FLOW-VEGETATION INTERACTIONS: A FIELD STUDY OF *RANUNCULUS PENICILLATUS* AT THE LARGE PATCH SCALE

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Flow-vegetation interactions occur at a wide range of scales, from the sub-leaf to the patch mosaic or river reach scale. At the larger scales, vegetation such as aquatic macrophytes can alter the flow, creating regions of enhanced or reduced turbulence and bed shear stress. This flow alteration can manifest as deposition of fine sediment in the wake region and scour in lateral regions, potentially leading to changes in river morphology. This study focuses on the spatial variation of flow variables around a large macrophyte patch in the River Urie (Scotland). Flow is quantified by a pair of synchronous Nortek Vectrino+ Acoustic Doppler Velocimeters (ADVs), while macrophyte motion is recorded by a synchronous underwater camera system. Preliminary results show reduced mean velocities, but elevated turbulent kinetic energy in the macrophyte wake, with the reduced mean velocities leading to enhanced sedimentation. Reynolds stress distributions indicate flow convergence in the wake as well as evidence of periodic bursting events. This research to experimentally determine the interactions between flow and large macrophyte patches is relevant for a wide range of applications, particularly in streams where high macrophyte densities alter flow and sediment dynamics.

1 INTRODUCTION

Flow-vegetation interactions occur over a variety of scales. However, the difficulties of conducting multiple scale studies has lead to a predominant focus on smaller scales (i.e., leaf, plant, or small patch), often using surrogate materials to approximate plant behavior [1, 2]. Since these finer scale studies have mostly been conducted in the laboratory, they may miss larger scale effects which occur in natural (field) settings. For example, in a laboratory study of *Ranunculus penicillatus* (Stream Water-crowfoot), stems were removed from a Scottish river, cut at 40 cm length and combined into macrophyte plant/patch surrogates of either 10 or 20 stems [3]. These surrogate plants correspond to either 4 or 8 total metres of stems. However, large patches found at the end of summer in Scottish rivers frequently have over 1,000 m of stems (for example the large patch in this study has over 1,200 m of stems). This represents a two orders of magnitude larger patch by total stem length than those used in laboratory studies such as [3]. Therefore, it is important to compare findings at the small scale with those obtained for large natural patches. This study attempts to address this knowledge gap by investigating the flow-vegetation interactions for a large patch of *R. penicillatus* in a turbulent cobble-bed Scottish river.

2 METHODOLOGY

A large patch of *R. penicilatus* (2.6 m length by 0.53 m width) was studied in the Urie River (NE Scotland) at the end of September 2014. All other large macrophytes were removed from the reach 65 m upstream and 35 m downstream of the patch, so that its effects on the turbulent flow could be isolated from background turbulence generated by the cobble-bed. A novel 3-axis field deployment frame for positioning two Nortek Vectrino+ ADVs was designed and manufactured as a part of this study (Figure 1: Left). The two ADVs were run as a synchronous pair so that two-point velocity correlations could be determined. Plant motion was investigated through a stereoscopic underwater camera system which used LEDs triggered from the ADV synchronisation unit to align image frames with ADV data in post processing (Figure 1: Right).

Figure 1. Left: 3-Axis positioning frame for synchronous ADVs. Right: Central plane of velocity measurements.

ADV data were recorded at 134 points located within 6 planes, with additional points in the patch wake for long duration measurements (Figure 2). The standard measurement duration at a point was 2 minutes, which was selected as a compromise between statistical robustness and experimental constraints. Longer duration measurements provide better convergence of statistical parameters such as mean velocities, variance, skewness and kurtosis, along with the ability to resolve longer period (low frequency) turbulent fluctuations. However, due to natural flow variability, the measurement time at the same river conditions is finite and thus a balance between spatial and temporal coverage must be determined. Adequate measurement duration is dependent on the number of large eddies that can pass during the measurement time. This can be evaluated under the assumption that the size of a large eddy is proportional to the flow depth, with 2 minutes duration corresponding to roughly 200 flow depths (taking average depth as 0.3 m, average velocity of 0.5 m/s and assuming Taylor's 'frozen' turbulence hypothesis [4]). Thus, for the objectives of this study 2 minutes duration is considered to be sufficient.

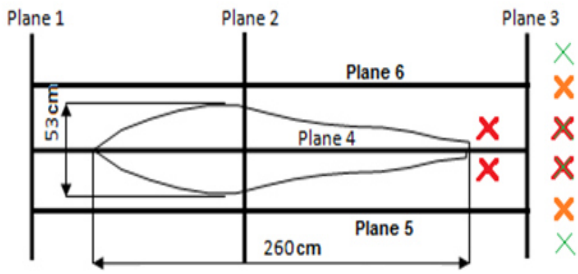

Figure 2: ADV planes (2 minute points) and longer wake pairs (Crosses: Red=10 min, Green & Orange=5 min).

