An investigation of the role of geomorphology in influencing biotope distribution

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Abstract Riffle–pool–point bar sequences provide the template for a number of aquatic habitats. Water flowing over these morphologies generates spatial hydraulic variation over a river's flow regime resulting in a changing mosaic of hydraulic habitats or biotopes. Little attention has been given to the explicit spatial and temporal distribution of biotopes in relation to channel morphology. This study uses terrestrial LiDAR data to map biotope distribution at two discharges. A link was found between the riffle units and key characteristic biotopes. Biotope type change was also broadly consistent over this scale but areal coverage varied between units. It is argued that management options for such river systems targeted at maintaining the gross morphology will succeed in creating a variety of hydraulic biotopes that are consistent in their types across riffles; however, distribution and dominance are likely to be controlled by more local factors such as bed material and channel slope.

Key words hydraulic habitat; biotope; riffle–pool; terrestrial laser scanning; flow regime

BACKGROUND

Habitat loss is one of the major threats to biodiversity globally (WRI, 2000) and quantifying habitat distribution and its changes is an important conservation issue. An important move towards achieving this has been a formal recognition that the morphology of river channels influences the distribution and abundance of instream physical habitats (Wadeson, 1994). At the catchment scale, the patterns of topography, rainfall, temperature, geology and land-use are expressed in the hydrological and geomorphological attributes of the river. This spatial expression provides the quasi-stable template of physical habitat. The hydrology then superimposes the dynamic nature of hydraulic habitat on this physical form.

Riffles, pools and point-bar features represent basic morphologic units present in temperate gravel-bed rivers and provide the physical template for a number of aquatic habitats. Water flowing over these morphologies generates spatial hydraulic variation over a rivers flow regime resulting in a changing mosaic of hydraulic habitats or biotopes in space (Wadeson & Rowntree, 1998; Dyer & Thoms, 2006) and time (Stalneker *et al.*, 1996; Newson *et al.*, 1998). Biotopes provide a standard, descriptive assessment of instream physical structure based on consistent recognition of features (Padmore, 1997; Newson *et al.*, 1998; Large & Heritage, 2007). They have their basis in the development of typologies to underpin the "Habitat Quality Index" developed as a framework for the protection of rivers (Raven *et al*., 1997), and provide a means of integrating ecological, geomorphological and water resource variables for management purposes. The biotope concept allows for a standard, descriptive assessment of instream physical structure based on consistent recognition of features over a range of spatial and temporal scales. Biotopes offer an opportunity to provide a meaningful habitat descriptor at the scale of the geomorphic unit (Stalnaker *et al*., 1996) and below (Heritage *et al*., 2009). Questions remain, however, as to the extent to which "physical habitats" (areas of distinct species assemblages associated with water depth, velocity and substrate combinations) may be mapped onto physical biotopes (riffles, runs, pools, and glides) in rivers.

This study utilizes terrestrial laser scanning technology to map a series of riffle units in a typical upland gravel-bed river in the UK across two flows, and maps biotope units based on their surface water expression following the methodology proposed by Heritage *et al.* (2009). Relative

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biotope coverage statistics are then computed allowing direct comparison between riffle sites allowing patterns of similarity and difference to be described and discussed across the measured flows.

Study site

The study focuses on a 175-m reach on the River Rede, Northumberland, UK, an upland gravel-bed stream. The Rede has a Strahler order of four, and has its source area in the Cheviot Hills at 490 m above Ordnance datum. The single-thread cobble-bed study reach has a catchment area of 18 km^2 and was selected on the basis of a well-defined sequence of 4 pools and 3 riffles (Fig. 1). The site (Grid reference NT 721 043) is unregulated and experiences a flashy hydrological regime. The geology of the Rede catchment is diverse; Silurian greywackes and shales are overlain by Devonian andesite lavas, part of a major igneous complex of the Cheviot Hills. Lower Carboniferous Fell sandstones predominate throughout the upper part of the catchment, interspersed with Scemerston coals. This mixed lithology is reflected in the bedload material within the River Rede main channel, and influences grain shape and gross morphology at any given point along the channel.

