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# *Ecohydraulics at scales relevant to organisms*

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# ABSTRACTS

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**Influence of bedload on salmonidae habitats.**

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Revitalization of rivers requires the perception of the physical factors interacting and conditioning local biota. In particular, salmonidae presence is intrinsically linked to the existence of prominent boulders in river beds. Their sheltering conditions provide habitat for salmon and trout. To understand the dynamics of salmonidae communities' it is crucial to know the flow structure around the boulders. Differences on the turbulent flow structure of gravel-bedded rivers are expected whether clear water flows or in presence of bedload. Under mobile and immobile bed conditions we analyzed the flow around a singular protuberant gravel boulder on a gravel-bedded, 40 cm wide and 10 m long, laboratory channel. A singular 14 cm long rock, protruding 6.4 cm, was introduced within the channel bed. Experiments were carried under uniform flow conditions with flow depth of 10 cm, discharge of 13.0 l/s and longitudinal slope of 0.27%. The bed was porous and composed of a bimodal mixture of gravel ($D_{50}$=50 mm) and sand ($D_{50}$=0.9 mm). For the mobile bed experiments, the sand fraction was transported in nearly-capacity conditions ($Q_s \approx 8x10^{-4}$ l/s). Velocity measurements were made using nine ultrasonic velocity profilers sustained by a support that allowed covering the entire flow depth and measuring streamwise velocity profiles in several longitudinal planes upstream and downstream the boulder. The turbulent structure of the flow around the boulder is discussed, namely the distribution of time-averaged streamwise velocities and longitudinal turbulent intensities.

**The biological reality of river habitats using macroinvertebrate species traits**

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The species composition of macroinvertebrates was previously shown to be related to within-channel patch scale (1-100 m2) river habitats. So far the relationship between habitats and macroinvertebrates has been limited to a single site or at multiple sites but along the same river. This is because every rivers tend to be characterised by different species of macroinvertebrates and this obscure the relationship between within-channel habitats and macro-invertebrates. The species characterising river habittas may be taxonomically different but functionally similar. Hence we hypothesised that river habitats discriminate biological macroinvertebrate species traits across rivers of England and Wales. We tested this hypothesis with 512 samples of macroinvertebrates collected in 16 river habitats across seven rivers in England and Wales.

# Patch-scale ecohydraulic dynamics in alpine river systems

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Alpine river systems are characterised by hydrogeomorphological conditions that vary both spatially and over time, and which contribute to the creation of dynamic habitat mosaics which sustain high ecological diversity (including many endemic species). Recent research has identified the importance of water source contributions, stream temperature and channel stability as key reach-scale controls on benthic macroinvertebrate communities, yet little is known about what controls their patch-scale distribution. Year round data collection (2008-2010)is currently underway on the Odenwinkelkees Glacier floodplain in the Central Austrian Alps to collect coupled geomorphological, hydrological, hydraulic and ecological data sets at the river-, reach- and patch-scale. It is anticipated that this fieldwork will provide an insight into patch-scale ecohydraulic dynamics as well as informing modelling techniques that aim to predict invertebrate distributions at the reach- and river-scale.

**The formation of fluvial obstacle marks at plants**

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Fluvial obstacle marks are bedforms that develop if flow is separated by an immobile obstacle at the stream bed. Due to local acceleration and deceleration of the flow, areas of potential erosion and deposition arise in the obstacle surrounding. This results in forms that commonly consist of a scour hole reaching from the upstream part to the sides of an obstacle and an adjacent sediment ridge. Up to now the determination of maximum scour at bridge piers has been extensively investigated by engineers. Mature trees can be considered as equivalents to bridge piers, although alignment, surface roughness and root system alter the formation of obstacle marks. In fact systematic studies on obstacle mark morphologies particularly at submerged obstacles are still missing. Therefore flume experiments were conducted with the aim of investigating the influences of different obstacle heights on obstacle mark morphologies. It could be shown that with rising obstacle heights the maximum depth and volume of the scour hole increases. Also a distinct change in morphology and particle transport pattern could be noted. Shrubby plants located in flood plains frequently turn into submerged obstacles during floods. They are flexible and partially permeable with complex geometries, which reduces scour in front of the plants. Obstacle marks at shrubby plants found in a secondary river channel demonstrate to what extend morphologies differ from those created in the flume. Nevertheless the results from the experiments are to a certain degree transferable to the forms found in the field.

