5. Macrophytes in Estuarine Gradients

Jasper Dijkstra[1]

[1] Delft University of Technology, Civil Engineering and Geosciences, Stevinweg 1 2628 CN Delft, the Netherlands, email: j.t.dijkstra@tudelft.nl

Present address: Deltares, P.O. Box 177, 2600 MH Delft, the Netherlands, email: jasper.dijkstra@deltares.nl

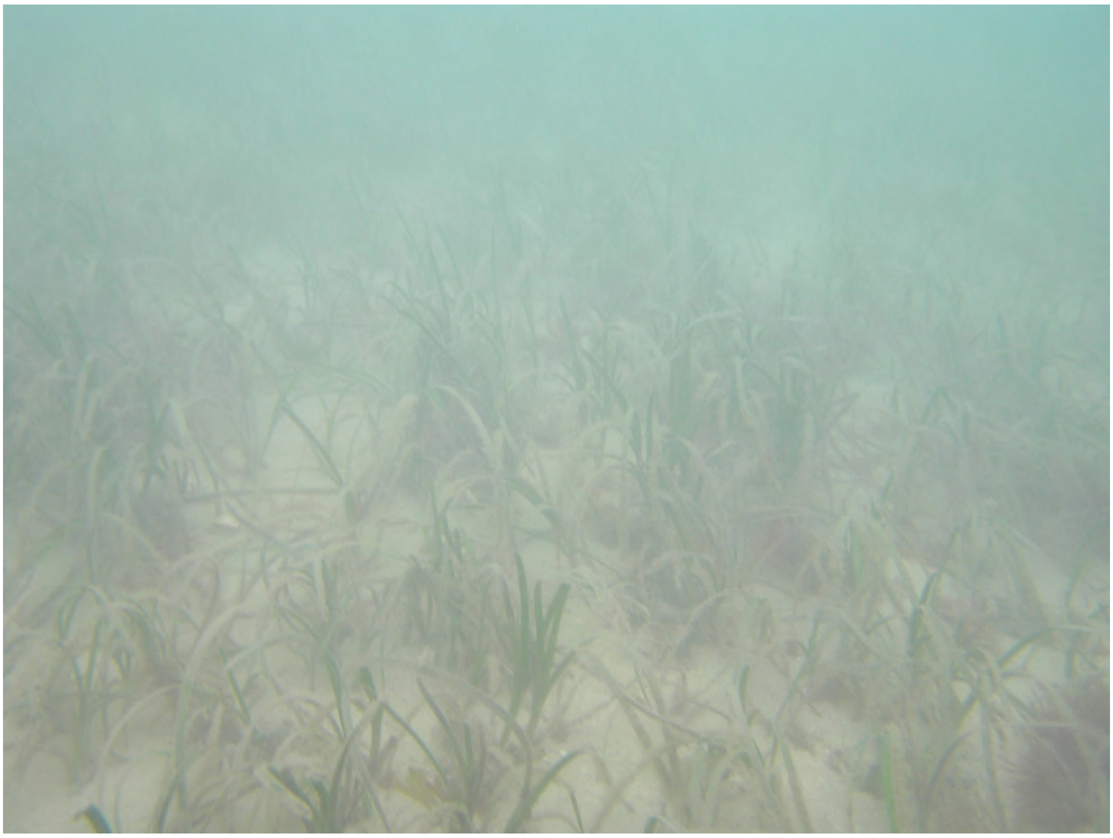

Fig. B-5.1: *Macrophytes*

Abstract

To study the interaction of estuarine vegetation with its environment, a physics-based model was developed and validated, accounting for the flexibility of plants. Using this model, the eco-engineering capacities of seagrasses and cordgrass in similar conditions were compared and breaking strategies of salt marsh plants were investigated on a local spatial scale. On a larger scale, the sediment transport patterns in a seagrass-covered bay and the long-term development of an intertidal flat in the presence of stiff and flexible vegetation were studied. To assess the potential for survival of eelgrass, for which water clarity is important, the developed biogeomorphological model was coupled to a model for eelgrass growth.