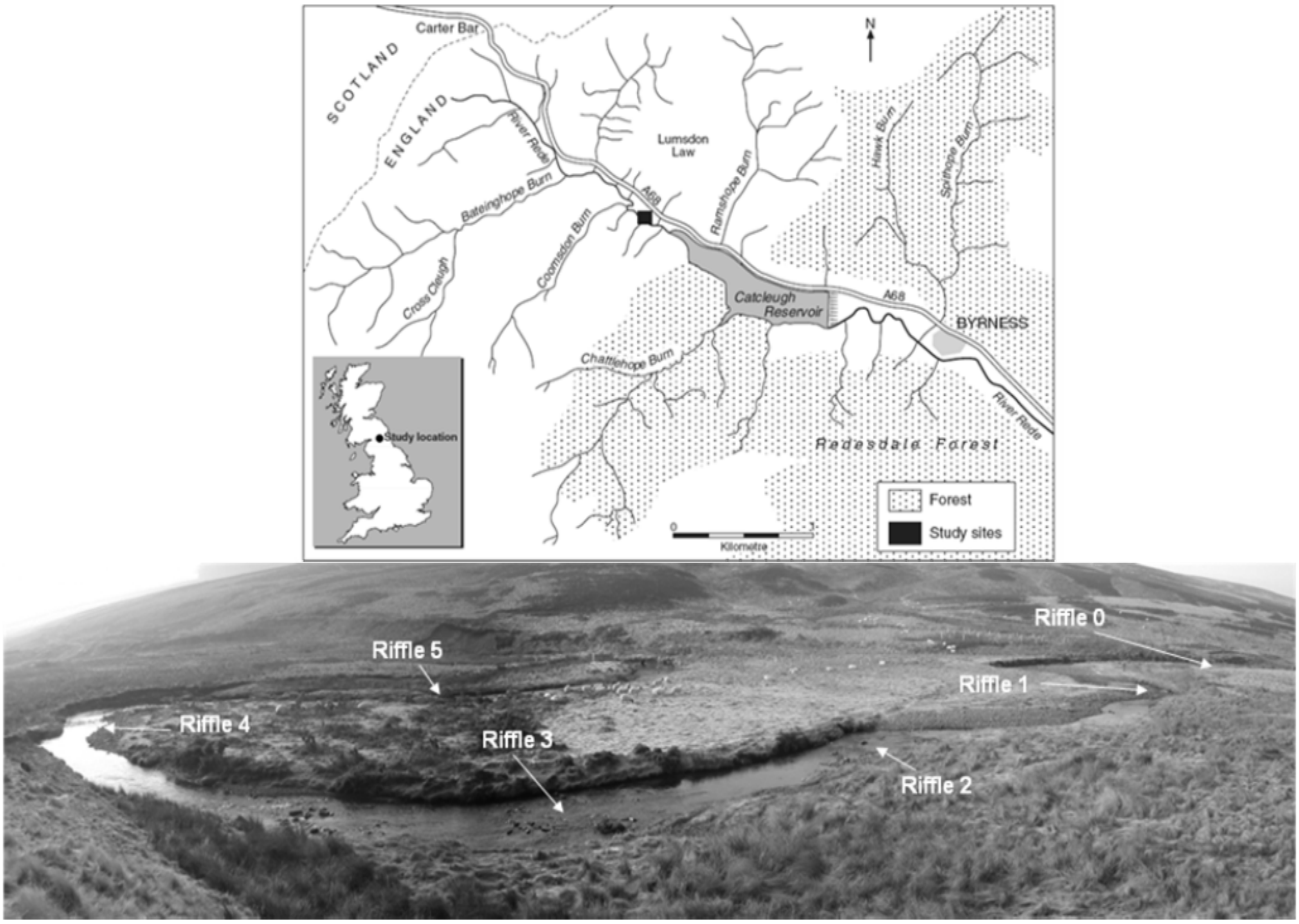

Fig. 1 Location of the pool-riffle sequence study site on the River Rede, Northumberland, UK.

METHODOLOGY

An LMS Z-210 scanning laser manufactured by Riegl Instruments was used to collect topographic data for the study reach. The instrument works on the principle of “time of flight” measurement using a pulsed eye-safe infrared laser source (0.9 μm wavelength) emitted in precisely defined angular directions controlled by a spinning mirror arrangement. A sensor records the time taken for light to be reflected from the incident surface and distance (d) is then calculated using equation (1).

$$D = ct/2 \tag{1}$$

where c = speed of light and t = time.

Angular measurements are recorded to an accuracy of 0.036° in the vertical and 0.018° in the horizontal allowing 3-D grid coordinates to be calculated using simple trigonometric functions.

