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Hydrolink

PISCES RESEARCH PROJECT: IMPROVING ECOHYDRAULIC MODELLING AND EXPERIMENTATION

BY STUART McLELLAND

Figure 1 - The Hopavågen tidal inlet, NTNU

Ecohydraulic modelling and experimentation are essential if we are to improve our understanding and management of the environment since organisms can modify their environment and they and their behaviour can be modified by the environment around them. The PISCES project in HYDRLALAB IV aims to improve the physical modelling of plants and animals through the development and improvement of measurement technologies and experimental methodologies and protocols. There is considerable potential for physical models of ecohydraulics to bridge the gaps between field observations and theoretical, stochastic and numerical modelling of aquatic ecology. This integrated approach to understanding ecohydraulics has the potential to improve our ability to predict changes to aquatic ecology resulting from present and future climate change. However, for such research to be meaningful and produce the greatest impact, care has to be taken to ensure that both the ecology and hydraulics are properly represented. The complex interactions between aquatic organisms and physico-chemical processes within ecohydraulics requires an interdisciplinary approach to research; therefore the PISCES research team included ecologists, geomorphologists, sedimentologists and hydraulic engineers to bring together knowledge and expertise from different disciplines.

Although it is challenging to incorporate plants and animals into physical models, it is an essential requirement to improve our representation of natural systems in experiments and to understand how those organisms can modify, or can be modified by, sediment transport dynamics and/or flow patterns and structures. The challenges include maintaining organism health and ensuring realistic behaviour of organisms during experiments as well as working with the complexity of the interactions among organisms, sediments and flow. To help the researchers meet these challenges, the PISCES team has produced an IAHR Design Manual entitled 'Users Guide to Ecohydraulic Modelling and Experimentation' to disseminate good practice. The guide includes practical information on experimental methods and procedures, including animal and plant husbandry, the design and use of surrogates and flow measurements around organisms. It also covers specific experimentation with different types of organisms including biofilms, plants and macrozoobenthos and the design manual concludes with a decision-making framework to assist researchers in their experimental design.

The PISCES project has also undertaken research to evaluate the limitations of using physical models to represent organisms in hydraulic experiments. Two of the key objectives from this research were to understand: (i) the complexity required to adequately reproduce the hydrodynamics of the natural system; and (ii) which aspects of living organisms must be replicated in surrogates to reproduce the hydrodynamics of the natural system.

These questions were investigated in a series of experiments that were conducted in both the field and the laboratory. Field experiments were undertaken at the Hopavågen tidal inlet, NTNU, (Fig. 1). Observations included bathymetry, bed sediment size distribution, macroalgal species distribution, macroalgal geometric properties (e.g. stipe length and diameter, blade length, width and depth, numbers of blades, and blade projected area), and mechanical properties of macroalgae (e.g. Young's bending modulus, flexural rigidity, buoyancy). Laboratory experiments were undertaken at the Total Environment Simulator at the University of Hull (Fig. 2), with replication of the physical conditions found at the field site including mean flow depth, flow rate, bed sediment characteristics, and macroalgal size and position. For both the field and flume cases, measurements of the flow field were taken for four different cases:

A. Full complexity of macroalgae as found in the 'undisturbed' natural environment;
B. Reduced complexity of macroalgae in which the macroalgae community was simplified to a single species *(Laminaria digitata)*;
C. Reduction of the number of macroalgae from 19 individuals to a single macroalga; and
D. "Cleared" condition with no macroalgae.

Additional tests were also undertaken in the flume experiments to investigate the effect of macroalgal arrangements with experiment B

Figure 2 - (a) Experimental set-up in the Total Environment Simulator, University of Hull with flags showing the locations of macroalgae to replicate field distribution. (b) View looking downstream in flume during experiments

a b

Figure 3 - Comparison of velocity magnitude for flume (red lines) and field (blue lines). At 0.9 and 1.1m cross-stream, locations without profiles are directly above the macroalgae being studied

