River habitat mapping: are surface flow type habitats biologically distinct?

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Abstract

Current river habitat mapping uses several methods, many relying on descriptions of habitat units based on depth, velocity, substrate and water surface patterns. Water surface patterns are controlled by local geomorphology and hydraulics and can be remotely sensed: if surface flow type habitats are physically and biologically distinctive this may provide a faster surveying method. Six UK lowland rivers were investigated, surface flow types were mapped and the physical characteristics of each habitat unit recorded. Samples of benthic macroinvertebrates were taken from representative units and quantified. The results show that habitat mapping, using surface flow types in small lowland streams, is viable and that those habitats have some degree of physical distinctiveness. Analysis of benthic macroinvertebrate communities shows that there is some association with mapped habitats, and therefore are potentially biologically relevant.

Introduction

River channels contain an infinitely variable mosaic of morpho-hydraulic habitat cells (microhabitats) which form the focus of much in-stream biological research. The meso-scale (several hundred metres of channel) is the scale at which fluvial-geomorphologists generally operate. Here a mesohabitat consists of a mosaic of several, perhaps different, microhabitats. Mesohabitats have many different names, although many are based on Hawkins *et al*. (1993) ‘Channel Geomorphic Units’ (CGU). Several methods of mesohabitat mapping have evolved, often related to PHABSIM (Bovee, 1982) e.g. Rapid Habitat Mapping (Maddock and Bird, 1996), MesoHABSIM (Paraseiwicz, 2001), Norwegian Mesohabitat Classification System (NMCM) (Harby *et al*., 2004) and MesoCASiMiR (Eisner, 2005). The biological realism of PHABISM and by implication other methods, has been questioned (Booker *et al*., 2006).

Water surface flow patterns (surface flow types, SFT) are governed by morpho-hydraulic conditions (Wadeson and Rowntree, 1998), and replaced CGUs habitat descriptors in the River Habitat Survey (Environment Agency, 2003). Padmore (1997) showed that SFTs respond to geomorphic changes; therefore, is it possible that SFTs could be used to map in-channel mesohabitats, and are they biologically relevant? Benthic macroinvertebrates have been studied for many years, particularly in relation to water quality issues; more recently, interest in macroinvertebrate community dynamics has developed e.g. Principie *et al*. (2007). This research aims to examine the biological relevance of mesohabitats defined by SFT.

Sites / Method

Six lowland (<200 m above Ordnance Datum) English streams (Figure 1, overleaf) were each surveyed at three different discharges between 1/4/2006 and 30/6/2006.

During each survey mesohabitat extents were mapped using SFT descriptions, adapted from the River Habitat Survey (Table 1), onto a large scale plan of the river channel, aided by a Global Positioning Satellite receiver. Within the core of each mesohabitat, data were recorded at five points. Depth, velocity (at 0.6 m depth); substrate as dominant (>50%), subdominant (<50%) and ‘present’

Table 1 *Surface flow type descriptions, adapted from the River Habitat Survey.*

No perceptible (NP)	Areas with no detectable net downstream flow may, have upstream (eddy) flow.
Smooth (SM)	Laminar flow with a ‘glassy’ surface.
Rippled (RP)	Small symmetrical surface ripples generally <1cm high moving downstream or laterally.
Unbroken standing wave (UW)	Stationary waves with upstream facing wavelets that have not broken, may resemble ‘dragon-backs’.
Upwelling (UP)	Strong upward flow resulting in ‘boils’ on the water surface.

