Measurements and modelling of the effects of seagrass meadows on flow and sediment transport in the Bay of l’Ecluse, Dinard, France

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ABSTRACT: Seagrasses are a valuable but threatened part of coastal systems. To aid restoration attempts, a model has been made to study the effect of such flexible aquatic vegetation on flow and sediment transport. Because this model needs to be tested against field results, a field experiment was undertaken around an eelgrass meadow in Dinard, France. The measurements showed larger flow velocities and higher sediment concentrations outside the meadow. The model showed similar behaviour, though the exact values differed.

1 INTRODUCTION

Seagrasses are an important part of aquatic ecosystems worldwide, but have to deal with a number of human and natural factors threatening their survival. Protection and restoration attempts are undertaken, which are costly and not always successful (e.g. Van Katwijk 2000). In many cases extensive field measurement campaigns have been performed (e.g. Gacia & Duarte 2001, Fonseca & Bell 1998), leading to useful but rather site-specific information. Modelling could help predict the result of restoration attempts in areas where seagrasses have disappeared long ago, as well as lead to a more general understanding of how plants shape the coastal environment.

Apart from the properties of the seagrass itself, hydrodynamics are the key factor in modelling: flow and waves exert stresses on the vegetation, they transport nutrients and contaminants and they govern sediment transport, which on its term determines the amount of light available for photosynthesis. To get a true representation of flow in and around an eelgrass meadow, the flexibility and buoyancy of the plants has to be taken into account. This has been successfully done at a very small scale with a computationally expensive model (see Dijkstra et al. 2006). Now, that model has been simplified and rendered useful on larger spatial scales (i.e. more than one kilometer), and requires testing.

Because useful validation data in the form of measurements on flow and sediment transport in and around meadows of flexible vegetation did not exist, a field experiment was set up in the Bay of l’Ecluse, Dinard, France. Here, flow velocities, water depth and sediment concentration were measured at two locations in field of eelgrass (*Zostera marina*) and two locations outside this field over several tidal periods. These data show some clear differences between the locations; so does the hydrodynamic model, which renders it useful for further explorations.

2 MATERIALS AND METHODS

2.1 *Field measurements*

The Baie de l’Ecluse (48°38’16’’N, 2°03’13’’W) in Dinard, France was considered as a suitable area for this field experiment because of the presence of a large eelgrass (*Zostera marina*) meadow, soft sediments, a sheltered orientation and a very large tidal amplitude that enabled us both to work from land during low tide and to measure a wide range of conditions. The experiment took place between May 1st and 8th, a time with sufficient eelgrass, usually fair weather, not too many tourists and an extreme spring tide.

For the hydrodynamic measurements, we used four frames equipped with an EMF, OBS and pressure sensor each, each pair connected to a data logger and power supply in watertight casing. Data was gathered at 4 Hz for three days in series of 15 minutes, from which the first three minutes were used to calculate an average and the last 12 were stored as raw data. Initially, three frames were placed in a vegetated transect in the prevalent ebb/flood direction, with another frame perpendicular to the middle one in a bare area, see Figure 1. All sensors were placed 10.5 cm above the bed. After a few days, the instruments from positions 1 and 3 have been relocated to positions 4 and 2 respectively, at one meter above the bed to have more data over the vertical.

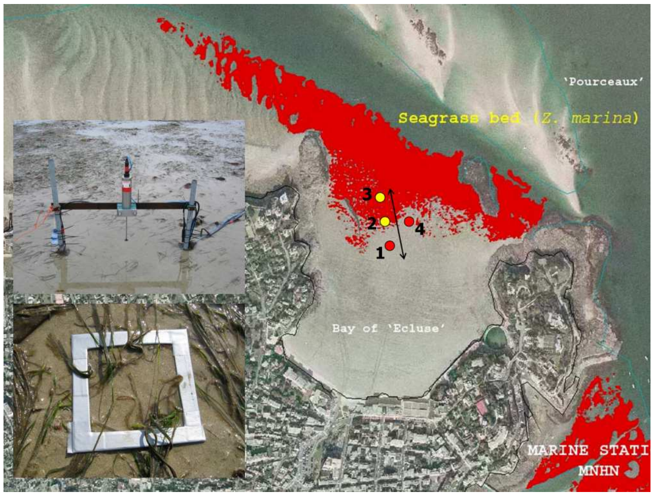

Figure 1 The Bay of Ecluse, with seagrass meadows (dark color) and the positions of the measurement frames. Inserts show a measurement frame and a seagrass sample.

