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Concurrent field measurements of turbulent velocities, plant reconfiguration and drag forces on Ranunculus penicillatus

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In lowland rivers, seasonal patterns of in-stream macrophyte growth and decay have significant implications for flood risk. For a given discharge, flood risk is increased when dense macrophyte canopies reduce flow areas, increase blockage ratios and alter reach-scale roughness values. These factors combine and can increase the flow depth. Conversely, submerged vegetation is exposed to drag forces exerted by the flow, which may be sufficient to damage limbs or dislodge plants. The classical drag equation suggests that the force exerted by fluid flows upon submerged vegetation is a function of the fluid properties, the projected area of the vegetation, and the square of the flow velocity. However, very few studies have simultaneously monitored all of these parameters, resulting in significant uncertainty in the estimation of the coefficient that relates these parameters to the drag force and also the related roughness parameters that control the flow depth for a given discharge.

To our knowledge, this study presents the first concurrent field measurements of turbulent velocities, plant reconfigurations and drag forces acting on Ranunculus penicillatus ssp. pseudofluitans (Syme) S.D.Webster. Measurements were undertaken in an artificially straightened reach of the chalk-bed River Wylye, near Longbridge Deverill, Wiltshire, UK. The reach is 5.7 m wide and during measurements there was a mean flow depth of 0.28 m and an average discharge of 0.28 m^3s-1. The reach is cleared of vegetation up to three times a year for flood defence purposes, but Ranunculus p. grows back within several weeks. Measurements were carried out after re-growth, when plants were fully developed with a mean length of 0.75 m and on average 6 nodes along the stem. The distances between the nodes increased from the base towards the tip and each node produced a capillary leaf, sometimes in conjunction with a branch. Floating leaves and flowers were not present. Plants were attached to a custom-made drag sensor that was deployed flush with the streambed. Simultaneously, a profiling Acoustic Doppler Velocimeter (Nortek Vectrino-II) was deployed 0.5 m upstream of the plants. Also, a video camera was installed with its field of view perpendicular to the mean flow direction, in order to record plant motion and reconfiguration associated with turbulent velocity and drag fluctuations. Measurements were repeated while the Vectrino-II was consecutively deployed at four vertical positions to: 1. obtain a velocity profile through the entire water column and 2. study which vertical position correlated most strongly to the drag force. Velocity measurements confirmed that turbulent structures were present throughout the water column and a response to these fluctuations was observed in the drag measurements. Responses lagged in time due to the horizontal distance between Vectrino-II and drag sensor position. Additionally, spectral analysis showed that the drag fluctuates with a frequency of 0.5 Hz which corresponds well with the undulating, quasi-sinusoidal, plant motion observed on the video footage. This motion was associated with the downstream propagation of coherent eddies.