DISTINCT PATTERNS OF INTERACTIONS BETWEEN VEGETATION AND RIVER MORPHOLOGY

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Modelling vegetation and morphodynamics is often one-way traffic that either takes into account the effect of vegetation on morphodynamics or vice versa. The few models that do incorporate an interaction have until now represented vegetation as cylinders causing hydraulic resistance that do not change over time. We coupled a morphodynamic model to a dynamic vegetation model, tested two vegetation scenarios with different functional trait sets and compared them to a control scenario without vegetation. Vegetation was modelled as either static softwood forest or dynamic riparian trees of different age, dimensions, density, settling conditions and flooding/desiccation tolerances. Results show that vegetation restricts lateral migration and static vegetation also restricts longitudinal migration. Dynamic vegetation results in more realistic vegetation patterns and fluvial morphology than static vegetation. This shows the importance of including dynamic vegetation in morphodynamic models.

1 BACKGROUND

In a dynamically meandering river vegetation interacts with flow and sediment. The pattern of vegetation on the floodplain is determined by hydro-morphological tolerances which in turn are determined by species specific traits (Gurnell *et al.* 2012). Processes at different scales (ecological, hydrological and morphological) interact and create a patchy, young vegetation pattern on the point bar close to the channel and older, denser vegetation higher on the floodplain (Figure 1A, (Corenblit *et al.* 2007)).

Modelling these processes at the right scales gives insight in the interaction between vegetation and morphodynamics and contributes to the design and long-term prediction of ecological rehabilitation measures. But advances in modelling have until recently only been one-way traffic either looking at the effect of vegetation on morphodynamics (Murray & Paola 2003) or the other way around (Ahn et al. 2007). The few models that do explicitly incorporate the interaction between vegetation and morphodynamics have until now represented vegetation as rigid cylinders causing hydraulic resistance that do not change over time (Perucca *et al*. 2007; Nicholas 2013; Crosato & Saleh 2011).

Here we present a dynamic vegetation model coupled to a morphodynamic model. We included multiple vegetation types with species traits changing in different life-stages when vegetation grows. Vegetation can colonize, grow, die and interact with the flow. We investigate the hypothesis that dynamic vegetation creates more realistic patterns in vegetation and fluvial morphology than the ‘old fashioned’ static vegetation. We compare a reference scenario without vegetation to a scenario with static vegetation and an innovative dynamic vegetation scenario.

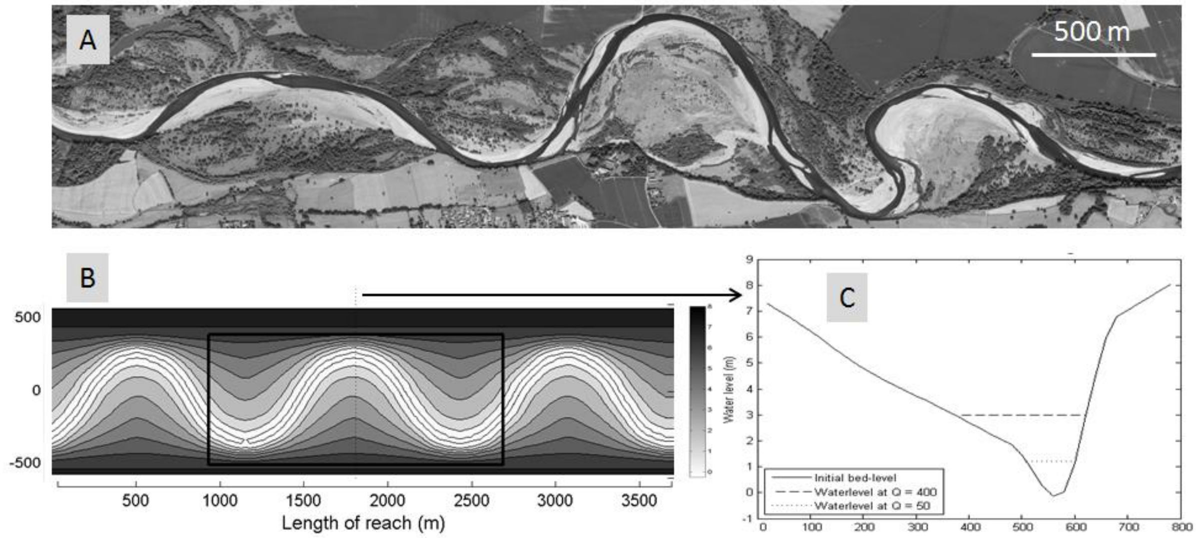

Figure 1. A) Allier river in France, B) idealized model schematization based on average geometry of the Allier river. Box indicates area for which results are presented (Figure 3). The dotted line in B) is location of cross-section in C).