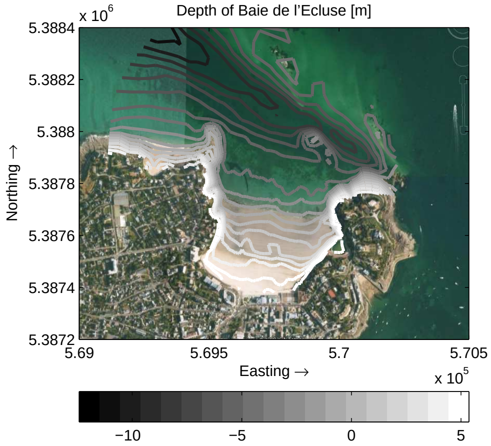

Figure 2 Depth contours of the bay as used in the hydrodynamic model.

Sediment samples were taken around the bay, and bottles were attached to the frames to collect samples for calibration of the turbidity sensors.

Further, the bathymetry of the bay has been mapped with a jetksi equipped with DGPS and an echo-sounder (see Fig. 2). Also, several vertical flow profiles have been measured with a floating ADCP. The spatial distribution and properties of the eelgrass have been determined too.

2.2 *Modelling*

Using our own measurements, plus additional bathymetry and tidal-gauge data from the Service Hydrographique et Océanographique de la Marine (SHOM), as well as eelgrass maps from the Musée National d'Histoire Naturelle (MNHN), we constructed a model for water motion and sediment transport using Delft3D. Temmerman et al. (2005) showed the applicability of Delft3D in a somewhat similar environment with stiff vegetation.

Eelgrass is very flexible; therefore we developed a code to simulate the bending of plants in currents and their feedback on flow (see Dijkstra et al. (2006)) and incorporated this in the hydrodynamic model. At an average of around 1800 leaves m^{-2} the spatial density is quite low, but other properties are comparable to usual values for eelgrass: average length 0.3 m, width 5 mm, thickness 0.35 mm and specific weight 970 kgm^{-3}. The modulus of elasticity was not measured, but considered to be the same as other seagrasses at 20 MPa.

The computational grid for the model of the Baie de l'Ecluse contains 32 by 50 cells horizontally with the smallest cells (~15 by 7 m) around the area of interest and larger ones (~60 by 40 m) farther away and 10 layers over the vertical. At the seaward boundaries, the water level recorded by the SHOM tidal gauge at St. Malo (~2 km away) has been applied with a small phase difference between the western and eastern side to mimick the tidal propagation.

3 RESULTS

3.1 *Field measurements*

Only the results for the last measurement period with just two frames are presented here. With one frame (nr. 2) inside the vegetated area, and one outside (nr. 4), this should be sufficient to give a general idea of what is happening. The graphs on the left side of Figure 3 show the measurements for this period in the vegetated area; all graphs on the right side are for the bare bed. Each data point is an average over 30 seconds.

Some remarks regarding the data for the vegetated area: 1) The settings of the pressure sensors and data logger made that high pressures were not recorded. 2) The velocity at one meter above the bed is not shown because this EMF probably drifted in this period. 3) The OBS signal close to the bed is also not shown because it gave extremely high and irregular readings, probably due to seagrass leaves swaying through the measurement volume.