Bed topography was assessed by 153 bed elevation measurements at 0.2 m grid spacing (15 points streamwise by 9 points transverse). Macrophyte geometry was determined at a higher resolution of 0.2 m by 0.05 m (150 additional data points, including edge points). As macrophytes reconfigure depending on the fluctuating velocity field and drag forces [5], the measured dimensions should be viewed as representative for the flow conditions investigated. A piezometer was used to estimate an energy slope of 0.0033 for the river reach, with repeat piezometer and water depth measurements at 30 minute intervals used to check for any changes in water level and thus discharge. Levels were found to be stable during the experimental campaign.

ADV data were despiked (Figure 3), via an implementation of the modified phase-space threshold, sample and hold (mPST-SH) technique of [6] based on the original PST technique of [7]. This technique offers superior performance at recreating power spectra of artificially contaminated data sets [6].

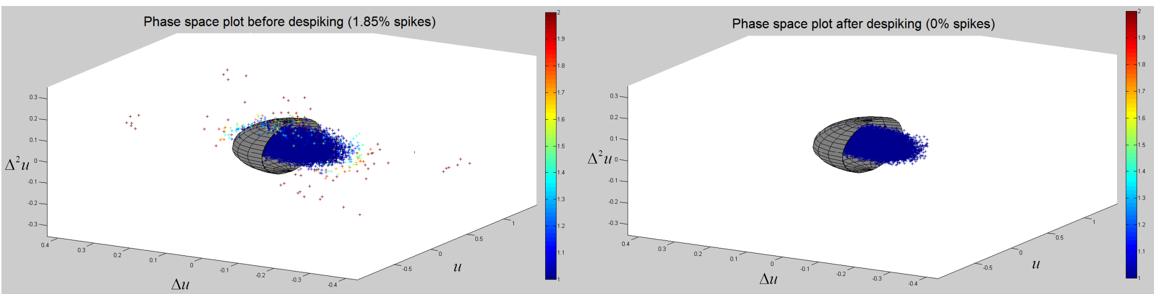

Figure 3. Example of ADV despiking (before and after) for a spike-contaminated data set (1.85% spikes).

ADV data also has inherent Doppler noise which should be corrected for where possible. Nortek Vectrino ADVs with their four receivers provide significant advantages over the previous generation 3 beam ADVs. For example, velocity components calculated from *Beam 1* & *Beam 3* (*u* and *w1*) are independent from those calculated from *Beam* 2 & *Beam* 4 (*v* and *w2*). Since noise has a Gaussian distribution with mean of zero [6], time averages of independent or uncorrelated terms obtained from the 4 beam configuration are theoretically noise free (i.e. mean velocities and the shear components of the Reynolds stress tensor).

3 RESULTS

The large patch of *R. penicillatus* caused appreciable alteration to the flow. Mean velocities were reduced in the wake region, while turbulent kinetic energy (TKE) was higher than in the patch-side shear layers (Figure 4), leading to increased values of relative turbulence intensity in the wake. Despite the high TKE and relative turbulence intensity, there was still an accumulation of fine sediment in the wake, which was not observed in the patch-side shear layers. This suggests that fine sediments were preferentially deposited in the wake and indicates that the influence of mean velocities in sediment dynamics around large macrophytes may be as important as TKE or relative turbulence intensity, if not higher.