Accounting for flexibility of vegetation is important, especially in local-scale studies. The actual eco-engineering capacity of plants depends on the combination of plant properties like density, shape and stiffness as well as the environmental conditions depth and flow velocity.

i. Problem

Macrophytes in estuaries are often considered to be 'eco-engineers'. By their presence they alter their environment in a way favourable to themselves or to other organisms. By doing so, these plants provide important functions to the estuarine ecosystem. For example, aquatic plants can stabilize the seabed, decrease turbidity by trapping sediment, reduce waves and provide a food source as well as a shelter to many animals. This feedback between plant presence and environment is probably crucial to their own existence in some situations: without plants the conditions are to tough to survive, with plants the conditions are sufficiently toned down to be endured. Such mechanisms support the existence of alternative stable states (Scheffer et al., 2001) and are relevant for the protection and possible restoration of macrophyte populations.

The difficulty however, is to express these feedbacks quantitatively: by how much is the turbidity decreased, how much is the bed stabilised? Because the strength of these effects not only depends on plant properties like biomass, length and flexibility but also on environmental properties like water depth, flow velocity and sediment composition, purely experimental research would only cover a small part of the situations that occur in the field.

ii. Aim and approach

The aim of this study therefore was to develop a generic, process-based computational model that can be used to quantify feedbacks between aquatic vegetation and its environment.

In order to incorporate the effect of macrophytes on flow, a model for the interaction between flow and flexible vegetation was developed: Dynveg (Dijkstra and Uittenbogaard, in press). Dynveg uses a finite-element approach to calculate the position of a plant and the hydrodynamic forces acting on it, based on measurable plant properties such as stem thickness, length, buoyancy and elasticity.

Subsequently, Dynveg was linked to Delft3D (Lesser et al., 2004), which is able to simulate flow, waves and sediment transport in estuarine –but also riverine and coastal- areas well. This link was made by adapting the height and the drag coefficient of the stiff vegetation already present in Delft3D, according to the actual depth and flow velocity, thus representing flexible plants.

After validation of this combined model (Dijkstra, 2008), several studies have been performed. The first of these studies compared the local eco-engineering properties of three different species that occur at similar depth zones in estuaries (Dijkstra and Bouma, in prep.). The species used were the long and flexible, sparse seagrass Zostera marina, the short and flexible seagrass Zostera noltii that occurs in high densities and the practically stiff cordgrass Spartina anglica. The reduction of the bed shear stress, reduction of flow velocity and the canopy flux were used as proxies for the eco-engineering capacity of a meadow.

In a second study, eight salt marsh species along a depth gradient were compared based on a 'bend or break' strategy: in low but dynamic areas it is more efficient to bend under load, whereas in higher, quieter areas with more competition between species a breaking strategy is a more energy-efficient investment.

A third study compared the effect of four different vegetation configurations on sedimentation-erosion patterns in a macro-tidal bay in Brittany, France (Dijkstra, in prep.). First, the model performance was compared to field measurements on flow velocity and sediment transport in this bay. Second, the density and stiffness of the vegetation was varied to study which vegetation property affects the environment the most.

One step further, the effect of stiff Spartina versus that of flexible Zostera noltii on long-term (30 years) development of an intertidal flat in the Western Scheldt was compared by extending the Delft3D-Dynveg model with rules for vegetation growth (Bouma et al., subm.). These rules were based on inundation time and bed shear stress among other things, as calculated by the morphodynamic model.

The final study links the possibility of survival of plants to changing environmental conditions, using the changes in the Dutch Wadden Sea as an example. In this area, seagrass used to be abundant until the 1930's, when a combination of the worldwide wasting disease Labyrinhtulae zosterae, high turbidity and altered tides due to the construction of the Afsluitdijk, combined with high nutrient levels from fertilisers caused Zostera marina to disappear (Den Hartog, 1975). Several small-scale restoration attempts failed; hence it would be interesting to see if Zostera marina can survive at all in the present conditions. This work is still in progress.

iii. Results

The performance of the Dynveg-model was tested against measurements of plastic strips of different lengths and stiffness for a range of flow velocities. In all cases, the model reproduced both the forces and the positions of the strips well. A comparison with flume experiments on flow through artificial seagrass performed by Nepf and Vivoni (1999) showed that also the effect of plants on hydrodynamic properties such as turbulent kinetic energy and eddy viscosity were simulated accurately. Figure B-5.2 shows the changes in plant position and flow velocity profile for a range of environmental conditions and plant properties. At higher velocities, plants bend more (Fig. B-5.2a). For larger water depths, the plant positions are very similar but the effects of plants on the flow velocity profile becomes less (Fig. B-5.2b). Plants with a higher elasticity modulus bend less, thereby having a more pronounced effect on the velocity distribution (Fig. B-5.2c). The same occurs for a larger number of plants per area (Fig. B-5.2d).