The flow velocity close to the bed shows some clear peaks in both tidal periods: A first, small one when they just have become flooded, the second and largest one about one hour later and a third small one just before they run dry again. Ebb velocities are higher than those during flooding. The maximum flow velocity in the bare area is clearly higher than in the meadow. Except from these peaks, velocities close to the bed are very low in both the bare and vegetated area, so the difference between these two seems hard to tell. However, the average velocity in the bare area is 0.046 ms^{-1}, whereas this is 0.034 ms^{-1} in the vegetated area.

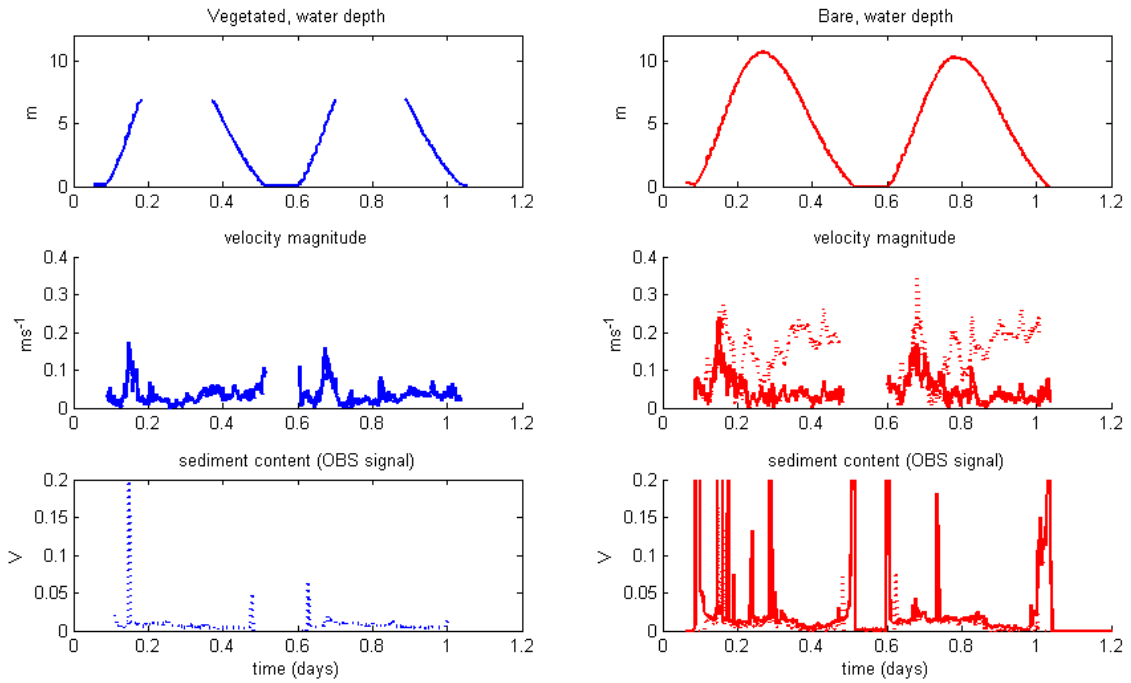

Figure 3 Measurements of water depth, flow velocity and sediment content over two tidal periods for a vegetated (position 2, left) and a bare (position 4, right) area. Continuous lines indicate values measured 10 cm above the bed, dotted lines are 1 m above the bed.

At one meter above the bed, a similar peak can be seen one hour after the onset of flooding, then velocities drop sharply to almost zero, followed by a second peak and smaller drop just before the turning of the tide. During ebb, the velocity is generally high.

Generally, the OBS signal is low, pointing to a low sediment concentration, which is in line with our observations of generally clear water. The sediment concentrations show the same peaks as the velocity at the bed. However, the sediment concentration peaks that occur when the water is shallow during ebb or flood are much bigger than those in the velocity, indicating that most of this sediment is transported from elsewhere rather than picked up locally. For the bare area both the OBS at the higher mounting and at the bed show a clearly lower signal during ebb than during flood.