# A comparison of flow structures over benthic macrophytes and benthic filter feeders: implications of spatial heterogeneity

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Abstract: The dynamics of the flow of water over benthic organisms has an important impact on their survival and development. This eco-hydrodynamic interaction is complicated when, as is often the case, the benthos are not uniformly distributed, but are arranged in spatially-complex patterns. Recent work on filter-feeding bivalves in marine environments[1] has suggested that they arrange themselves in patterns in order to maximise the efficiency of nutrient uptake and biomass growth. Spatial patterning in response to hydrodynamic forcing has also been observed in benthic flora[2]. We present the results of laboratory flume experiments which have sought to elucidate, at the organism scale, the hydrodynamic characteristics of flow structures in the vicinity of both extended beds of flexible plants (representative of many common freshwater and marine macrophytes) and of sessile filter-feeding bivalves. Our results demonstrate the importance of making the distinction between boundary layer and mixing layer environments, the surprising isolation of gaps within benthos patterns from the free-stream flow above them, and the extent to which wake decay rates dominate the overall hydraulic properties of these environments.

[1] van de Koppel et al. 2005. American Naturalist 165 (3): E66-E77
[2] Fonseca et al. 2007. J. Experimental Marine Biology & Ecology 340 (2): 227-246

# From organism ecohydraulics to population ecohydraulics : Making riverscapes a practical reality.

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The riverscape concept proposed by Fausch et al (2002) argues for the need to apply landscape ecology methods to lotic ecosystems. Landscape ecology approaches require information on the spatial distribution of organism-scale habitats across entire ecosystems. In the case of riverine landscapes, the application of landscape ecology methods implies the need for detailed ecohydraulic maps. Crucially, localised knowledge of organism ecohydraulics will need to be replicated spatially throughout the entire riverscape to document and predict total habitat availability and production. Likewise, information on time-dependent variations in these ecohydraulic habitats is also necessary. Given these requirements, it is not surprising that the riverscape approach remains largely a conceptual framework with limited practical applications. However, recent technical developments are opening the way for quantitative applications of the riverscape approach. Remotes sensing methods now allow for sub-meter measurements of key flow variables such as grain size and depth, as well as estimation of parameters such as velocity and stream power. Furthermore, progress in desktop computing suggests that it will soon be possible to develop hydraulic models of small catchments with sub-meter grid cells. This paper, presented by fluvial remote sensors, will argue that targeted research efforts within the next 5 years could feasibly deliver a working ecohydraulics model which considers organism scale habitat for entire catchments.

# Hydro-ecological studies on stream water crowfoot

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Over 2001-2005 Thames Water commissioned studies on the hydrology and ecology of the River Kennet, which included investigations of stream water crowfoot, *Ranunculus penicillatus ssp. pseudofluitans* (Syme). The objectives of this work were to assess the hydro-ecological requirements of the plant, and then to use this information to quantify the possible effects of a nearby groundwater abstraction upon optimal conditions for *Ranunculus*, through changes in the river flow regime (reduced flow and velocity). From empirical studies and expert judgement arose a series of water velocities to which *Ranunculus* was sensitive, allowing the definition of hydro-ecological conditions. Hydrological data collected in the Kennet were used to translate these velocities into flow thresholds specific to the river reach of interest, and a traffic-light system was developed to express below-optimal, acceptable, and optimal flows. Translating velocities into flow bands allowed the use of long-term gauging station data to see how conditions for *Ranunculus* changed over a 30 year time period. To understand the effect of the abstraction, a semi-naturalised flow series was generated and compared to historic flows to quantify the change in time spent in each flow band and therefore the impact upon the preferred conditions for *Ranunculus*.

**Aquatic Habitat Characterization, Flow Variability and Habitat Use by Brown Trout (*Salmo trutta*) and Bullhead (*Cottus gobio*)**

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Riverine flow variability and its influence on habitat use by fish are not well understood. This study examined the utilization by brown trout (*Salmo trutta*) and bullhead (*Cottus gobio*) of mesohabitats that vary with flow in terms of size and type, persistence or duration, and frequency of change from one state to another, by comparing groundwater-dominated sites (stable regime) with runoff-dominated (flashy regime) upland, riffle-pool streams. Mesohabitat surveys carried out at two-month intervals on the River Tern (groundwater-dominated) and on the Dowles Brook (surface runoff-influenced) showed differences in habitat composition and diversity between the two streams. The temporal variability in mesohabitat composition was also shown to differ between the two flow regime types. Fish surveys using direct underwater observation (snorkelling) were carried out; analysis of the fish observations aimed to determine whether fish select optimal habitat by preference and how this choice changes with variations in flow. The results show that fish adopt different strategies of habitat use according to flow variability. Although differences in habitat use between the streams also reflect the differing ecology of the two species, habitat variability appears to play a key role in fish habitat choice. In particular, the hypothesis that flow regime and flow variability influence the balance between biological processes and habitat related behaviour to explain fish choice of location was validated.