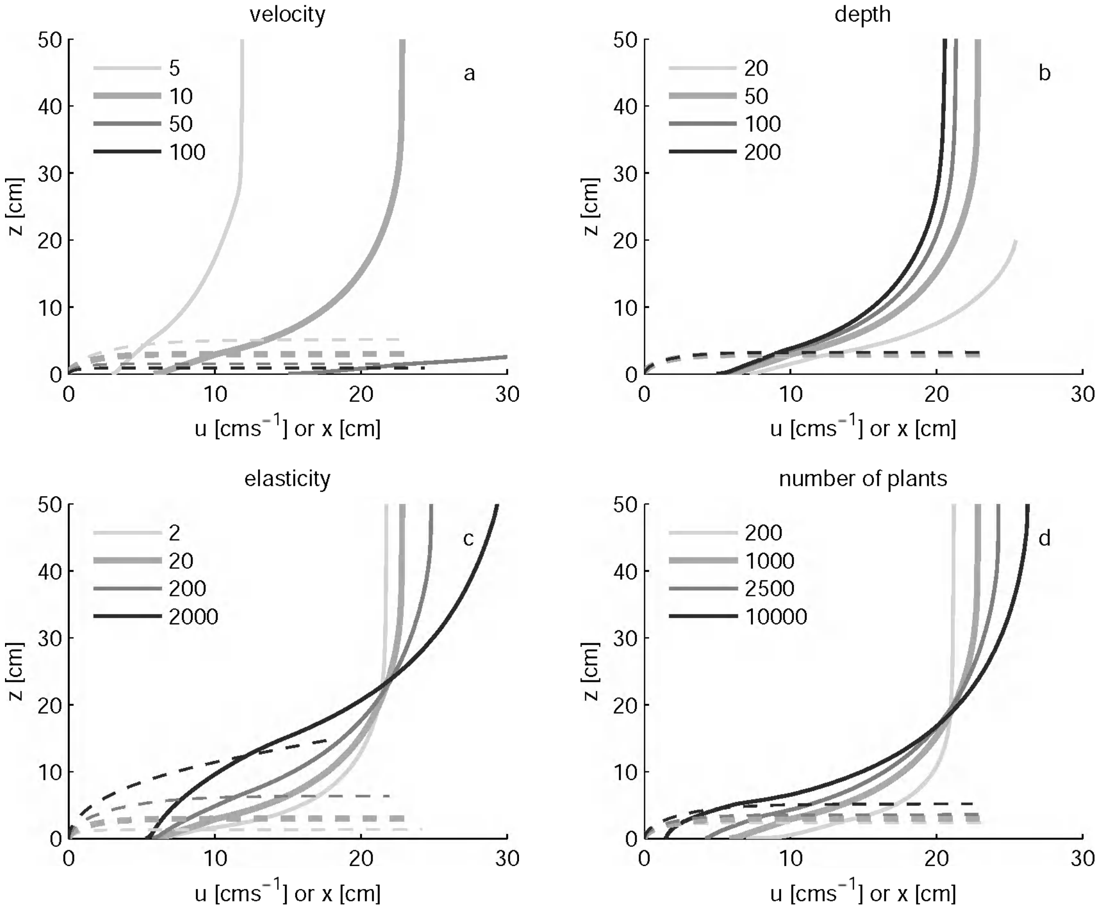

Fig. B-5.2: *Flow velocity profiles (continuous lines) and plant positions (dashed lines) in a flume for a) various depth-averaged velocities (cm.s^{-1}); b) various flow depths (cm); c) various elasticities (MPa); d) different plant densities (per m^{2}).*

The integration of Dynveg into Delft3D enabled the study of spatial adaptation patterns in meadows. As Figure B-5.2 shows, this integrated model captures the adaptation of the plant position and the velocity profile very well, for two different species. The adaptation length of meadows of Spartina, Zostera marina and Zostera noltii is rather similar, in the order of 0 to 2 meters in the most common flow conditions. The eco-engineering capacity of these species differs however (Fig. B-5.3), with Spartina having only a minor effect on bed shear stress but with a large canopy flux, whereas Z. noltii strongly reduces the bed shear stress and has a small canopy flux, indicating a strong potential for sediment stabilisation but little for sediment trapping.