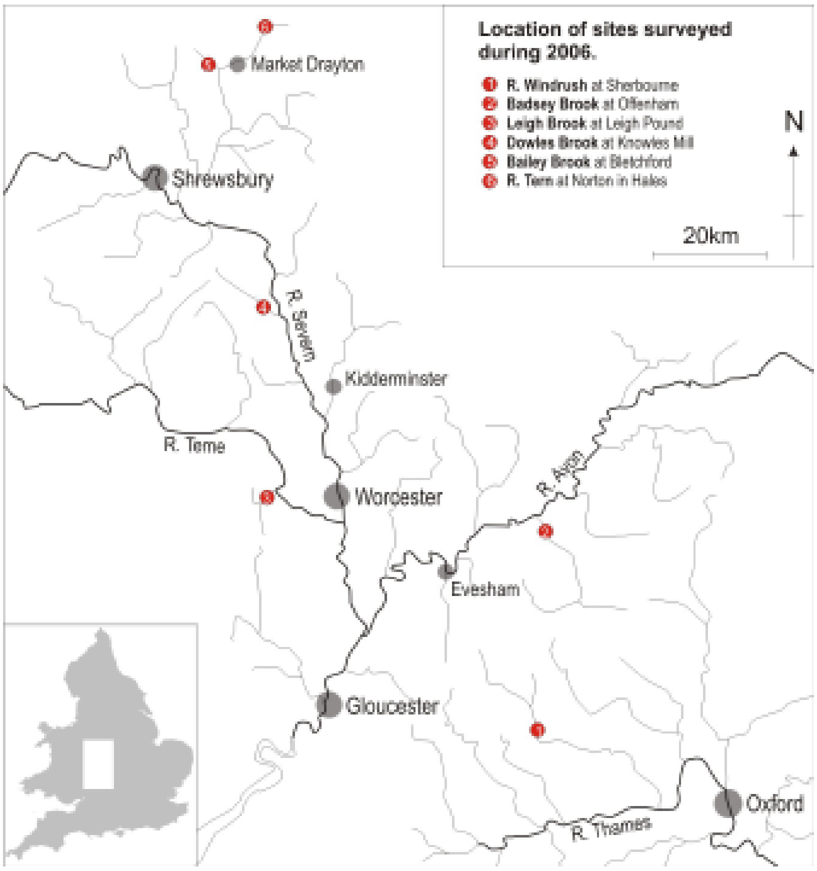


Figure 1 *Location of sites surveyed between 1/4/2006 and 30/6/2006*

(classes based on the Wentworth scale); estimates of embeddedness (Eastman, 2004), algal, bryophyte, macrophyte and overhead vegetation cover. A representative example of each mesohabitat was selected for macroinvertebrate sampling. Three one-minute kick-samples of an area approximately 0.35 m × 0.23 m using a 500µm mesh D-net were conducted. The samples were preserved and later examined in the laboratory, with identification to taxonomic family level. At each kick-sample point physical data were recorded: depth, velocity (on the bed, at 0.05 m and 0.1 m above the bed and at 0.1 m intervals to, and including, the surface); substrate as dominant (>50%), subdominant (<50%) and 'present'; estimates of embeddedness, algal, bryophyte, macrophyte and overhead cover.

A few instances of broken standing wave, chute and confused (mixture of several types) flow were mapped but not investigated further; free fall was not encountered in these lowland streams.

Results

Eighteen surveys identified 341 mesohabitats: NP flow – 42, SM flow – 97, RP flow – 119, UW flow – 55, UP flow – 10, others – 18. Figure 2 shows SFT mapping of three surveys at Leigh Brook, Worcestershire.

The proportion of each SFT type can be seen to change as discharge decreases (L1 – L3) whilst at 'A' a small side channel is only inundated at the highest discharge and at 'B' a bed-controlled area of unbroken wave flow (riffle) contracts as discharge increases demonstrating the increase in bed controls at lower discharge. Figure 3 shows the proportion of each SFT habitat present at three discharges, Q_{10}, Q_{30} and Q_{65}. Broadly, lower energy mesohabitat areas (NP and SM) increase as discharge decreases, whilst higher energy mesohabitat areas (RP and UW) decrease.