Survey control was facilitated by RiScan Pro survey software, capable of visualising point cloud data in the field. Scans were generally restricted to 240° in front of the scanner and scans were collected with substantial overlap ensuring that the surface of the study reach was recorded from several directions (see Heritage & Hetherington, 2007). The effect of this approach is to increase the point resolution across the surface and to reduce the possibility of unscanned areas due to the shadowing effect of roughness elements along the line of each scan. Before scans were taken, a total of 22 reflectors were placed on and around the study reach. These reflectors were tied into the project co-ordinate system using an EDM theodolite, and these were automatically located by the RiScan-Pro software and matched to the project co-ordinates using a common point configuration algorithm.

Although clear, still water is a poor reflector of infrared light (Fig. 2), suspended solids and surface disruption both serve to increase the chances of recording return energy from a laser pulse. High disruption over riffle surfaces, combined with the very large number of potential data points, permits collection of variable amounts of data from flowing water dependent on surface character and scan angle (Karabulut & Ceylan, 2005; Höfle *et al.*, 2008).

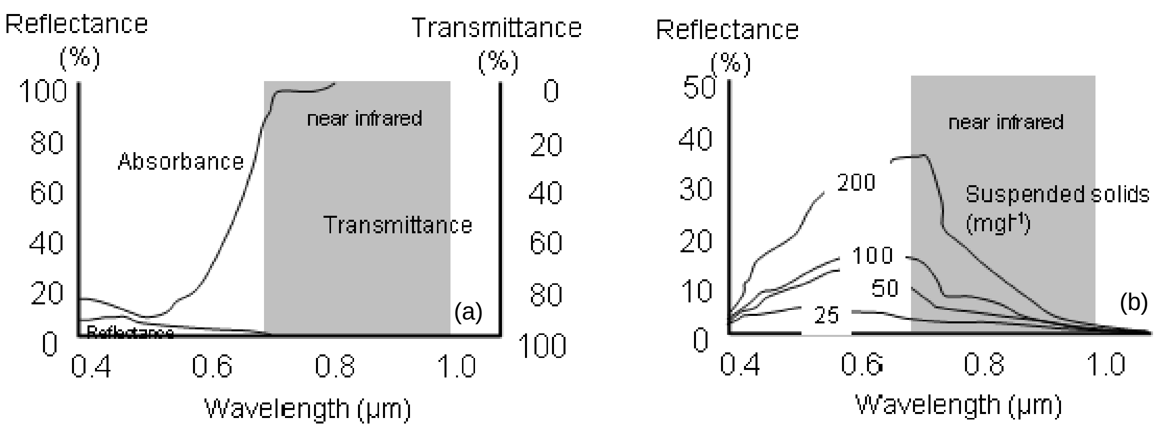

Fig. 2 The spectral character of clear still water with reference to laser reflection in the infrared region.

Table 1 Scan data coverage statistics for the River Rede study site.

Flow level ($m^3 s^{-1}$)	Riffle 0	Riffle 1	Riffle 2	Riffle 3	Riffle 4	Riffle 5
May						
Points	101 576	262 007	67 839	353 059	12 634	154 688
Area	5.79	63.57	22.6	5.16	7.96	39.3
Density	17 543	4122	3002	68 422	1587	3936
November						
Points	–	374 008	5262	197 718	10 5276	–
Area		76.32	5.9	41.43	10.26	
Density	–	4901	892	4772	10 261	–

A total of 10 riffles were scanned across two flows (Table 1), four of which were mapped for both discharges. The flow was gauged locally as 0.35 $m^3 s^{-1}$ in May 2008 and 0.77 $m^3 s^{-1}$ in November 2008. The water surface data were extracted as Ascii files for analysis in the Surfer 3-D mapping and geostatistical package.

The local standard deviation of the data were computed using a 0.1 m radius moving window and these data were gridded at 0.2 m so as to capture the smallest biotope unit seen across the riffle surfaces. These data were then classified using the surface roughness delimiters defined in Table 2 determined by Heritage *et al.* (2009) in a study of UK gravel-bed channels.

RESULTS

The water surface roughness data were analysed in terms of their frequency of occurrence across each of the riffles surveyed at both measured discharges. The resultant frequency plots (Fig. 3)

Table 2 Biotope surface roughness limits used to map the water surface data at sites one and two on the River Esk (after Heritage *et al.*, 2009).

