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The drag and reconfiguration experienced by five macrophytes from a lowland river

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Abstract

Drag and flexibility of five macrophytes (fresh mass 3 g) collected from the same river were measured at velocities from 0 to 0.5 m s^{-1} in a flume. Drag increased with increasing velocity for all five species examined. *Sparganium emersum* Rehmann, which has simple strap-like leaves experienced significantly less drag than the other, bushier species whilst there was no significant difference between the drag on *Callitriche stagnalis* Scop., *Ranunculus penicillatus pseudofluitans* (Syme) S.D. Webster, and *Myriophyllum spicatum* L. above 0.4 m s^{-1}. *Potamogeton x zizii* W.D.J. Koch ex Roth, which has large flat leaves, experienced significantly higher drag than all the other species. All the plants were very flexible but flexibility (as angle of bend) did not explain the drag experienced by the plants, e.g. *S. emersum* was the least flexible. The plants also changed shape and compressed (reconfigured) under increasing water velocity which reduced the rate at which drag increased. Reconfiguration capacity was assessed as *E*-values. There were no significant differences in *E*-values between species indicating that all the samples examined had a similar capacity to reconfigure. It is concluded that measurement of the drag experienced by plants is useful and may prove helpful in explaining the distribution of macrophytes in rivers.

Keywords: Drag; Reconfiguration; *Ranunculus*; *Callitriche*; *Sparganium*; *Potamogeton*; *Myriophyllum*

1. Introduction

Submerged macrophytes living in flowing water, both freshwater and marine, are subject to drag, the force or stress caused by the moving fluid surrounding an organism (Vogel, 1984), which can damage them and contribute to wash-out in rivers due to flood flows (Bilby, 1977; Sand-Jensen et al., 1999; Riis and Biggs, 2003) whilst macroalgae in marine environments are subject to violent forces of ocean swell (Friedland and Denny, 1995). Several macrophytes species are morphologically adapted to prevent this from occurring (Dawson and Robinson, 1984; Usherwood et al., 1997; Koehl and Alberte, 1988; Denny et al., 1997). In both freshwater and marine systems, plants must deal with similar forces and often have comparable strategies; they can invest in strong roots or holdfasts, be flexible and reconfigure to reduce drag (Haslam, 1978; Koehl and Alberte, 1988; Denny et al., 1997).

It is important to distinguish between actual drag and the rate of change in drag with velocity. Macrophytes may have a form which experiences low drag and they may also have a form which reduces the rate at which drag increases with increasing water velocity.

It has been shown that the forms of aquatic macrophytes which experience low drag are those with strap-like leaves, whilst those that experience high drag have broad leaves and bushy shoots (Sand-Jensen, 2003; Dawson and Robinson, 1984). Schutten and Davy (2000) also found plant form to be important; leaf width, shoot stiffness and shape, in combination, were useful predictors of a hydraulic roughness factor for a wide range of lake macrophytes.

Plants alter their shape, 'reconfigure' *sensu* (Vogel, 1994), to reduce drag in two main ways. In high flows, the stem bends downstream, and aligns with the flow reducing the frontal area and lowering the pressure drag, whilst the leaves can compress against the stem reducing the skin friction (Sand-Jensen, 2003; Ennos, 1999; Vogel, 1994). It is due to reconfiguration that drag increases with the first power of velocity for flexible freshwater macrophytes not the square of

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velocity as with ridged objects (Sand-Jensen and Pedersen, 1999; Usherwood et al., 1997).

Significantly less hydraulic resistance has been recorded in freshwater macrophytes with relatively flexible stems compared to those with relatively inflexible stems (Schutten and Davy, 2000). Dawson and Robinson (1984) recorded higher resistance in the relatively stiff *Elodea canadensis* Michx., *Potamogeton pectinatus* L. and *Potamogeton crispus* L. compared to the flexible *Ranunuculus penicillatus* (Dumort.) Bab. in their study of a lowland chalk stream.

Our aim was to compare the ability of different riverine macrophytes species to reconfigure in a flume environment.