2 METHODS

2.1 General model set-up and scenarios

We coupled the morphodynamic model Delft3D to a new dynamic vegetation model. The morphodynamic model was designed to represent average morphodynamic characteristics of the Allier river in France (Figure 1A, 1B). Non uniform discharge was used with monthly discharges for 5 different years randomly distributed over the total simulation time (but equal for each scenario). The general shape and magnitude of the hydrograph are comparable to the hydrograph of the Allier. The model was run on a grid of 1000 by 3600 metres with grid cell sizes of 25 x 25 m (Figure 1B). The vegetation model interacted with the morphodynamic model through hydraulic resistance at user-defined ecological time steps. We defined two vegetation types with different functional properties in different life stages (Table 1). The total simulation time was 150 years, enough to simulate at least one life cycle of riparian trees.

Three scenarios were tested: 1) No Vegetation, which is the control run of the morphodynamic model without vegetation, 2) Static Vegetation, where vegetation could colonize and cause flow resistance but did not grow or die, and 3) Dynamic Vegetation, where vegetation colonized, grew and died with time-dependent flow resistance. The vegetation types are loosely based on riparian tree Salicaceae species with ecosystem engineering properties. We have defined a Salix-type and a Populus-type with differences in life span, dispersal timing and mortality thresholds for dry and wet conditions, particularly in that Salix prefers wetter conditions than Populus.

2.2 Vegetation processes

The vegetation model includes three classes of vegetation processes: colonization, growth and mortality. Colonization takes place depending on the timing of seed dispersal and the water levels during that period. We assume unlimited seed supply, which is a realistic assumption for dominant riparian trees with a high number of seeds. The location for colonization is on bare substrate between the highest and lowest water levels during the annual dispersal period. Growth of vegetation is calculated based on initial shoot size and diameter and a growth increment per year (Figure 2). When the vegetation survives, its age increases each subsequent year until the maximum age is reached. Depending on the life stage which is related to age, the characteristics of the vegetation types are different. Multiple vegetation types of different ages can reside in one grid cell. But when the grid cell is fully covered, no vegetation is allowed to settle anymore. Death of vegetation clears space for settlement of new vegetation. Mortality of vegetation depends on days of subsequent flooding, days of subsequent desiccation or high flow velocities. It is implemented as a function containing a threshold value and a slope. When the threshold value is exceeded, vegetation starts to die with a magnitude determined by the slope. Total mortality is calculated at the end of each year.

Table 1. Parameterization of vegetation model for the ‘Static Vegetation’ and ‘Dynamic Vegetation’ scenario.

General parameters	**Static vegetation**		**Dynamic vegetation**	
	Salix type	**Populus**	**Salix type**	**Populus**
Maximum age (years)	None	None	60	150
Number of life-stages	1	1	4	4
Initial shoot height (m)	2.12	18.9	0.25	0.1
Initial stem diameter (m)	0.212	0.252	0.002	0.036
Timing of seed dispersal (months)	5, 6	5	5, 6	5
Life stage specific parameters				
Shoot growth increment (m/year)*	0	0	0.37	1.75
Stem diameter growth increment (m/year)*	0	0	0.028	0.036
Mortality threshold flooding, desiccation (days) ,flow velocity velocity (m/s)	365,365,20	365,365,20	150,75,5	110,120,5
Number of stems (no/m^2)*	15	13	13	13
Drag coefficient *	1.5	1.5	1.3	1.3

* Average over all life stages for dynamic vegetation

At each ecological time step the flow resistance caused by vegetation in each cell is calculated with the equation for flow through and above vegetation derived by Baptist (2005, Eq 1):

$$C = \frac{1}{\sqrt{\frac{1}{C_b^2} + \frac{C_D n h_v}{2g}}} + \frac{\sqrt{g}}{\kappa}\ln\left(\frac{h}{h_v}\right) \quad (1)$$

Where C is the Chezy value of the vegetation (m$^{1/2}$/s), C_b is the Chezy value for the un-vegetated parts, C_D is the drag coefficient, n is the vegetation density (stem diameter x number of stems /m^2), h_v is the height of the vegetation (m), h is the water depth (m), κ is the Karman constant (0.41) and g is the gravitational force (9.81 m/s). Because multiple vegetation types with different ages and different properties can occur in one grid-cell, the Chezy value is calculated for each fraction separately and subsequently the total sequential Chezy coefficient is calculated weighted by fraction coverage.

3 RESULTS

Figure 3 shows the results after the simulation. There are distinct differences in fluvial morphology between the scenarios after 150 years. In particular the dynamic vegetation scenario has a more patchy distribution of vegetation and bed level change. Both scenarios with vegetation reduce lateral migration and produce local differences in erosion and sedimentation patterns. The scenario without vegetation is tending towards a braided planform while the scenario with dynamic vegetation has a clearly meander-like pattern. The cumulative erosion/sedimentation in the scenario without vegetation is higher than in the scenarios with vegetation (results not shown) which is in line with the development of a braided planform. In the static vegetation scenario the meanders do not migrate or change shape while in the scenario with dynamic vegetation the meanders are clearly migrating downstream and sharper bends develop.