Unit descriptor	Minimum surface roughness (m)	Maximum surface roughness (m)
Pool	0	0.005
Accelerating flow	0.012	0.016
Glide	0.016	0.02
Deadwater	0.018	0.02
Chute	0.019	0.023
Run	0.023	0.025
Riffle	0.025	0.03
Cascade	0.035	0.046
Boil	0.036	0.039
Unbroken standing wave	0.046	0.05
Broken standing wave	0.05	0.09

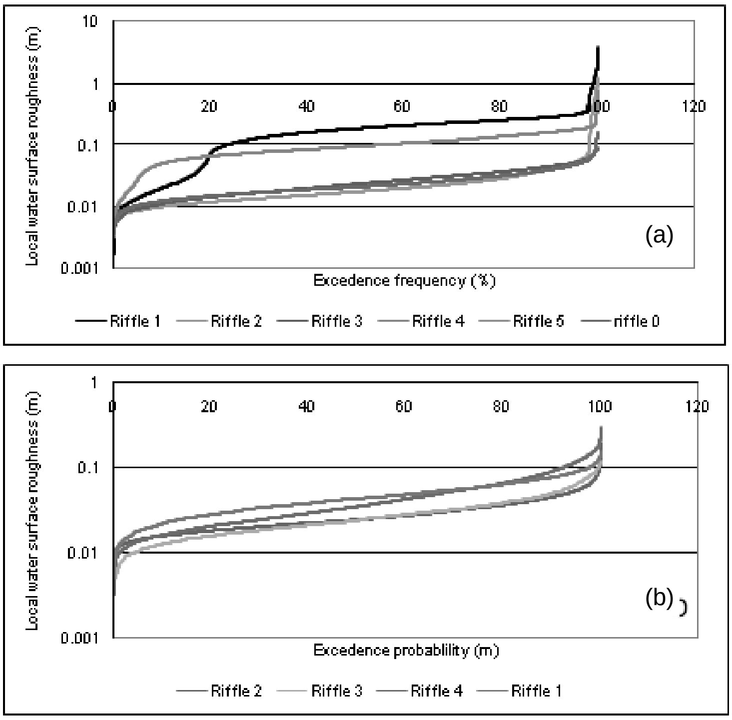

Fig. 3 Riffle surface roughness character for: (a) May and (b) November 2008.

Table 3 Grain characteristics for the riffle study sites on the River Rede, Northumberland, UK.

Site	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Sorting
Riffle 0*	33	70	125	0.97
Riffle 1	41	75	133	0.85
Riffle 2	44	84	150	0.89
Riffle 3	56	96	150	0.71
Riffle 4	55	90	170	0.81
Riffle 5	60	100	155	0.69

* Data from upstream riffle site.

indicate that the broad pattern of roughness is consistent between riffle sites for the same flow level. Most surface roughness is of the order of 1 to 5 cm, as would be anticipated from visual inspection of the flow. Increased discharge from May to November also appears to increase surface roughness slightly as the local effect of micro-topography in retarding the flow and creating calm water areas is reduced. Riffle 0 and Riffle 3 appear to be slightly different, generally displaying rougher water surface, this may indicate that these units are transitional between riffles and rapids, or that the underlying grain roughness is greater at these two sites (Table 3).

Spatial pattern of biotope distribution may also be determined using the surface roughness delimiters given in Table 2. Figure 4 illustrates the pattern recorded for May 2008; the results for November 2008 are shown in Fig. 5.