**The Stability of Fine-Grained Sediment Deposits in Lowland Streams**

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Water flow, aquatic organisms and geology interact to create a mosaic of sediment patches within stream reaches. Patches of fine-grained sediment form in local low flow areas, and their stability is dependent on their particular combination of physical, chemical and biological attributes. Fine-grained sediment deposits are a concern in streams because of their potential to degrade aquatic ecosystems, impede surface-ground water connectivity, increase flood risks, and store contaminants. By identifying the factors that influence sediment stability and how they vary in different streams types, we can better predict fine sediment dynamics and its impact on humans and the environment. The main objectives of this project are to 1) investigate the spatial and temporal variability in sediment stability in lowland streams, and 2) to identify the major physical, chemical and biological factors that influence stability. Objective 1 is being explored with a 2-year field survey, in which paired sediment cores and *in situ* cohesive strength measurements are being taken in areas of sediment accumulation in a range of lowland stream types. Objective 2 will be addressed preliminarily with the survey data, and will be examined further with experiments in microcosms and annular flumes.

**Hydraulic controls on the transport, storage and deposition of plant propagules and implications for riparian vegetation**

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This paper presents the findings of a study which investigated the hydrological and hydraulic controls on propagule transport (hydrochory), storage and deposition in the riparian zone and considered the importance of this for the riparian vegetation. The study was conducted along two reaches of the River Frome, Dorset. Viable propagules present in channel drift, river bed sediment and deposited on the riverbank were considered alongside the flow regime and the existing vegetation. The river channel was an effective transport medium for propagules, although this was influenced by in-channel hydraulic variation and the hydrological regime. The channel bed was a dynamic store for propagules, which showed preferential accumulation in habitats hydraulically influenced by vegetation. The redistribution of propagules onto the riverbank was heavily dependent on the duration of inundation and the volume of deposited sediment, reflecting the varying depositional environment across the riverbank. The effectiveness of hydrochorous transport and deposition was very dependent upon high flows and small-scale hydraulic variation. Propagules were characterised by high species richness, including species not present in the vegetation, illustrating the importance of these processes for riparian vegetation diversity. Through facilitating propagule storage, the active role of vegetation in this process was also demonstrated.

**Response of macroinvertebrates community to modulation of species-filtering permeability by in-stream vegetation in a small mediterranean-type stream**

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Mediterranean-type streams are fluvial ecosystems that are characterized by a distinct hydrology, having a period of scouring flows (late fall-winter), a period of moderate flow (spring - early summer) and a period of reduced flow and drying (late summer-fall). This distinct flow pattern acts as a "species-filter" determining community structure. We expect macroinvertebrate community richness and density to portray an annual "hump-shaped" dynamic; being lowest during winter, recovering and peaking during spring and early summer and gradually decline throughout summer and fall. In-stream vegetation is also influenced by the hydrology, undergoing an annual cycle of growth and senescence. We assessed the ecosystem-engineering function of the vegetation on macroinvertebrates community in a small mediterranean-type stream. We found that throughout the year, in-stream vegetation increases species-filtering permeability by adding macroinvertebrates that otherwise would be excluded from the assemblage or would be present in relatively small numbers. We also show that the engineering impact of the vegetation is highest in winter and spring, doubling macroinvertebrate richness. Contradictory to our expectation, annual macroinvertebrate richness failed to exhibit "hump shape" dynamics. We ascribe that to contrasting dynamics of macroinvertebrates exclusively associated with vegetation and the rest of macroinvertebrates (habitat-independent; and plant-free species).