Depth and velocity data were recorded from 1457 points in 323 mesohabitats, the range of data by SFT mesohabitat is shown in Table 2. Mean depth decreased from UP > NP > SM > RP > UW whilst mean downstream

Table 2 *Range of data recorded from 1 446 points in six UK rivers during 2006*

Depth (m)	NP	SM	RP	UW	UP
N=	140	461	584	244	28
Mean	0.51	0.42	0.26	0.19	0.64
Range	1.42	1.16	0.92	0.67	0.85
Minimum	0.08	0.04	0.04	0.03	0.25
Maximum	1.50	1.20	0.96	0.70	0.10
Velocity (m s-1)	NP	SM	RP	UW	UP
N=	140	461	584	244	28
Mean	-0.03	0.24	0.27	0.53	0.28
Range	0.52	0.90	1.03	1.29	0.74
Minimum	-0.30	-0.03	0.94	1.25	0.61
Maximum	0.22	0.87	0.94	1.25	0.61

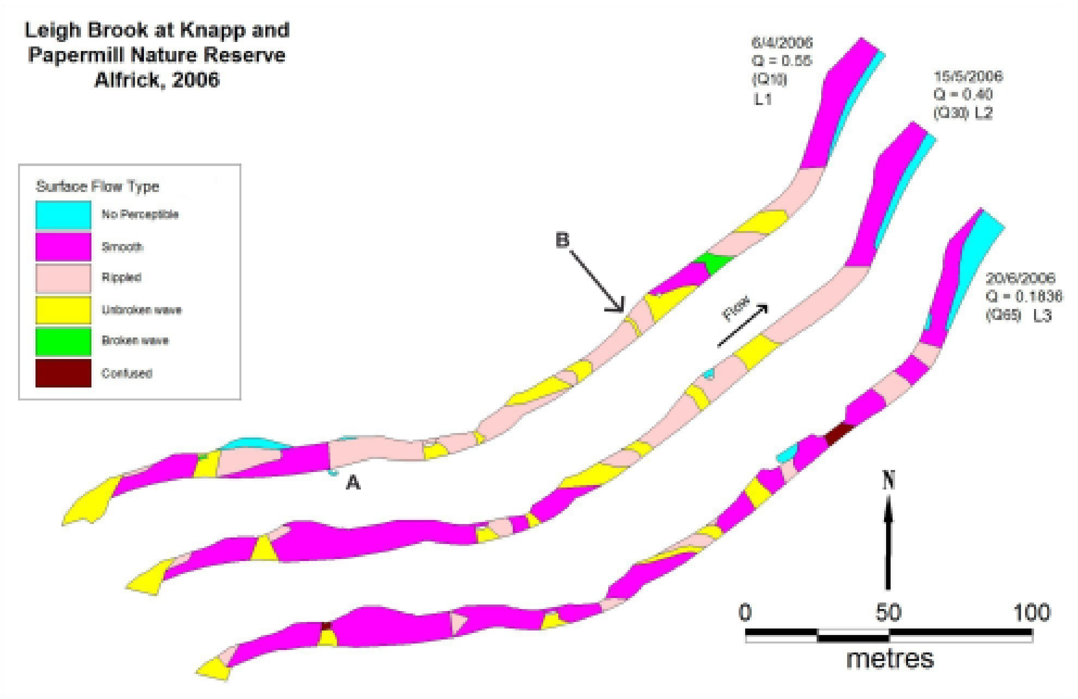


Figure 2 *Habitat types from three surveys of the same reach of Leigh Brook, Worcestershire, UK. 'A' shows a small backwater inundated only high discharge and 'B' a bed controlled area of unbroken wave.*