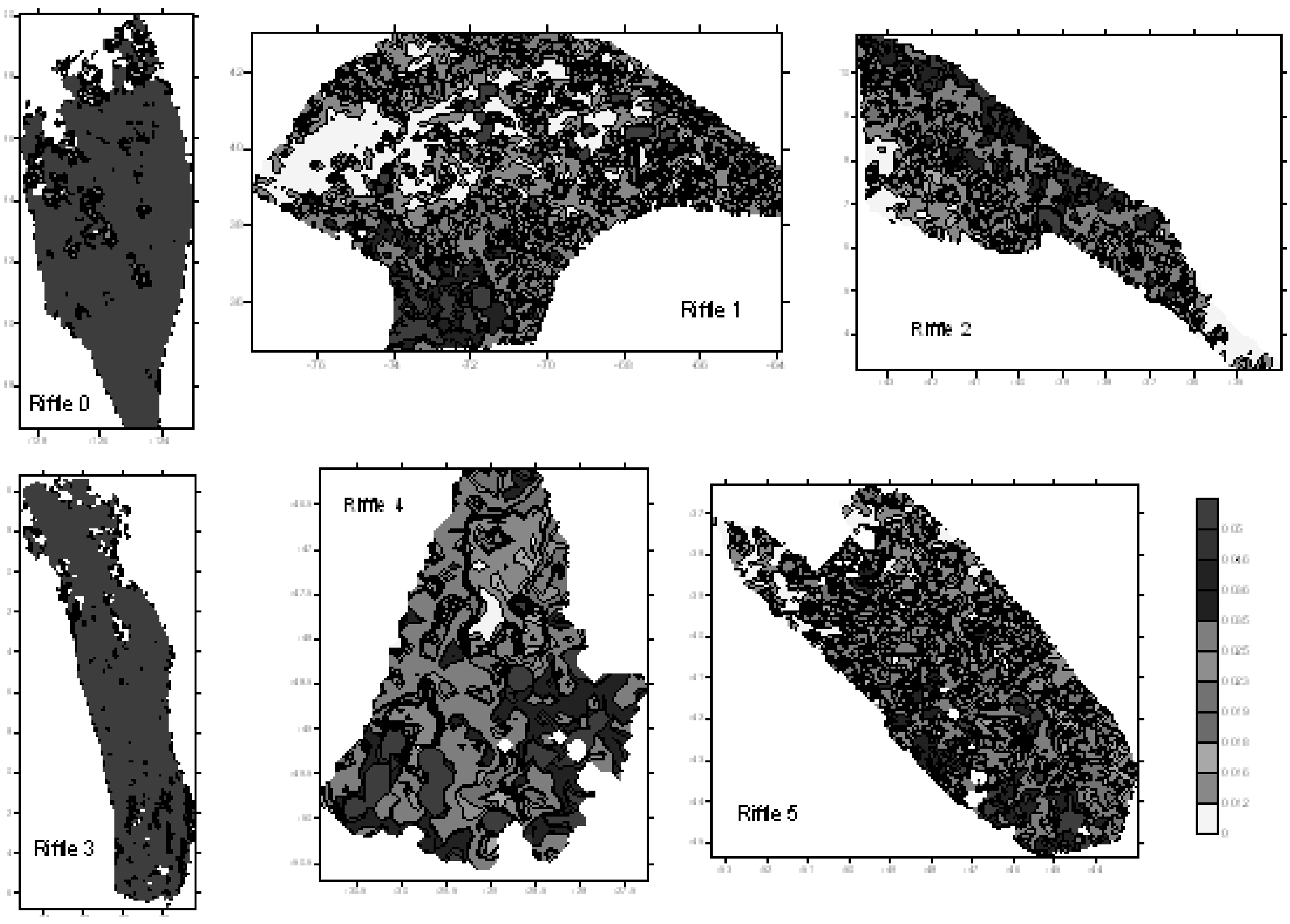

Fig. 4 Biotope distribution across the surveyed riffles for May 2008.