# Are Surface Flow Type mesohabitats biologically distinct?

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Traditionally river ecologists have focused interest on the microhabitat scale whilst fluvial-geomorphologists have studied at the mesohabitat scale. Bringing together micro- and meso-habitat research, six lowland English rivers were investigated using water Surface Flow Types (SFTs) as habitat descriptors to assess their biological relevance using benthic macroinvertebrate. Multiple surveys of each site were made during summer 2006. Mesohabitats were mapped; water depth and velocity, substrate and other data collected from each mesohabitat. Macroinvertebrate samples were collected from representative mesohabitats and identified to family level. Water depth and velocity, substrate, embeddedness data was recorded from each microhabitat. Analysis showed that there were, statistically, significant differences between water depth, water velocity, substrate and embeddedness across five SFT habitat types. Analysis of depth/velocity using HydroSignature identified the dominant SFT habitat for each depth/velocity class. Water depth and velocity, substrate and embeddedness from microhabitat data has been used to produce preference matrices for macroinvertebrate families identified within the samples obtained. It is intended that the preferences matrices could be used to predict biological relevance of SFT mesohabitats.

# Physical Habitat Complexity and Macroinvertebrate Diversity of Urban River Habitats (River Thames, central London)

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The tidal Thames is a major urban river characterized by extensive environmental degradation due to engineering, pollution and management impacts. Despite some recent recovery of water quality, riverine and riparian habitats within the river through central London are spatially restricted and of poor quality. The resulting urban ecosystem is consequently highly disturbed and supports only a restricted invertebrate community. This study evaluates the physical variability and macroinvertebrate diversity of the two most common habitats along the river: inter-tidal foreshore and embankment wall surfaces. A 35 km reach of the Thames through central London was surveyed with 16 sites spaced every 2km from Mortlake to Woolwich. Initial results suggest that the greatest control on invertebrate diversity on the foreshore was particle size distribution of sediment, although both the aquatic salinity gradient and river width were also important. Wall macroinvertebrate diversity was strongly related to wall material type, with more complex wall surfaces supporting higher biodiversity. River walls were more biodiverse than inter-tidal foreshore, possibly due to a combination of lesser disturbance and increased refugia. It is suggested that fine scale variations in physical habitat structure and complexity influence macroinvertebrate biodiversity within broader environmental gradients within comparable urban river systems.

## The influence of net-spinning caddisfly larvae on river-gravel stability: an experimental field and laboratory flume investigation.

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The impact of Hydropsychidae caddisfly larvae on the incipient motion of two sizes of narrowly graded fine-gravel (4–6 and 6–8 mm) was examined relative to other abiotic and biotic processes that are potentially important conditioning agents. Trays of gravel were placed in the River Soar, Leicestershire, UK where they were colonised by natural densities of caddisfly larvae. Identical trays that were surrounding by 250 μm mesh to prevent colonisation whilst allowing conditioning processes to operate, were also placed in the river. After 21 days, trays were transported from the river to a laboratory flume where entrainment stresses for the gravels within trays were established. In addition to the river-exposed trays, entrainment stresses were measured for gravels which were not placed in the river (laboratory trays). Gravels that were colonised by Hydropsychidae required significantly greater shear stresses for entrainment than conditioned trays ($p \leq 0.002$), however, there was no significant difference between conditioned and laboratory gravels. A two-way ANOVA showed that 4–6 mm gravels were stabilised to a similar degree as 6–8 mm gravels. The temporal and spatial distribution of silk-spinning caddisfly larvae suggests that they have the potential to influence fine-sediment mobility in many rivers.

**Bridging the gap between hydraulics and fish behaviour: the application to fish passage**.

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The ability of fish to negotiate either natural or anthropogenic impediments to migration significantly influences individual fitness and population status. Barriers to migration are not only related to physical structures *per se*, but to the hydraulic conditions created. Traditionally, the development of criteria that describes the ability of fish to pass obstructions has been based on the swimming capability of economically significant species during upstream movements. Downstream migrating life-stages and non-commercial species have been less often considered. Further, the behavioural response of fish to hydraulic conditions created are usually ignored, despite evidence that fish exhibit avoidance at impediments that they would otherwise be expected to pass based on swimming capability alone. Research is required to define how fish behaviour is influenced by hydraulics in order to address current gaps in understanding and facilitate application to fish passage design. This presentation will highlight interdisciplinary research conducted at the International Centre for Ecohydraulics Research (ICER) at the University of Southampton. Fish biologists work closely with hydraulic engineers to quantify the response of multiple species of fish to hydraulics in an effort to develop generic models that may help water resource manager's better provision fish passage strategies. The results of some of these studies will be discussed.