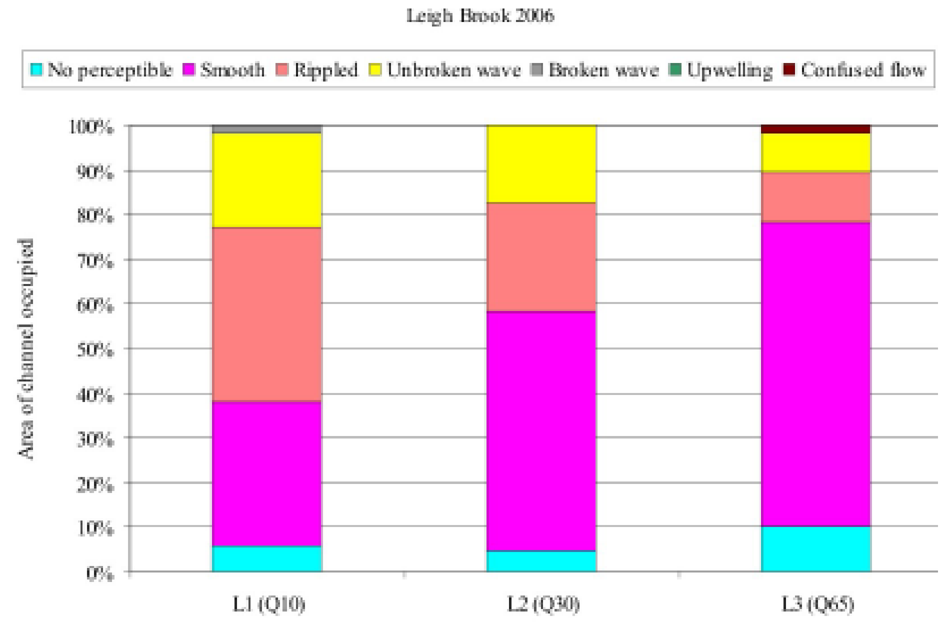


Figure 3 *Relative proportions of the channel occupied by six surface flow types in Leigh Brook, Worcestershire, UK during three surveys in 2006.*

velocity increased through NP > SM > RP > UP > UW. These data show that generally within SFT mesohabitats, as depth increases velocity decreases. However, a proportion of velocity in UP flow is in a vertical direction, reducing the downstream velocity considerably. These results are likely to be broadly in line with similar data from other mesohabitat surveying methods.

There are overlaps in the range of both depth and velocity between SFT mesohabitats. The depth and velocity data for each SFT mesohabitat was tested for significant differences using the Man-Whitney *U* Test. Table 3 presents a contingency table showing the significance of the differences. There is a significant difference ($P=<0.05$) in depth between all SFT mesohabitat combinations, and in velocity between all SFT mesohabitat combinations except between UP and SM, and between UP and RP.

Benthic macroinvertebrates live on or close to the river bed, being influenced by near-bed conditions. Therefore, the relationship between near-bed conditions and river

Table 3 *Results from Mann-Whitney U test analysis of depth and velocity data from five surface flow type habitats. (Significant: P = <0.05, Not Sig.: P = >0.05)*

Depth	No Perceptible	Smooth	Rippled	Unbroken wave
No Perceptible				
Smooth	Significant			
Rippled	Significant	Significant		
Unbroken wave	Significant	Significant	Significant	
Upwelling	Significant	Significant	Significant	Significant
Velocity				
No Perceptible				
Smooth	Significant			
Rippled	Significant	Significant		
Unbroken wave	Significant	Significant	Significant	
Upwelling	Significant	Not Sig.	Not Sig.	Significant

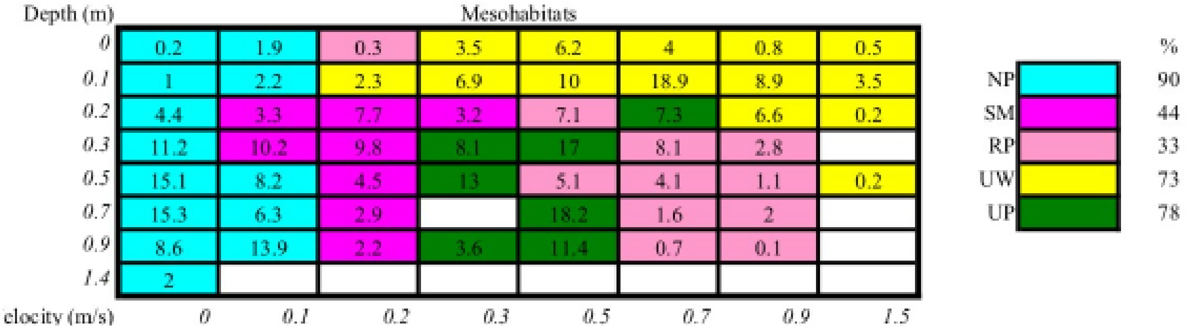
surface conditions is crucial, posing the question – "is what you see, what you get?" Downstream water surface velocity at each macroinvertebrate sample point was plotted against downstream water velocity on the river-bed and velocity 0.05 m above the river-bed. Table 4 shows the R^2 values of the correlation between the data sets, and that there is a strong relationship between the data. This suggests that downstream velocity at the surface is related to that on or near the riverbed. Upwelling mesohabitats have the least strong relationship.