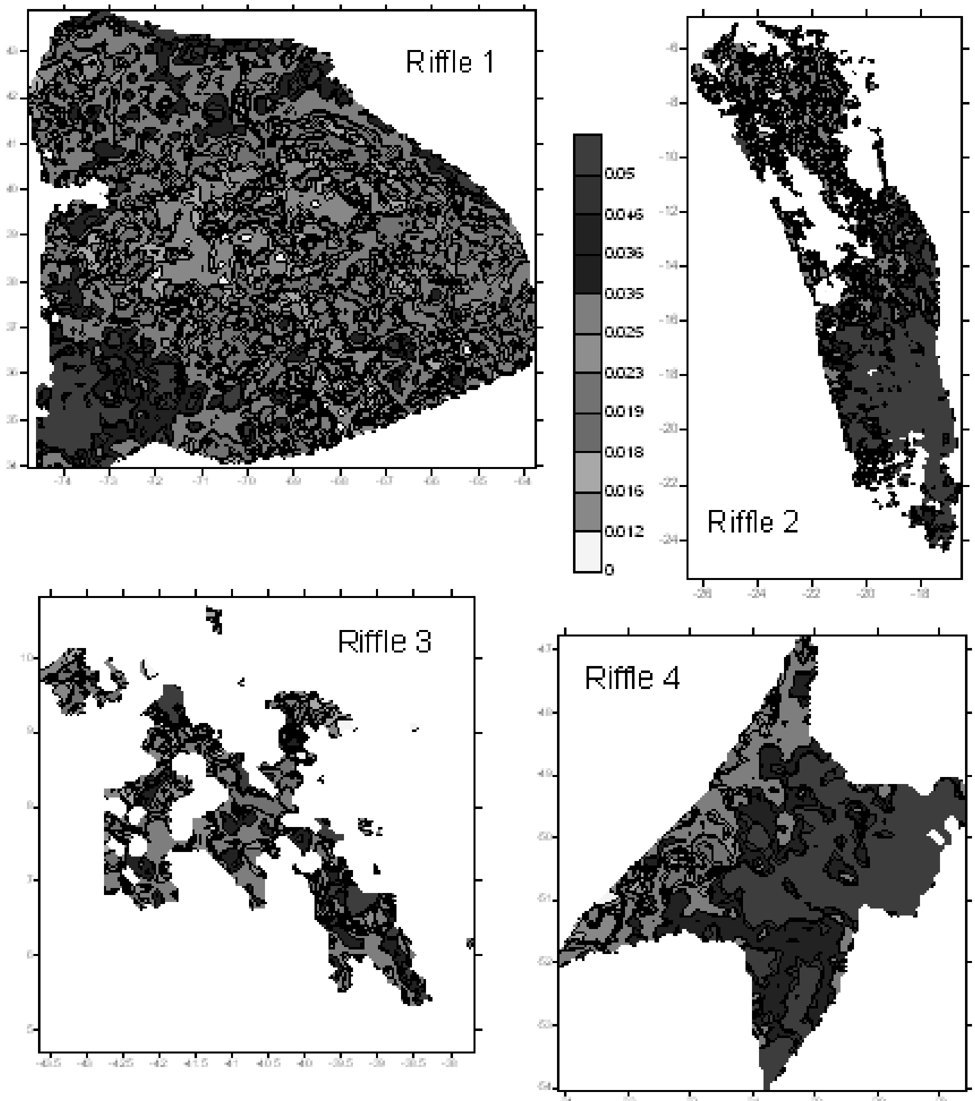

Fig. 5 Biotope distribution across the surveyed riffles for November 2008.

Biotope distribution is extremely patchy in all cases, and in some instances water surface roughness exceeds the limits defined by Heritage *et al.* (2009) resulting in no biotope classification being assigned to the riffle surface. This may in part reflect the inclusion of macro-roughness elements present across some of the riffles (Fig. 6) which were not excluded from the analysis. Additionally, where there were insufficient data points to allow for the calculation of local standard deviation, the node was blanked and appears as white on the maps.

The patchy nature of the results is partly a function of the moving window specified during the analysis; this was set to detect the smallest biotope unit present according to visual inspection (boils and chutes) but has resulted in larger biotope units being sub-divided into smaller spatial components. This would indicate that internal hydraulic variability is high within biotopes. This suggests an overly complex set of biotope classifications, a point previously suggested by Clifford *et al.* (2006) and Shoffner & Royall, (2009) in relation to overlapping hydraulic conditions (Froude number). There is a clear issue of scaling within the current biotope classifications (see Heritage *et al.*, 2009) which could explain some of the apparent surface roughnesses overlap of units composed of several smaller components.

Fig. 6 Example of macro roughness elements present at riffle 3.