# The Development of Geomorphological Complexity and its Influence on Fish Communities.

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Rapid glacial recession within Glacier Bay National Park and Preserve, Alaska, has created a unique opportunity to study the development of geomorphological and hydraulic complexity, and their influence on fish populations by examining watersheds of differing ages. By identifying channel geomorphic units across a chronosequence of six rivers representing 200 years of development, we have analysed characteristics of bed morphology and hydraulics within and between the study sites. Initial results show that streams of intermediate age have the highest geomorphic and hydraulic complexity, as measured using hydraulic characteristics such as water depth, current velocity and Froude number, and habitat diversity indices such as Simpson's and Shannon's Diversity and Evenness indices. However, the presence of complex coarse woody debris in older streams appears to be key in determining the availability of instream habitat for juvenile salmonids by creating small scale hydraulic diversity in and around the CWD, as well as altering the geomorphic development of the stream. Results from this study suggest that large scale geomorphic changes at the landscape level are producing small scale hydraulic changes which fish are able to utilise as they continue to colonise these novel habitats.

**Linking the hydraulic world of individual organisms to larger scale ecological processes**

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Most ecologists have rather little interest in hydraulic processes, but hydraulics often interact with ecological processes and then these interactions must be addressed before ecological understanding can be achieved. Using stream insects as a model system, this talk will discuss some ways in which stream hydraulics may influence population dynamics (spatial and temporal variations in population density), with particular attention to the vital rates of birth and mortality. Although the physical world is experienced by individual organisms, whether hydraulics has any impact on population dynamics requires scaling up from individuals to the spatial and temporal scales of whole populations. These scaling challenges will be discussed in the context of each example, but a mechanistic understanding of the eco-hydraulic interaction is paramount to success. Examples of hydraulic influence on birth rates include: (i) the transfer of eggs from terrestrial adults into the aquatic medium and the supply of suitable oviposition sites within streams may set population density, and (ii) feeding success, and hence egg production, of filter feeding larvae varies with hydraulics and food supply, and may drive between-stream differences in population density. Examples of hydraulic influences on mortality rates focus on displacement during hydrologic disturbances and include: (iii) the ability (or not) of animals to move through near-bed flow fields and into flow refugia may reduce disturbance-related mortality, but population-level effects will depend on the spatial distribution of refugia and species-specific movement behaviours, and (iv) whether dislodgement and entrainment in the drift results in mortality, depends on the ability of larvae to exit the drift and re-attach to bed substrates, and this will also vary with stream-wide topography and flow patterns. These, and many other, eco-hydraulic interactions that may drive population dynamics are poorly understood and there is scope for much more research.

## Fully integrated micro-habitat requirements for spawning Chinook salmon in the Yuba River, California

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The physical micro-habitat of spawning salmonids (typically flow depth and velocity and substrate characteristics) has been studied for many decades for a wide range of species. Such information is required for defensible prescription of environmental flows (using habitat modelling such as PHABSIM), to guide river/ habitat restoration design and in predicting ecological response to changes in physical channel conditions (e.g., due to river management, land-use, climate change etc). However, many of these studies examine one aspect of micro-habitats in isolation (i.e., substrate or hydraulics); hydraulic habitat requirements (i.e., depth and velocity) are typically not integrated and the studies that examine both hydraulics and sediments tend to treat them as physically independent. This fails to consider the inter-dependent fluvial processes that control the provision of these conditions, potentially resulting in misleading predictions of habitat availability in ecological assessments. We present data from the Yuba River, California that describes the integrated hydraulic and sedimentary characteristics of micro-habitat utilised by spawning Chinook salmon (*Oncorhynchus tschawytscha*). The data demonstrate that there is a clear joint depth-velocity distribution in locations selected for spawning. However, this was shown to largely reflect a channel geometry control on hydraulic function rather than a preference for a specific combination of depth and velocity. It was evident that, in terms of simple hydraulics, fish only selected for suitable velocities; depth appeared to be a binary control, either permitting or denying fish access to a specific location. Furthermore, it was demonstrated that substrate characteristics selected by spawning Chinook were linked to local flow velocity conditions; fish utilised coarser sediment in faster-flowing conditions. It was found that this did not reflect the availability of joint sedimentary-hydraulic conditions (i.e., through a hydraulic sorting mechanism); pre-spawning surveys across the entire study site showed no significant relationship between any combination of sedimentary and hydraulic descriptors. This showed that Chinook selected specific combinations of hydraulic and sedimentary conditions within that available across the entire site. Specifically, fish tended to spawn in coarser sediment if that was associated with faster flow velocities, suggesting that more energetic locations provided a 'background' force that assisted spawners in dislodging larger clasts from the stream bed. Conversely, spawning was observed to occur in small sediment sizes (fine gravel) if associated with low velocities that permitted the maintenance of that calibre of substrate. Such locations exhibited much smaller values of flow velocity and sediment size that previously quoted in the literature for spawning Chinook. It is proposed that species-specific 'preferences' for micro-habitat reflect the integration of the availability of joint hydraulic-sedimentary conditions, with the ability of a spawning fish to gain access to those conditions (controlled by depth and, therefore, related to animal size) and dislodge the substrate (controlled by the combination of animal and hydraulic forces, the former linked to fish size).

