height 0.37m; Dragcoeff: 1.13; stem diameter:5 mm, Volplant: 0.0026 m^3 stems/m^2

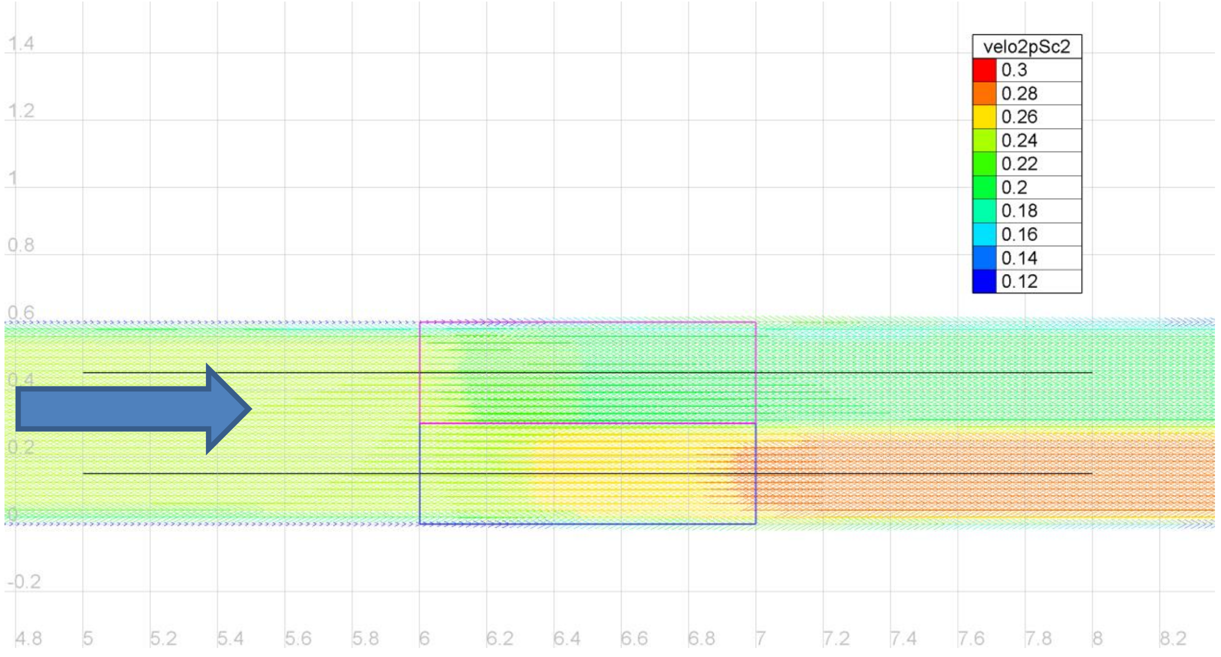
(sp2): 200stems/m2; plant height 0.37m; Dragcoeff: 1.13; stem diameter:7.1 mm, Volplant: 0.0026 m^3 stems/m^2

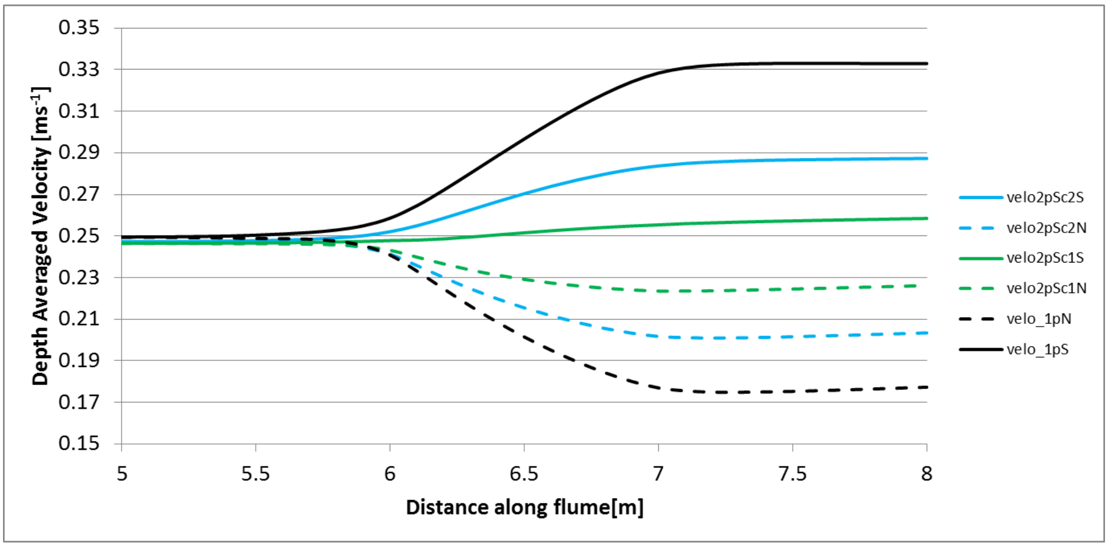


Velo2pSc2: 2 Plant Species (sp1) in purple square, (sp2) in dark blue square

(sp1):400stems/m2; plant height 0.37m; Dragcoeff: 1.13; stem diameter:5 mm, Volplant: 0.0026 m^3 stems/m^2

(sp2): 50stems/m2; plant height 0.37m; Dragcoeff: 1.13; stem diameter:14.2 mm, Volplant: 0.0026 m^3 stems/m^2





Above we show a comparison between the 3 scenarios along the two in the graphs indicated long-flume transects (N represents the upper transect, S represents the lower transect). As expected by using 1 plant patch to block out the flume the flow velocity within the patch is reduced (0.175 m/s) and velocity accelerated in the gap(0.333 m/s). Furthermore two vegetated patches were compared, representing different thigmomorphogentic adaptations. Adaptations were shown by comparing the same volume of biomass per square meter, but differently spread out, the closer the density(400 stems/m2; 200 stems/m2) between the two patches the more the velocity is slowed down without the establishment of a preferential flow direction (**Velo2pSc1**)(0.258 m/s; 0.226 m/s). However increasing the difference in density (and diameter) between the 2 patches results again in a clear preferential flow direction (**Velo2pSc2**)(0.287 m/s; 0.203m/s).

This comparison clearly shows the effect of thigmomorphogenesis on flow routing.

As a next step the static comparison needs to be changed into a coupled thigmomorphogenetic model, where the above shown adaptations (reduction in stem density and increase in stem diameter) need to be dynamically linked to the incoming flow velocity and subsequently adapting to it, resulting in a configuration optimizing stress avoidance. However for this step additional flume experiments need to be performed to calibrate flow dependent thigmomorphogenetic adaptation.

5. Future steps:

This research grant provided by MASTS has enabled us to build an experimental setup testing plant morphological adaptations across a range of mechanical bending stresses. We have provided a proof of concept that a) plant morphology is affected by bending stress, b) plant morphological adaptations to mechanical stress feeds back to preferred flow routing and hence distribution of mechanical stress and c) that this feedback mechanism can be modelled using numerical modelling. We will now carry out further experiments with different species to proof the general importance of this mechanism across ecosystems and will further parameterize and develop the numerical model. This may only be possible with further funding and we will seek to apply for additional collaborative research grants in the near future.

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