2. Methods and materials

2.1. Plants

Five fresh water macrophyte species were selected for the study, these were: *Potamogeton x zizii*, *R. penicillatus pseudofluitans*, *Myriophyllum spicatum*, *Callitriche stagnalis* and *Sparganium emersum*. *Ranunculus penicillatus pseudofluitans* (Syme) S.D. Webster is typically found in fast flowing water and we expected it to have low drag and to be relatively better than any of the other species at reducing drag, as all the other species tested occur predominantly in slow flowing water or are habitat generalists occupying both fast and standing water. *C. stagnalis* Scop. and *M. spicatum* L. can occur in running or standing water (Preston et al., 2002) and as generalists we expected them to have poorer drag reducing abilities and suffer higher drag. *P. x zizii* W.D.J. Koch ex Roth is a hybrid of *Potamogeton lucens* L. and *Potamogeton gramineus* L. It is broad leaved and was expected to exhibit a poor ability to reduce drag and suffer from high drag. *S. emersum* Rehmann lives mainly in slow flowing waters (Preston and Croft, 2001) which suggests that it may be relatively poor at reducing drag, however it has a simple strap like shape and as such was expected to exhibit low drag.

All of the species were found in the River Frome between Dorchester and East Stoke, Dorset, UK. The river is typical of systems flowing over chalk in southern England and is described in detail in Bowes et al. (2005). The plants were stored in plastic air filled bags and refrigerated at approximately 4 °C. All measurements were taken within three days of collection. Average flow velocities at the sites where the samples were collected from, ranged between 0.062 m s^{-1} (in the Mill stream at East Stoke) and 0.331 m s^{-1} (in the main channel of the River Frome) at the time of sampling.

2.2. Flume

The flume is a re-circulating system with an experimental channel 15 cm deep, 12.5 cm wide and 2 m long. The water velocity within the channel could be set between 0 and 0.50 m s^{-1}. Velocity (50 s averages at 40% of depth) was measured using an ADS SENCA-RC2 electromagnetic velocity meter. The meter was calibrated to better than 0.5% of range ±0.005 m s^{-1}. The ranges were 0–0.2, 0.2–0.4, 0.4–2.0 and 2.0–4.0 m s^{-1}. The flume does not have a fully developed boundary layer (Smith, 1975) so velocity does not exhibit a normal logarithmic profile with depth. Velocity was constant (to within 5%) upstream of the plants.

2.3. Experiments

There are a range of methods available for measuring drag on macrophytes, not all of which are directly comparable, (Statzner et al., 2006). The method adopted here provides a natural orientation for the plant and exposes it to increasing flow, in a manner comparable to that experienced during increasing river flow. Drag was measured on the plants using a series of precision spring balances (Pesola AG, Baar, Switzerland), maximum deviation ±0.3% of load. The balance was suspended vertically above the flume over a section of low-friction tubing. The tubing was cemented to a platform from which the balance was suspended and to the channel floor. The plant samples were glued, along the first 1 cm of the stem, to a thread that passed through the tube and attached to the spring balance, hence causing the horizontal drag to be converted into a vertical downwards force. Attached to the thread in this manner the macrophyte shoots orientated in a fashion similar to that observed in the river. The angle of the thread emerging from the tube, on the floor of the channel, was less than 75°. A pilot study indicated that any friction caused by this angle of emergence was minimal.

Reconfiguration was measured by recording the deflection of the macrophyte shoots using a protractor attached to the side of the flume, to within 5°. Ten replicates of each species were used (fresh mass of 3 g). Measurements were made at 0.05 m s^{-1} increments.

During the experiment, the water height within the channel (which ranged between 107 and 115 mm) and the velocity of the water were measured. The fresh weight of each shoot was recorded, after excess water had been removed by absorbent paper. Plant surface area was also measured. For the flat leaved species, *C. stagnalis*, *P. x zizii*, *S. emersum*, leaves were removed from the stems and surface area measured using Skyeleaf software (Llandrindod Wells, Powys, UK) to within 10%. For the fine, cylindrical leaved species, *M. spicatum* and *R. pseudofluitans* leaves were dissected from stems and the total length of each leaf filament measured using Skyeroot software (Llandrindod Wells) to within 11%. The width of the leaf sections was measured using a dissecting microscope as was the stem width for all species.

2.4. Data analysis

Analyses of variance (ANOVA) were used to test for differences between species in the amount of drag they experienced and the bend angle they exhibited at different velocities. The velocities used were 0.1, 0.2, 0.3, 0.4 and 0.5 m s^{-1} (to within 4%). The range and variance of replicate drag measurements tends to increase with mean drag and bend angle for each species. Taylor's Power Law regressions of log replicate variance against log replicate mean were used to