**Bridging spatial scales in aquatic ecosystems: a role for 3D hydraulic models?**

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One justification for 3D computational fluid dynamics models of river reaches is the need to estimate hydraulic variables at a scale relevant to aquatic organisms. However, natural river channels present quite difficult problems for such models – particularly with respect to the representation of gravel bed roughness /microtopography and in-stream macrophytes. In a hydraulic sense, both of these can be described in terms of blockage (or occupying volume), momentum loss and additional turbulence terms. This paper presents results from two examples. The first relates to the benthic environment and examines how we might deal practically with bed microtopography at the field scale to produce realistic distributions of near-bed velocity and other hydraulic variables at a range of spatial scales. The second example focuses on aquatic macrophytes. Results are presented which show the flow and turbulence fields around and within a single plant of *Ranunculus fluitans* and offer insights into the vexed question of drag and reconfiguration.

# Hydrodynamic of aquatic ecosystems at the organism scale

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Biophysical processes that shape biological communities in rivers, estuaries, lakes and seas are largely controlled by flow hydrodynamics. The importance of biophysical processes for developing better management strategies of aquatic systems has led to the appearance of several quickly growing branches of fluid mechanics, hydraulics, and ecology known as ecohydraulics, environmental hydraulics, environmental fluid mechanics, and biofluiddynamics. These new disciplines, although still vaguely defined, cover a wide range of terrestrial and aquatic environments, scales, and organisms, and represent a good example of a multidisciplinary approach in modern science. Among many problems addressed by these disciplines, there are two fundamental issues of crucial importance: (i) physical interactions between flow and organisms (e.g., due to drag forces); and (ii) ecologically relevant mass-transfer-uptake processes (e.g., due to molecular and turbulent diffusion). The study of these interlinked processes can be defined as the *hydrodynamics of aquatic ecosystems*. Flow-biota interactions and ecological transport processes occur over a wide range of scales and are dependent on the matching of both physical and biological scales such as organism dimensions, patch/community dimensions, life cycles, turbulence scales, and others. This multi-scale property together with physical and biological complexity of boundary conditions in ecosystems often makes the conventional methodologies impracticable and therefore new approaches are required.

This talk will outline several such approaches that constitute tools of the *hydrodynamics of aquatic ecosystems*. Relevant concepts of boundary layer and eddy cascade and their interrelationships with biota will be reviewed first. Then, a methodology based on spatial averaging of the governing hydrodynamic equations will be presented as it provides a rigorous framework within which hydrodynamics is directly linked to biota with explicit representation of transport processes and physical interactions between turbulent flow and organisms. An important advantage of this approach is that it allows for scale decomposition (or separation of scales) and can be viewed as a scaling-up procedure that changes the scale of consideration from one level in time-space domain to another level (e.g., from a scale of an individual organism to the patch scale to the scale of the whole community). In other words, the spatial averaging methodology provides a natural way for integrating bio-physico-geochemical processes at the organism scale into larger scale behaviour important for resource management. The talk will include a number of examples illustrating application of the outlined approaches for quantifying and predicting effects of physical interactions and mass-transfer-uptake processes in benthic communities.