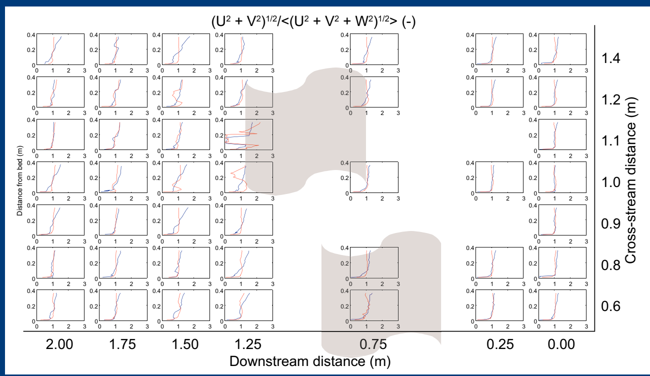
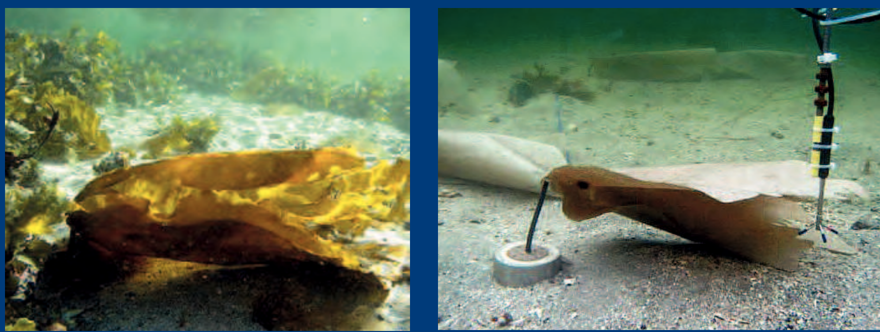


Figure 4 - (a) Photograph of real macroalgae (Laminaria digitata). (b) Photograph of surrogate macroalgae at the field site (Vectrino profiler measuring flow velocities shown to right of image)



a b

being repeated using the same density of colonization, but with different geometric arrangements of macroalgae.

In all cases, flow measurements in the field and laboratory were repeated with an identical methodology. Detailed, three-dimensional flow measurements were made using the Nortek Vectrino Profiler ADV sampling for 240 s at 100 Hz and with a 0.25 m lateral and longitudinal spacing within a 2 × 2 m grid. New techniques were developed to process ADV data to reduce spikes and noise in these measurements as part of the data analysis programme. In addition, we developed and tested new PIV measurement techniques that could be used in both the field and laboratory so that such measurements can be compared between different environments. Figure 3 shows an example of the flow measurements.

Detailed experiments were also undertaken to improve our understanding of how to use surrogates in experiments and how closely their behaviour replicates natural organisms. Measured macroalgal properties from the field site were used to select potential surrogates of varying stiffness, buoyancy and geometric complexity. The hydrodynamic behaviour (i.e., mean and turbulent flow fields, together with applied drag forces and observations of reconfiguration behaviour) of these test surrogates were compared to real macroalgae during experimental tests at FZK, Hannover (Fig. 4). From these experiments, an "optimum" surrogate was selected for further testing in field and flume experiments where 19 live *Laminaria digitata* thalli (Case B, above) were replaced with 19 of the optimised surrogates.

The key result from our comparison of field and laboratory experiments is that flume experiments can successfully replicate Reynolds- and double-averaged flow conditions at scales larger than individual thalli. But flow structures and behaviour at the same spatial scale as the macroalgae are not as well reproduced since these aspects of the flow field are particularly sensitive to the variability of properties between individual macroalga, which cannot easily be replicated. We have also begun to develop new diagnostic tests to be enable experimentalists to monitor and quantify the integrity of macroalga health and behaviour.

Following two highly successful workshops, attended by research from within Europe and beyond, the PISCES team have also considered the future needs of experimental ecohydraulics research. Together we identified five key themes that should be addressed if we are to improve and progress our understanding of ecohydraulic interactions:

1. Abiotic Factors: the detection of, reaction to, and modification of a number of environmental factors that may be dependent on or independent of the flow field by subaqueous plants and animals;
2. Adaptation: the adjustments made to or by organisms at multiple spatio-temporal scales in response to hydrodynamic forcing, abiotic stimuli or both;
3. Complexity and Feedback: complex interactions between organisms and the hydrodynamic environment and the role of feedback, whether positive or negative, in amplifying or moderating organism or environmental response, respectively;
4. Variation: differences between (parts of) individual organisms, or groups of organisms of any species caused either by genetic differences or by the influence of environmental factors; and
5. Scale and Scaling: is it possible to scale down biological (and biomechanical) processes operating at the large scale, are the variables measured at the large scale pertinent at the small scale and does technology permit us to measure the same variable across scales?

The PISCES project has brought together researchers from a wide range of disciplines to improve experimental research in ecohydraulics through better sharing of existing knowledge and also by developing improved experimental protocols. Results from an extensive series of experiments comparing flow fields around real and surrogate plants in the field and in the laboratory has shown the importance of heterogeneities in plant properties, orientation and position. This will help improve future experimental design so that results can be more widely applicable. The project has also developed robust methodologies for surrogate design and for flow measurements around organisms. Continued interdisciplinary discussion and collaboration are essential if hydraulic experiments are to make a significant contribution to future ecohydraulic research and environmental management under a changing climate.

Stuart McLelland is a Senior Lecturer in the Department of Geography, Environment and Earth Sciences at the University of Hull. His main research interests are in physical modelling and fluvial processes. This report was written on behalf of a team of over 20 researchers involved in the PISCES project.

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