HydroSignature (Le Coarer, 2005) calculates the percentage of user defined depth and velocity classes in a given area of stream habitat. A calculation was made for each SFT from all mesohabitat depth/velocity surveys. For each depth/velocity cell, the SFT with the highest percentage of habitat was identified. The matrix in Figure 4 shows that NP habitat (blue) is slow and deep plotting to the left of the matrix, UW habitat (yellow) is shallow and fast, plotting to the upper right. SM habitat (deep pink) is to the left of UP (green) and RP (light pink). 90% of NP habitat area is represented by the blue area, 78% of UP habitat by the green and 73% of UW habitat by yellow; SM habitat (44%) and RP habitat (33%) are less well defined. White cells show depth/velocity classes which were not present during the surveys. The percentages represent the likelihood of an observer correctly identifying the depth/velocity class of each SFT mesohabitat depth/velocity by using surface flow type mapping.

Table 4 *R^2 values of the relationship between surface velocity and velocity at near-bed, and surface velocity and bed + 0.05 m from 18 surveys of six UK rivers.*

Downstream velocity	R^2 near-bed	R^2 at bed + 0.05m
No Perceptible	0.903	0.914
Smooth	0.943	0.939
Rippled	0.977	0.986
Unbroken wave	0.946	0.898
Upwelling	0.881	0.884

Two hundred and four macroinvertebrate samples were taken. Forty-three taxonomic groups were identified with between 5 and 6712 individuals from all samples. DECORANA ordination of the macroinvertebrate data showed that it was not possible to differentiate between sites because water quality, as BMWP score, varied from 29–76 across sites. However, DECORANA ordination of the macroinvertebrate data from each site showed some degree of separation between SFT mesohabitats. Figure 5 shows Leigh Brook DECORANA ordination of the two strongest axes, one and two. Depth, velocity and biofilm are driving the *x*-axis whilst depth and season are driving the *y*-axis. The numbers of individuals found in each mesohabitat type varied. Figure 6 shows the percentage of macroinvertebrate groups found in each SFT mesohabitat across 18 surveys. It is clear that some groups favour lower energy SFTs, e.g. 52% of worms (*Oligochaeta*) (n = 1 081) were found in no perceptible mesohabitats, whilst 88% of the caddis fly (*Glossosomatidae*) (n = 114) were



Depth (m)	Mesohabitats							
0	0.2	1.9	0.3	3.5	6.2	4	0.8	0.5
0.1	1	2.2	2.3	6.9	10	18.9	8.9	3.5
0.2	4.4	3.3	7.7	3.2	7.1	7.3	6.6	0.2
0.3	11.2	10.2	9.8	8.1	17	8.1	2.8	
0.5	15.1	8.2	4.5	13	5.1	4.1	1.1	0.2
0.7	15.3	6.3	2.9		18.2	1.6	2	
0.9	8.6	13.9	2.2	3.6	11.4	0.7	0.1	
1.4	2							
elocity (m/s)	0	0.1	0.2	0.3	0.5	0.7	0.9	1.5

	%
NP	90
SM	44
RP	33
UW	73
UP	78

Figure 4 *Distribution of depth and velocity classes by surface flow type from mesohabitat data based on HydroSignature analysis*