**Imposed sand transport on gravel-bedded streams. Consequences for young salmonidae habitats.**

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The diverse morphological features of gravel-bedded rivers provide valuable habitats for wildlife. Pools induce deposition of finer sediment and nutrients and provide food and shelter for fish species and for a varied range of benthic species. Riffles, associated to larger stream velocities, are populated by several fish species, including salmonids. These morphological features are self formed, usually during periods of higher flow. Some degree of sediment mobility is essential for the ecological health of gravel bed streams. However, the introduction of sand sizes in gravel-bedded streams, as a consequence of deforestation or land use mispractices in the catchment, may have adverse impacts on salmonidae spawning and breeding areas: bed porosity may decrease and near-bed turbulent intensities are likely to increase. This study is aimed at the characterization of the complex interaction between flow turbulence, sediment transport and bed texture in gravel-bedded streams subjected to sand overfeeding. The research methodology is based on the collection of laboratory data in two open-channel flow situations, with and without sand fractions moving as bedload, maintaining constant discharge (23.3 $ls^{-1}$) and bed slope (i=0.0044). In the first of these flow situations, the sand fraction was imposed at a rate close to capacity ($Q_s \approx 1.3 \times 10^{-3}$ l/s). In both flow situations the bed was clast-supported, the gravel fractions had $D_{50}$=50 mm and the sand fractions had $D_{50}$=0.9 mm. Relative submergence was low ($h/D_{50} \approx 3$). The data comprehends 2D instantaneous velocities obtained with Particle Image Velocimetry and bed texture. The turbulent structure of the flow near the bed is discussed, namely the distribution of double-averaged streamwise and vertical velocities and out-of-plane vorticity.

**On resuspension phenomena of benthic sediments: the role of cohesion and biological adhesion**

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The incipient motion conditions of benthic sediments are analized and an original parametrization for the threshold shear stress to initiate motion is proposed. Starting from momentum balance considerations on a single sediment floc, the Shields dimensionless mobility parameter in incipient motion conditions is expressed also as a function of both cohesive and adhesive forces that concur to stabilize the superficial layer of the benthic sediment. The entrainment model is validated on the basis of laboratory experiments carried out on natural benthic sediments sampled from three alpine italian lakes, presenting different trophic conditions and different compositions of the bed. The experimental results show that the cohesive effects decrease as the sediment water content increases. Moreover the role of bioadhesion is experimentally evaluated: the critical shear stresses of "living" sediments are higher than that measured on similar but "dead", poisoned, sediments; this stabilizing effect shows a variation in time on a seasonal time scale, accordingly to the licterature indications where biological adhesion is related to phytoplankton and bacteria activity, the life and growth of which obviously depends on seasonal variations.

**The relations between standard fish habitat variables and turbulent flow properties at multiple scales within different morphological units of a gravel-bed river**

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Fluvial fish habitat is often characterized by highly turbulent flow conditions. Several laboratory experiments suggest that unpredictable turbulent fluctuations can increase the swimming energy costs of fish. At the scale of fish habitat models, it can be hypothesized that turbulence can be captured by the combined effects of the standard habitat variables: depth, velocity and substrate. However, recent studies suggest that at the reach scale, turbulent properties could be more influenced by the large scale bed morphology than by individual roughness elements. In this study, we investigate the potential causal relationships between standard habitat variables and turbulent flow properties in pools and riffles of a shallow gravel-bed river. The study explores these relations at multiple spatial scales. Mean turbulent properties and turbulent flow structures statistics were computed from 2016 bed velocity time series sampled with acoustic Doppler velocimeters on a regular grid in four morphological units (two pools and two riffles) presenting a gradient of complexity. We used a novel multivariate variation partitioning analysis involving principal coordinates of neighbour matrices (PCNM). This technique allowed us to partition turbulent flow properties into six significant spatial scales (VF: 0.35, F: 0.75, M: 1.25, L: 2, XL: 2.5 and XXL: 3 m). Between 58 and 66 % of the variance of the turbulent flow properties were explained by the spatial PCNM. Most of this variance was explained by the larger scale submodels, corresponding to the scale of large scale turbulent flow structures. However, standard fish habitat explained less than 30 % of the variance, and mostly in the fine scales, especially in the riffles. These results highlight the need for linking flow turbulence and fish habitat use within large river morphological units.

**Shear forces and bedload transport as drivers of invertebrate drift in gravelly and sandy bed rivers**

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The downstream drift of invertebrates constitutes a fundamental ecological process in rivers and streams around the world. Understanding the patterns and causes of drift has been a focus of research ever since the phenomenon was first described. Animals enter the drift both voluntarily and involuntarily. Involuntary drift may occur as a result of shear forces which can dislodge animals from exposed areas of stream bed. Involuntary drift typically increases during periods of elevated discharge, as a result of increases in shear stress and, consequently, channel instability. During floods river-bed sediments are mobilized and this may lead to more animals being dislodged (i.e. they may be entrained along with sediment). Assessing the relative importance of the hydraulic forces acting on the river-bed and sediment transport as causes of drift has proved difficult because of the practical problems of working in river channels during floods. We created a small portable flume which allows controlled manipulation of hydraulic conditions *in situ* within river channels. Here we present the results of two sets of experiments in which we used the flume to assess the role of channel hydraulics and bed instability in driving drift entry. Experiments were conducted in two rivers with contrasting sedimentary characteristics – a gravel bed river with patches of fine sediments and a sandy-gravel bed river with a very low entrainment threshold– where bed-material dynamics and invertebrate assemblages differ markedly. We compare patterns of drift under hydraulic conditions that are typical of high flows and the early stages of floods; data allow examination of whether drift loss from highly mobile beds (sand bed river) differs (in terms of total loss and species composition) from more stable ones. We discuss the invertebrate behavioral traits and body forms which influence drift propensity under these conditions.