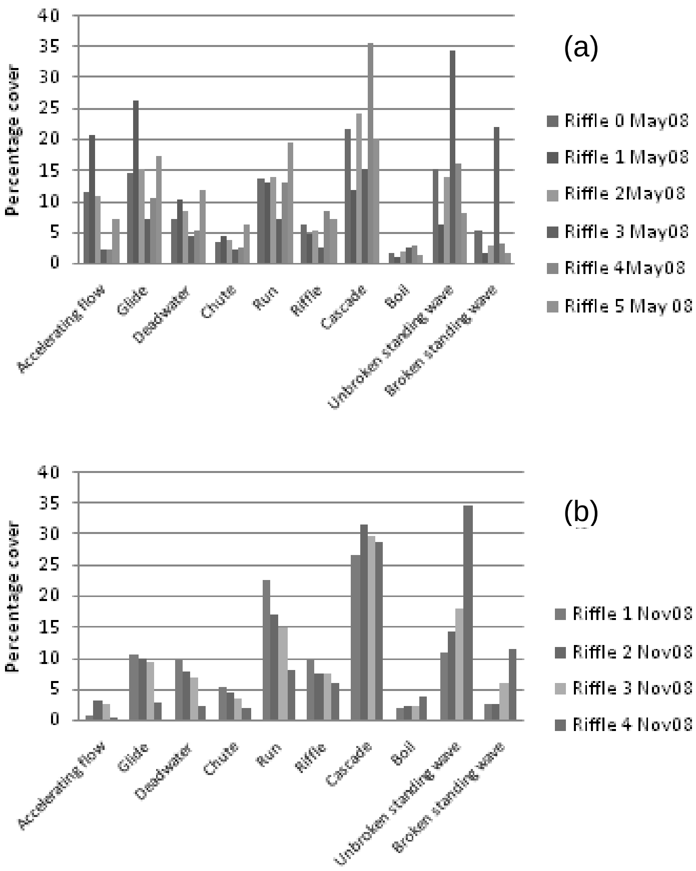

Fig. 7 Relative biotope dominance between riffles for: (a) May 2008 and (b) November 2008.

A comparative analysis of the relative dominance of each biotope unit across each riffle was conducted by dividing the aerial extent of each unit by the overall riffle area to produce a percentage cover value. These were calculated for both flows and the results are presented in Fig. 7. It should be noted that all surface roughness data were included in the analysis, including very high roughness values; however, these unclassified areas are not shown graphically.

Whilst the between riffle variation for each biotope unit appears quite high there is an overall dominance sequence that may be postulated with accelerating flow, glides and cascades dominating at lower flows, but being replaced by unbroken standing waves and runs as discharge increases. Higher energy broken standing waves remain rare across the two flows, as do chute and deadwater areas. These general changes are summarised in Fig. 8.

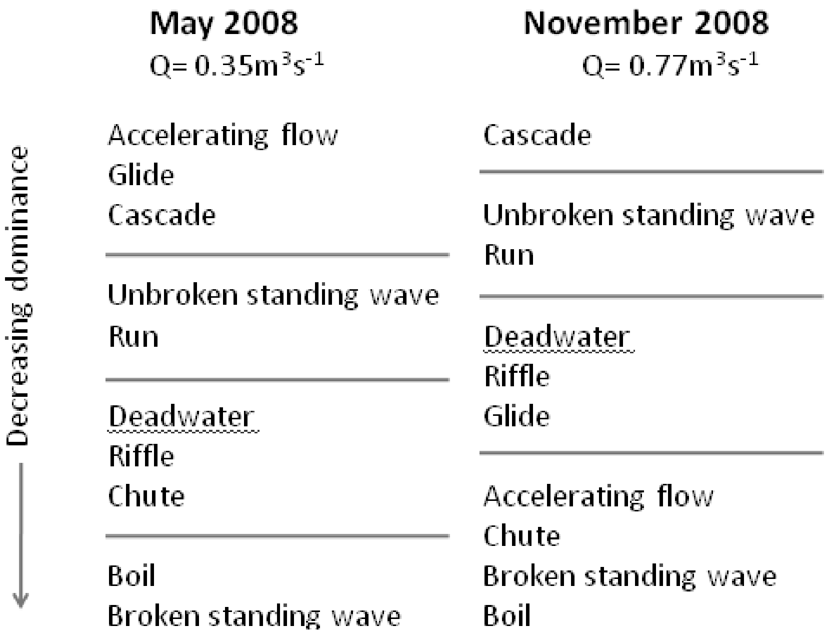

Fig. 8 Relative changes in dominance across riffles as discharge increases for the River Rede, Northumberland.

DISCUSSION AND CONCLUSIONS

Despite issues of signal loss due to absorption and transmission of infrared light through the water column, the volume of laser pulses emitted from terrestrial laser scanners is so great that the limited reflected signal still generates an extremely detailed and accurate objective map of water surface roughness, which may be visualized using standard interpolation and rendering techniques. Sufficient information may be acquired to perform a surface roughness analysis using a local moving window standard deviation approach set at the scale of the smallest biotope present. As a result, biotope distribution and relative dominance has been determined for a total of 6 riffles, 4 of which were scanned over two flows. Biotope coverage is extremely patchy in nature and suggests that the within-unit hydraulic variation is often as great as the variation between units. This would indicate a scale issue with observer-driven biotope delimitation effectively ignoring this very local variation in favour of broader categorization based on more arbitrary boundaries. This issue is reflected in the criticism of biotope classifications expressed by Clifford *et al.* (2006) and Shoffner & Royall (2009) based on overlapping hydraulic Froude number conditions. Froude number has been used as a hydraulic delimiter to support the existence and ecological relevance of biotopes (Padmore, 1997; Newson *et al.*, 1998; Wadeson & Rowntree, 1998); however, the data presented also display similar overlap between biotope units as well as considerable within unit range.