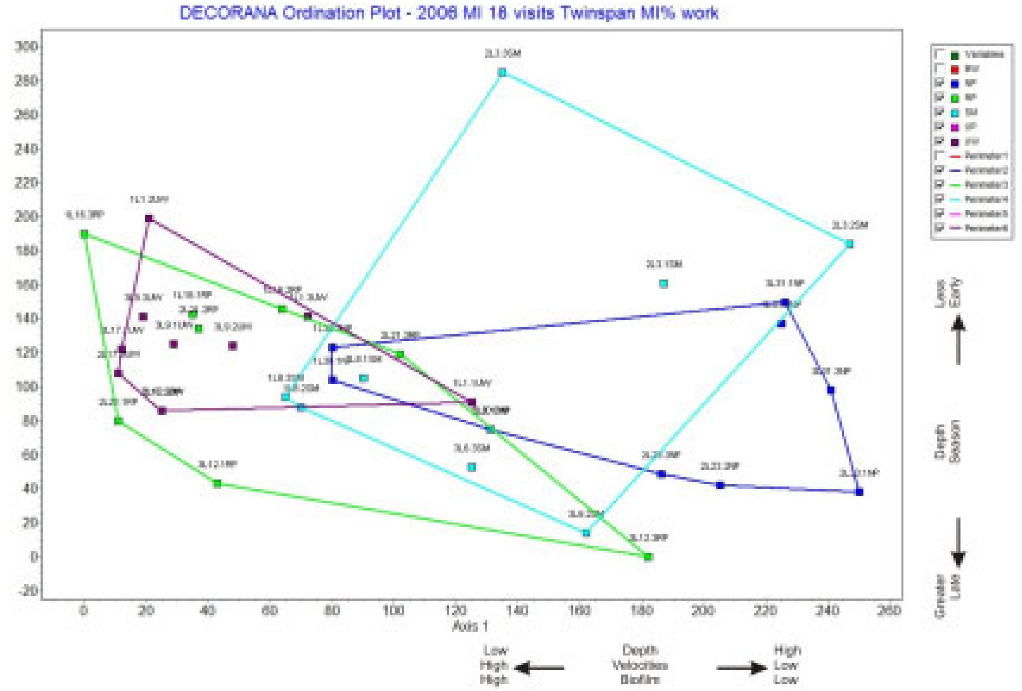


Figure 5 *Axes one and two from DECORANA ordination of macroinvertebrate samples grouped by surface flow type habitat for Leigh Brook, 2006*

found in unbroken wave habitats. This chart suggests a relationship between SFTs and the benthic macroinvertebrate community.

Discussion

Mesohabitat mapping using SFTs has been shown to be practical. Further, the habitat location and extent change with discharge similarly to other habitat descriptions, e.g. CGUs. Mapping the spatial extent of habitats, rather than using the dominant habitat across the whole channel, provides greater resolution and greater detail which, given the complexity of in-stream habitats, is beneficial.

Surface Flow Type mesohabitat mapping can only be appropriate if the physical properties of each are distinct and they are biologically relevant. Water depth and velocity are key variables, of interest to fluvial geomorphology, hydrology and ecology. Here, whilst there is inevitably an overlapping range of values across the data, mean depth increases as mean velocity decreases. The Mann-Whitney *U* Test shows that NP, SM, RP and UW mesohabitats are significantly different, UP mesohabitat is less so. Similarly the relationship between surface downstream velocity and both near-bed velocity and velocity at 0.05 m above the bed is strong, with UP mesohabitat less strong.

HydroSignature analysis suggests that it is possible, with varying degrees of success, to correctly identify a depth/velocity class from the SFT observed. Rippled and smooth flow had the lowest chance (33 and 44% respectively) of correct identification, which is probably related to the manner in which these two SFTs swap proportions as discharge changes. At low discharge there is likely to be a greater proportion of smooth flow than rippled, whereas at high discharge there is likely to be a greater proportion of rippled flow, with the expectation that the greater part of the channel will have rippled flow at near bankfull.