**An evaluation of the spatial configuration and temporal dynamics of hydraulic river habitats**

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Flow is the dominant force shaping the hydraulic habitat template and physiology of freshwater biota (Statzner et al., 1988; Southwood, 1977). Biodiversity and ecological processes are affected by the arrangement (fragmentation, juxtaposition, interspersion etc) and diversity of hydraulic patches (Palmer et al., 2000; Townsend, 1989). The inherent temporal dynamics in riverine environments caused by changes in flow constantly alters the distribution of hydraulic habitats, yet little is understood about the effect of changing flow rates on spatial patterns (Clifford et al., 2006). Development of quantitative methods to describe the spatial configuration and temporal dynamics of hydraulic habitats at scales relevant to organisms may enable a more effective understanding of the ecological implications of hydraulic variability. Current habitat assessment methods are limited. Rapid mapping from the bankside is subjective and suffers from operator variability. Quantitative methods using remotely sensed data lack sufficient spatial resolution (Legleiter & Goodchild, 2005). Cluster analysis has been used successfully to define hydraulic habitats objectively based on field data (Emery et al., 2003) but only with crisp boundaries which do not always reflect spatial variations in hydraulics accurately. Using ADCP technology to collect depth and velocity data at reach, meso and patch scales, and fuzzy clustering to delineate hydraulic patches and the transitional zones between them, this research aims to map the dynamic hydraulic habitat mosaic at flows between Q5-Q95. Landscape ecology metrics, areal boundary analysis and multivariate statistics will be used to quantify spatial configuration and analyse temporal dynamics.

**Linking morphological sediment budgeting to salmonid embryo survival**

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High-resolution, repeat, topographic surveys are frequently used to estimate the storage terms in reach-scale fluvial sediment budgets through DEM-differencing. Recent advances in quantifying surface representation uncertainty gives increased confidence in making more detailed, bar-scale, mechanistic interpretations of recorded geomorphic changes. Moreover, some new simple masking tools allow a quantitative segregation of the morphological sediment budget in terms of such interpretations. Here, these tools are used to consider ecological implications of monitored geomorphic changes. With examples of redd surveys and repeat topographic surveys from the Mokelumne River and Sulphur Creek in California, some questions related to the significance of geomorphic changes to spawning and incubating Chinook salmon (*Oncorhynchus tshawytsch*) were explored. These questions included: 1) the impact of a large flood on incubating salmonids embryos; 2) the influence of high-flow dam releases on physical habitat quality; and 3) documenting changes that took place specifically where salmon spawned. The results highlight some simple but interpretively powerful techniques for linking ecohydraulic and geomorphic field monitoring data at a scale relevant to salmon.

# Comparing spawning habitat estimates with young of the year fish densities in flooded areas in the River Waal, The Netherlands.

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Fish spawning habitat availability is greatly affected by seasonal and annual variations in discharges of the River Waal. We defined habitat models, based on a literature survey on spawning preferences of roach, bream, pikeperch and bleak. Important environmental parameters in the model were water depth, current velocity, water temperature and vegetation type. Spatial data for the parameters were derived from a 2-D water movement model and from the Dutch monitoring database. The amount of suitable habitat was calculated with the 'Habitat' tool, based on species-specific models and the environmental parameters for two different locations in the river Waal during three consecutive years (1997-1999). Three methods of determining the appropriate parameter values for the spawning period for each year were compared, the discharge occurring at minimum and optimum spawning temperature and the average discharge during the spawning period described in literature. The resulting amount of available area was compared to field data on the recruitment of young fish in the same years and locations. There was a positive relationship between observed young of the year densities of the fish species (except pikeperch) and available area when average discharge during the spawning period was used. Using discharges at minimum or optimum spawning temperature to determine habitat availability resulted in a less good fit. The results of this study can be used for the design of wetland restoration plans.