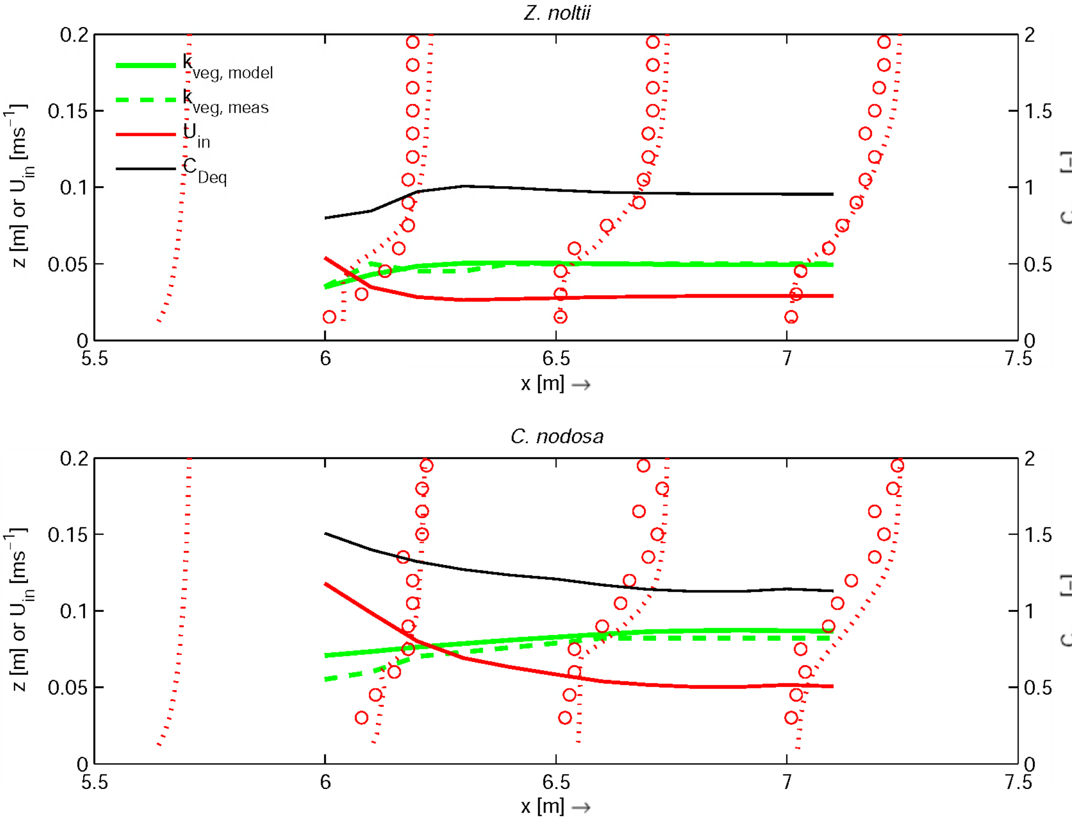

Fig. B-5.3: *Longitudinal cross-section of the flume as used by Morris et al. (2008), with hydrodynamic and plant properties predicted by the model compared to measurements. Circles and dotted vertical lines indicate measured resp. modelled flow velocity profiles. a) Zostera noltii b) Cymodocea nodosa*

The study of Bouma et al. (subm.) shows how these different eco-engineering properties affect landscape formation over several years: a tidal flat colonized by Spartina will develop into a system with several deep unvegetated channels, whereas a flat colonized by Z. noltii will be densely and uniformly covered with plants.

Similarly, the sedimentation patterns in and around a bay differ according to the type of vegetation present (Fig. B-5.4): a rather sparse canopy (RV in Fig. B-5.4) captures some of the sediment and stabilises it, giving the highest import into the bay. If no vegetation is present (NV), sediment is eroded too, whereas dense or stiff (FV resp. SV) vegetation prevents some of the sediment from entering the bay. The fine sediment fraction, which is suspended throughout the entire water column, is less affected by the presence of plants than coarser sediments, which are transported close to the bed.