Although some macroinvertebrate families appear to be associated with certain SFT mesohabitats (Figure 6), DECORANA ordination of the whole data set was unable to separate the SFT mesohabitats. Macroinvertebrates respond to a range of variables, in addition to depth and velocity. Water quality is of great importance, with substrate, habitat disturbance and food also important. Although sites were selected so as to minimise between-site differences, the signature of these variables appears to be swamping the between-site ordination. A greater understanding of the variables may allow the SFT mesohabitat signature to be identified.

Conclusion

Mapping mesohabitats using surface flow types appears to have some merit and may provide a practical method of identifying in-stream habitats at a broad scale. The biological relevance of SFT habitats is still at an early stage, but progress to date is encouraging.

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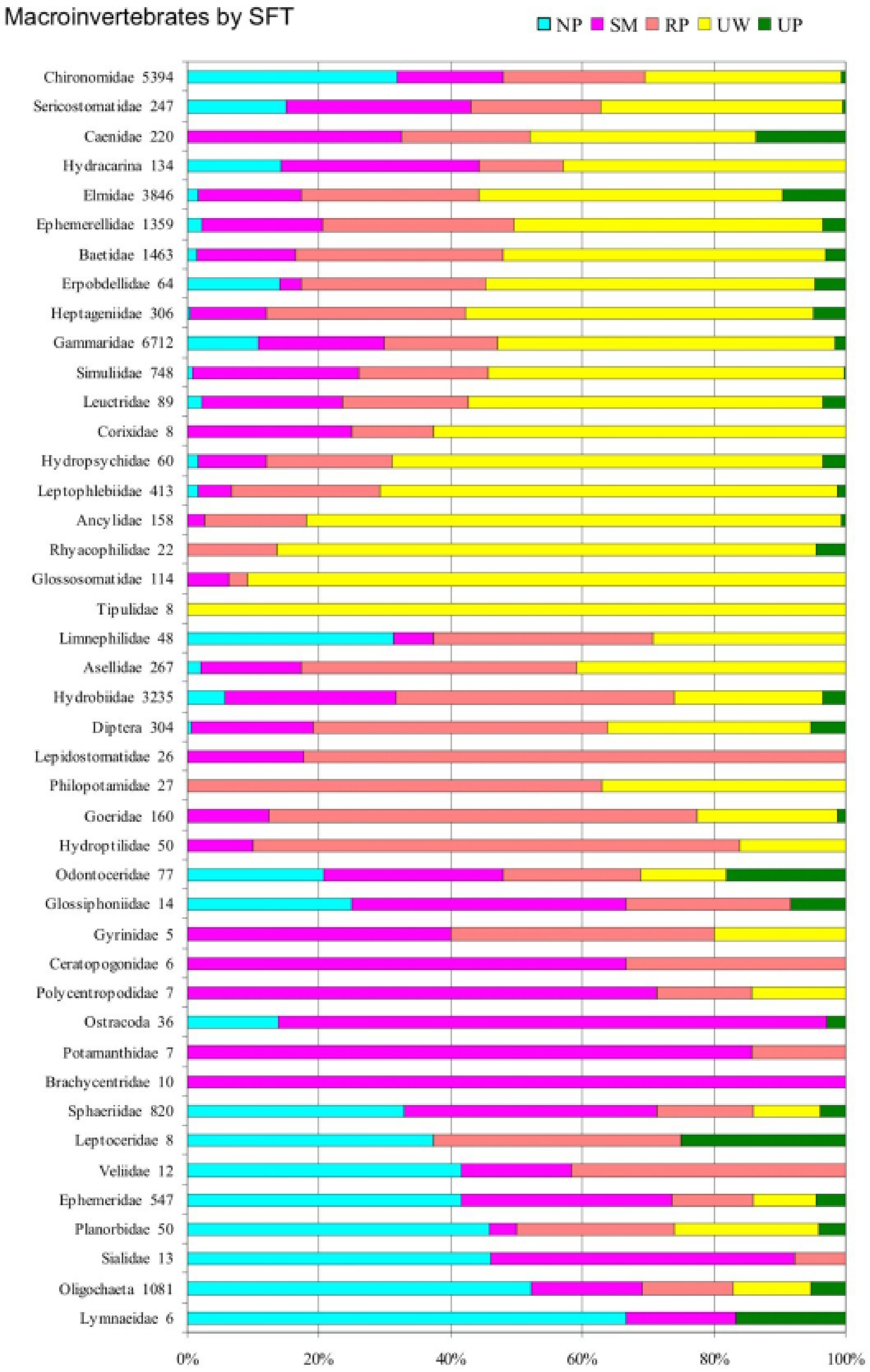