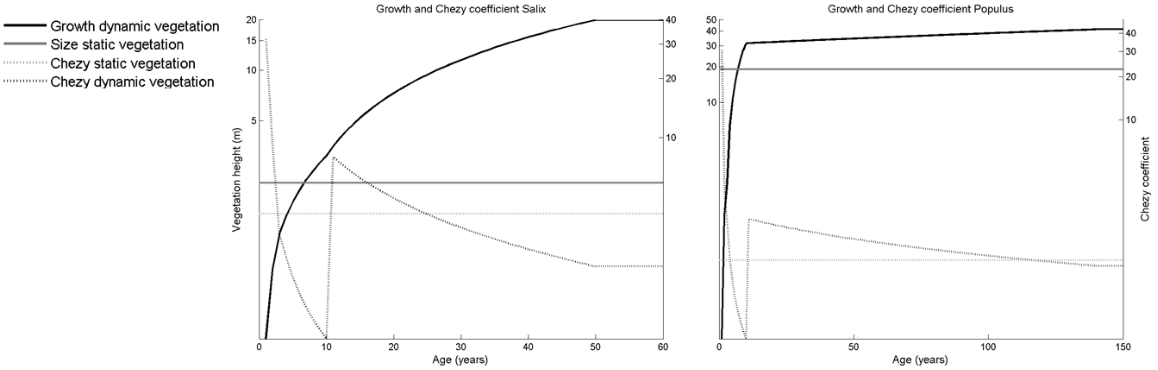

Figure 2. Growth of vegetation types over time with corresponding Chezy coefficients at average water level (1m) for ‘Static vegetation’ and ‘Dynamic vegetation’. Left: Salix type, Right: Populus type.

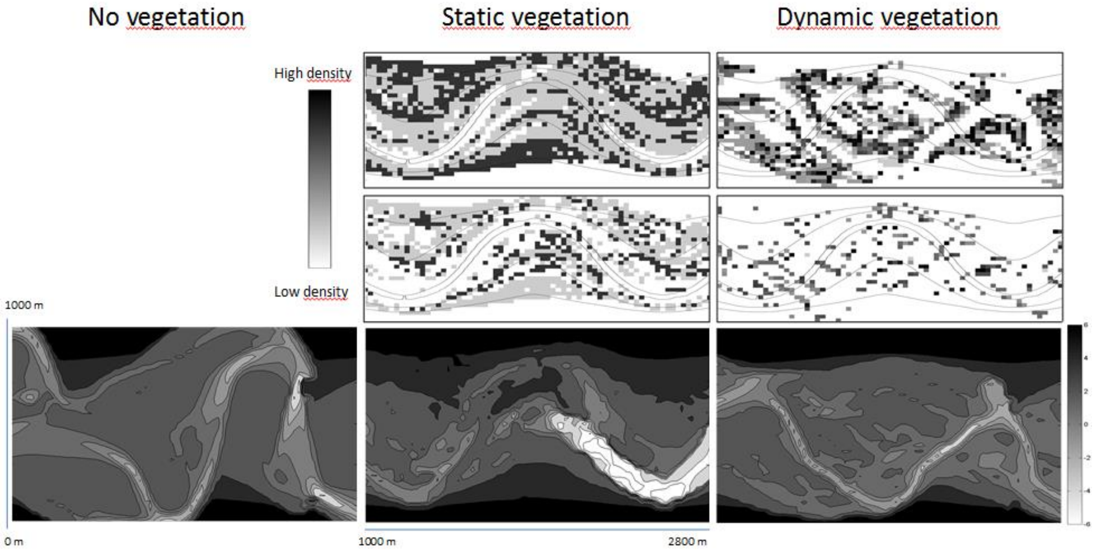

Figure 3. Left: ‘No vegetation’ scenario, Middle: ‘Static vegetation’ scenario, Right: ‘Dynamic vegetation’ scenario. Top: vegetation settlement location and density of vegetation types (Top: Salix type, Bottom: Populus type), Bottom: bed level de-trended with slope.

4 DISCUSSION AND CONCLUSIONS

Results show that vegetation reduces the lateral migration of the channel. This is in line with previous modelling work and flume experiments showing that vegetation changes river planform from multi-thread to single-thread channels (Murray & Paola 2003; Crosato & Saleh 2011). Static vegetation also reduces longitudinal migration as the channel is fixed by un-removable vegetation. This can also cause a more chaotic bed level pattern with large incisions and higher patches. At high discharge strong backwater effects create large differences in erosion and sedimentation patterns on the floodplain (Figure 3). Dynamic vegetation creates a patchy landscape which resembles the natural pattern more than the static vegetation (Figure 1A). Meanders migrate downstream and the bed level gradient on the point bars is more gradual.

The three scenarios show distinct differences in fluvial morphology. We show that inclusion of dynamic vegetation processes in morphodynamic models creates more realistic vegetation patterns and river morphology than static vegetation. This demonstrates the importance of including vegetation dynamics into morphodynamic models. We are extending the work to include more vegetation processes and vegetation types and investigate key processes of interaction to support design and evaluation of ecological restoration measures.

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