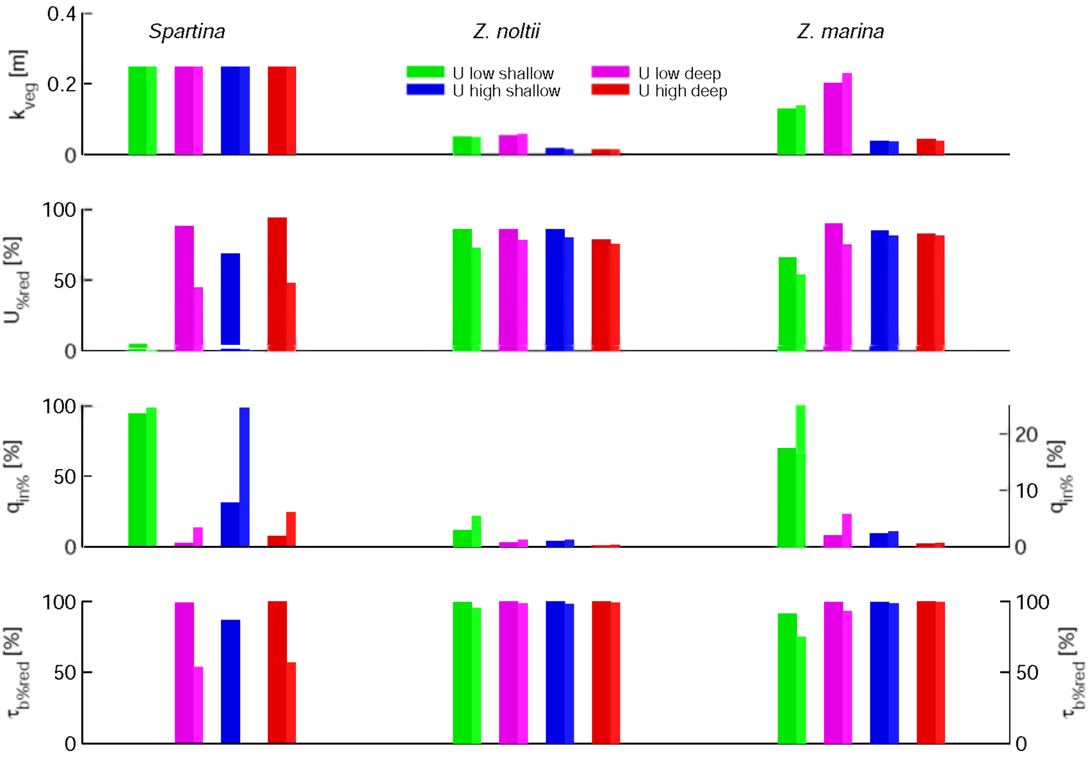

Fig. B-5.4: *Relative performance of the eco-engineering performance of Spartina, Z. marina and Z. noltii. U%red means percentage of reduction with respect to d.a. velocity, qin% the canopy flux as percentage of total discharge, τb%red is percentage reduction of bed shear stress with respect to a bare bed. For Spartina in shallow water and a low flow velocity, τb is increased instead of reduced.*

When studying the effect of different environmental conditions and the presence of seagrass itself on its growth and survival, the amount of light available for photosynthesis seems the crucial factor. Preliminary results show that the timing of the vertical tide –the water level- and the horizontal tide –flow velocity, advection of sediment- is very important. As seagrass meadows are not able to alter processes on this meta-scale, their presence might contribute only little to their chances for survival.

iv. Conclusions and recommendations

Flexible plants affect hydrodynamics in a way different from stiff plants. Dynveg is able to simulate the interaction between flow velocity and plant position well for a range of environmental conditions. Moreover, because Dynveg is based on measureable plant properties, it is generally applicable.

The coupling of Dynveg with Delft3D showed that flexible vegetation can be simulated as stiff vegetation, provided its properties are adapted according to flow conditions. The spatial gradients in meadows –i.e. the length of the leading edge- are in the order of 0-2 metres usually. Different species that occur at the same elevation have very different eco-engineering capacities. Therefore, these eco-engineering capacities cannot simply be related to the amount of biomass per square metre or the leaf area index.

Application of the model to real environments such as the macrotidal coast of Brittany and the mesotidal Western Scheldt show that different plant species have different effects on the development of the environment. The strength of these effects depends as much on plant properties like stiffness and density as well as on environmental properties such as the water depth and sediment characteristics. It is difficult to obtain general rules for such biogeomorphological interactions.

The survival of seagrasses seems to depend more on factors that are not affected by the presence of meadows, such as the water depth and the advection of fine sediments, than on factors that can be affected locally, such as bed stabilisation.

Two processes that can have considerable effects on plants in coastal environments are not taken into account in this study: the direct trapping of sediment particles against leaves and the reduction of wave energy. Especially the latter requires considerable attention in future studies, as it relates strongly to the survival of plants in storm conditions, sediment transport and coastal safety. Despite the fact that not all processes are incorporated in the biogeomorphological model treated above, it can be a useful tool to study ecosystem- and landscape dynamics in estuaries, rivers and coasts.

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