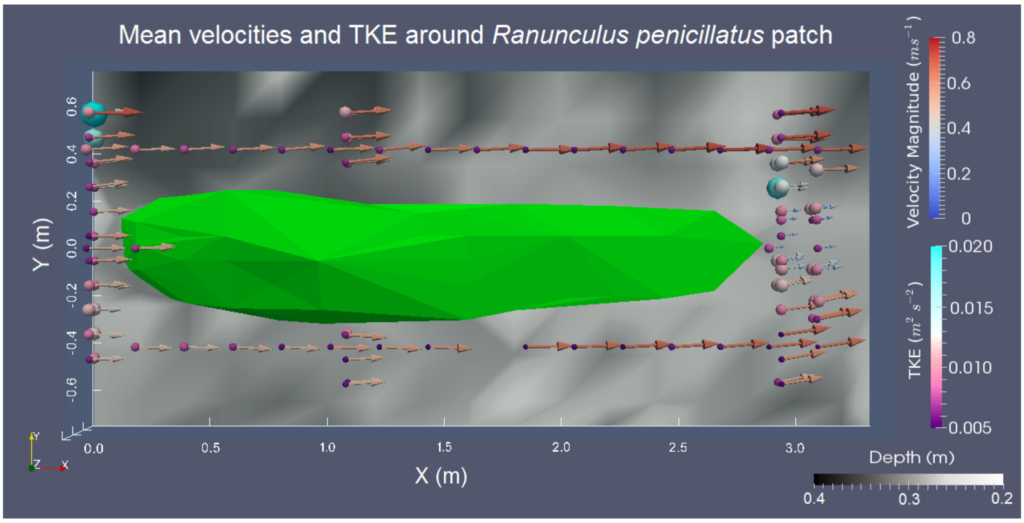

Figure 4. Mean velocities, turbulent kinetic energy (TKE), Macrophyte geometry and bed topography.

Reynolds stress distributions ($\overline{u'v'}$ and $\overline{v'w'}$ components) in the wake region indicate flow convergence and lateral turbulent transport of momentum towards the centre of the wake (Figure 5). The $\overline{v'w'}$ stress also indicates upwelling in the wake region that could be attributed to periodic bursting events which were observed in the field. Physical interpretation of the $\overline{u'w'}$ component is not as clear however, since there is significant dependence on the vertical position of the measurement points. This may be an effect of localised bed forms (gravel/cobble clusters) or macrophyte oscillation and further investigation is needed.

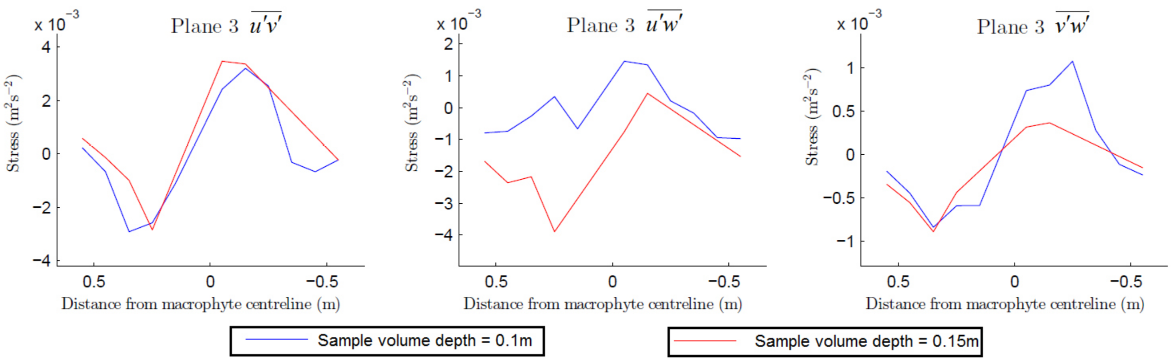

Figure 5. Lateral distributions of Reynolds stresses $\overline{u'v'}$, $\overline{u'w'}$ and $\overline{v'w'}$ in the macrophyte wake (Plane 3).

Frequency spectra were computed for planes 1 & 3, with the goal to convert these to wavenumber spectra, then analyse turbulent length scales, in front of and behind the macrophyte. However, in order to do this, Taylor's 'frozen' turbulence hypothesis [4], which states that eddies propagate downstream at the local mean velocity, has to be used. This assumption is widely accepted when relative turbulence intensities are low (less than 7% [9]); however the assumption breaks down in wake regions where mean velocities are low and relative turbulence intensities are high (greater than 100% in many cases). Therefore it is only physically valid to consider frequency spectra in these cases. Preliminary analysis of the frequency spectra indicates a redistribution of energy to higher frequencies in the wake that may correspond to stem and leaf scale turbulence. Analysis of the current data is ongoing and differences in the energy distribution at lower frequencies still need to be compared with macrophyte oscillation frequencies before causality can be inferred and the underlying physical mechanisms of energy redistribution understood.

4 CONCLUSIONS

A 3-axis system was developed to allow the deployment of two ADVs for synchronous measurements. This system was then coupled with stereoscopic underwater cameras via synchronisation lights. Preliminary results show reduced mean velocities but elevated TKE in the macrophyte wake, with the former likely leading to enhanced sedimentation. The Reynolds stress distributions indicate flow convergence in the wake and may also show evidence for periodic bursting events that were qualitatively observed in the field. Further analysis and quantification of macrophyte motion is needed before techniques such as phase averaging can be employed to couple macrophyte oscillations with turbulent fluctuations. Further analysis is also needed to investigate the redistribution of turbulent energy from upstream to downstream of the patch and compare this with the frequencies of macrophyte motion.

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