3.2 *Model results*

The overall picture (see Fig. 4) shows a flow field that is comparable to the flow patterns we observed during the fieldwork: Velocities outside the bay during flood are from west to east, and quite large, whereas in the measurement area they are oriented more to the south-east and much smaller.

Looking at the measurement locations in Figure 5, the water level is very similar to the measurements. A strong similarity can also be seen in the flow velocities close to the bed (also Fig. 5): An average value around 0.04 ms^{-1}, a clear peak of about 0.2 ms^{-1} an hour and a half after flooding has begun, and a small peak just before drying. Also, the differences between the vegetated and bare site are just like the ones measured: both the peak velocity and the average velocity are slightly higher.

The sediment concentration has not been modelled because we had some difficulties in determining its properties; this is being done again but could not be incorporated here anymore.

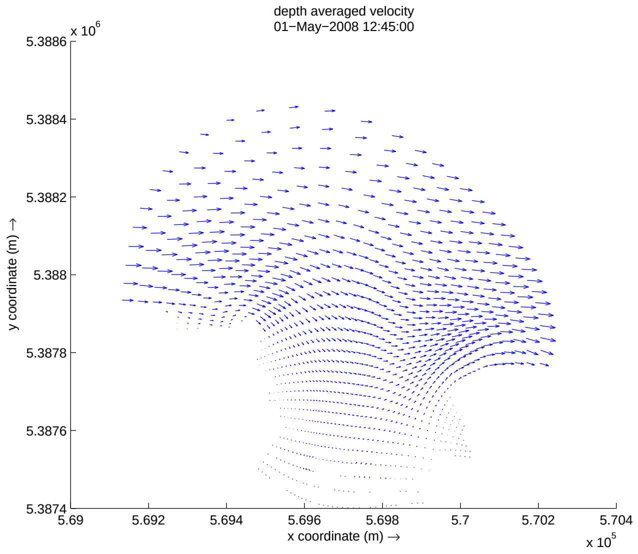

Figure 4 Model results of the flow field during flood. The largest arrows are around 1.4 ms^{-1}.

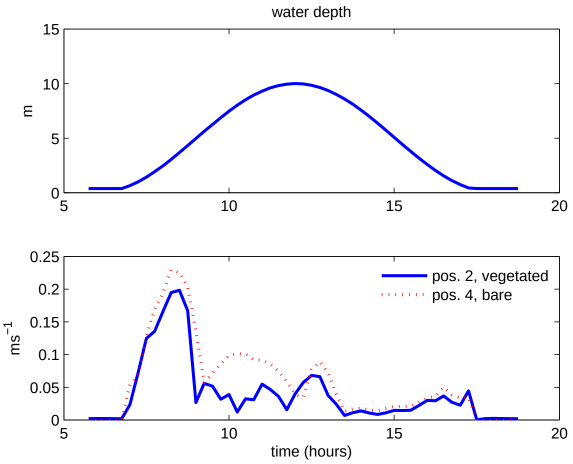

Figure 5 Model results of water depth and flow velocity close to the bed over one tidal period.

4 DISCUSSION AND CONCLUSIONS

The measurements show that flow velocities close to the bed are a bit higher in a bare area than in a vegetated area, and the model shows a very similar result. Although at the moment it is not yet possible to compare the sediment concentrations that were measured to simulated ones, the good agreement in velocities gives confidence that a proper reproduction of sediment concentrations will be possible too. Then, this model could be used to study how the morphology of the bay would change in case no seagrass was present, or in case it would be covered with even more seagrass.

Though the measured differences in flow velocity between the vegetated and bare area are clear, they cannot be ascribed with absolute certainty to the presence of vegetation alone. One could argue whether in water of more than ten metres deep at some stages, flexible vegetation with a canopy height of several centimeters has any considerable effect on hydrodynamics, and whether the differences between bare and vegetated areas described above should not simply be contributed to differences in bed topography. Therefore, the combination of field work and modelling –where some influences can be switched off- is a more solid one.

5 ACKNOWLEDGEMENTS

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