Figure 6 *Chart showing percentage of macroinvertebrates in surface flow types, 2006. The number by the taxonomic group name shows the number of individuals found in all samples.*

References

Booker, D.J., Acreman, M.C., Dunbar, M.J., Goodwin, T., Gowing, I. and Young, A., 2006. Rapid assessment of physical habitat-discharge relationships. *Proc. Inte.Conf.on Riverine Hydroecology: Advances in research and applications*, University of Stirling, 14th – 18th August 2006.

Bovee, K.D., 1982. A guide to stream habitat analysis using In-stream Flow Incremental Methodology. *In-stream Flow Information Paper 12*. FWS/OBS-82/26, Office of Biological Services, US Fish and Wildlife Service.

Eastman, K., 2004. Effects of embeddedness on fish habitats: an approach for implementation in the Habitat Simulation Model CASiMiR. Unpublished Masters Thesis, Universität Stuttgart.

Eisner, A., Young, C., Schneider, M. and Kopecki, I., 2005. MesoCASiMiR – new mapping method and comparison with other current approaches. In: *COST 626 - European Aquatic Modelling Network. Proceedings from the final meeting,* A. Harby *et al*. (eds), Silkeborg, Denmark 19–20 May 2005. National Environmental Research Institute, Silkeborg, Denmark.

Harby, A., Halleraker, J.H., Sundt, H., Alfredsen, K.T., Borsanyi, P., Johnse, B.O., Foreseth, T., Lund, R. and Ugedal, O., 2004. Assessing habitat in rivers on a large scale by linking microhabitat data with mesohabitat mapping. Development and test in five Norwegian Rivers. *Proc. Fifth Int. Symp. on Ecohydraulics*, D. García de Jalón and P.V. Marteninez (eds.), Madrid, Spain, 12–17 September 2004.

Hawkins, C.P., Kershner, J.L., Bisson, P.A., Bryant, M.D., Decker, L.M., Gregory, S.V., McCullough, D.A., Overton, C.K., Reeves, G.H., Steedman, R.J. and Young, M.K., 1993. A Hierarchical approach to classifying stream habitat features. *Fisheries*, **18**, 3–12.

Le Coarer, Y., 2005. HydroSignature software for hydraulic quantification. In: *COST 626 - European Aquatic Modelling Network. Proceedings from the final meeting,* A. Harby *et al*. (eds), Silkeborg, Denmark 19–20 May 2005. National Environmental Research Institute, Silkeborg, Denmark.

Maddock, I.P. and Bird, D., 1996. The Application of Habitat Mapping to Identify Representative PHABSIM Sites on the River Tavy, Devon, UK. *Int. Symposium on habitat hydraulics, M.* Leclerc (ed) ., Quebec, IAHR.

Padmore, C.L., 1998. The role of physical biotopes in determining the conservation status and flow requirements of British rivers. *Aquat. Ecosystem Health Manage.*, **1**, 25–36.

Parasiewicz, P., 2001. MesoHABSIM: A concept for application of instream flow models in river restoration planning. *Fisheries*, **26/9**, 6–13.

Principe, R.E., Raffaini, G.B., Gualdoni, C.M., Oberto, A.M. and Corigliano, M.C., 2007. Do hydraulic units define macroinvertebrate assemblages in mountain streams of central Argentina? *Limnologia*, **37**, 232–336.

Wadeson, R.A. and Rowntree, K.M., 1998. Application of the hydraulic biotope concept to the classification of instream habitats. *Aquat. Ecosystem Health Manage.,* **1**, 143–157.