The overall pattern of biotope types and dominance is reasonably consistent between riffle units for the two flows measured. This provides general support for the recognition that the morphology of stream channels influences the distribution and abundance of instream physical habitats. It is clear, however, that the between unit variation in dominance is often significant and two distinct water surface roughness distributions have been recorded for the survey in May 2008. It may be that the morphologic unit scale is too large to reliably guarantee the presence of certain potentially critical biotopes, which may be controlled by factors such as local bed slope micro-morphology and grain roughness that remain variable between riffle units.

It is argued, however, that practical management options for such river systems targeted at maintaining the gross morphology will succeed in creating a variety of hydraulic biotopes that are consistent in their types across riffles; however, distribution and dominance are likely to be controlled by more local factors. Rehabilitation strategies are best focused at the morphologic unit scale to achieve a dynamic system displaying the biotope assemblage appropriate to the flow regime.

REFERENCES

Clifford, N. J., Harmar, O. P, Harvey, G. & Petts, G. E. (2006) Physical habitat, eco-hydraulics and river design: a review and re-evaluation of some popular concepts and methods. *Aquatic Conservation, Marine Freshwater Sci.* **16**, 389–408.

Dyer, F. J. & Thoms, M. C. (2006) Managing river flows for hydraulic diversity: an example of an upland regulated gravel-bed river. *River Res. Appl.* **22**(2), 257–267.

Heritage, G. L. & Hetherington, D. (2007) Towards a protocol for laser scanning in fluvial geomorphology. *Earth Surf. Processes Landf.* **32**, 66–74.

Heritage, G. L., Hetherington, D., Milan, D. J., Large, A. R. G. & Entwistle, N. (2009) Temporal characterisation of biotope units across the flow regime using repeat LiDAR survey. In: *Proc. 7th International Symposium on Ecohydraulics* (Concepción, Chile, January 12–16, 2009).

Höfle, B., Pfeifer, N., Ressl, C., Rutzinger, M. & Vetter, M. (2008) Water surface mapping using airborne laser scanning elevation and signal amplitude data. *Geophys. Res. Abstracts* **10**, EGU2008-A-06897.

Karabulut, M. & Ceylan, N. (2005) The Spectral reflectance responses of water with different levels of suspended sediment in the presence of algae. *Turkish J. Eng. Env. Sci.* **29**, 351–360.

Large, A. R. G. & Heritage, G. L. (2007) Terrestrial laser scanner based instream habitat quantification using a random field approach. In: *Proc. RSPSoc Conf. 2007* (Newcastle University, 4–8 September 2007).

Newson, M. D., Harper, D. M., Padmore C. L., Kemp J. L. & Vogel, B. (1998) A cost-effective approach for linking habitats, flow types and species requirements. *Aquatic Conservation: Marine and Freshwater Ecosystems* **8**, 431–446.

Padmore, C. L. (1997) Biotopes and their hydraulics: a method for defining the physical component of freshwater quality. In: *Freshwater Quality: Defining the Indefinable*? (ed. by P. J. Boon & D. L. Howell), 251–257. The Stationery Office, Edinburgh, UK.

Raven, P. J., Fox, P., Everard, M., Holmes, N. T. H. & Dawson, F. H. (1997) River habitat survey: a new system for classifying rivers according to their habitat quality. In: *Freshwater Quality: Defining the Indefinable*? (ed. by P. J. Boon & D. L. Howell), 215–234. The Stationery Office, Edinburgh, UK.

Shoffner, D. & Royall, D. (2009) Hydraulic habitat composition and diversity in rural and urban stream reaches of the north Carolina piedmont (USA). *River Res. Appl*. (in press).

Stalnaker, C. B., Bovee, K. D. & Waddle, T. J. (1996) Importance of the temporal aspects of habitat hydraulics to fish population studies. *Regulated Rivers: Research & Management* **12**, 145–153.

Wadeson, R. A. (1994) A geomorphological approach to the identification and classification of instream flow environments. *South African J. Aquatic Sci.* **20**, 38–61.

Wadeson, R. A. & Rowntree, K. M. (1998) Application of the hydraulic biotope concept to the classification of instream habitats. *Aquatic Systems Health & Manage.* **1**, 143–157.

World Resources Institute (2000) *People and Ecosystems: The Fraying Web of Life. United Nations Development Programme.* United Nations Environment Programme, World Bank, World Resources Institute, Washington DC, USA.