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HABITAT SURVEY AND CLASSIFICATION OF URBAN RIVERS

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ABSTRACT

River surveys are undertaken for a variety of purposes including (i) to establish inventories of particular features and their changes, (ii) to collect data to underpin the classification of river types or to assess resources according to particular criteria, and (iii) to identify sites that have particular qualities or may require particular types of management. In this paper we describe a new reach-scale survey technique, a range of synthetic indices, and a series of classifications specifically developed for application to urban rivers.

The Urban River Survey (URS) is developed from the River Habitat Survey (RHS) which is applied routinely to UK rivers. A number of important differences between the URS and RHS allow the former to provide improved discrimination between urban river channels to support management decision-making. Urban river stretches are identified for survey according to their engineering type (a combination of planform, cross-sectional form and level of reinforcement). The URS is then applied to stretches of a single engineering type and incorporates recording of (i) additional variables to the RHS that are particularly relevant to urban channels (e.g. indicators of pollution); (ii) improved resolution in the recording of some variables in comparison with the RHS (e.g. habitat features); and (iii) separation of layers of information that relate to the engineered (e.g. artificially introduced materials) and more natural (e.g. bank materials and morphological features) channel properties so that the interaction between these properties can be identified.

The URS is applied during two surveys of approximately 50 stretches of the River Tame, West Midlands, UK. The data are used to estimate a range of synthetic indices describing 'Materials', 'Physical Habitat' and 'Vegetation' attributes of urban river stretches. Cluster analysis is then applied to these indices to derive three classifications of urban river stretches. The similarity in classifications based on measurements from two different surveys indicates their robustness. Because the type of engineering applied to a stretch appears to have a significant influence on the class to which the stretch is allocated in each of the three classifications (with the strongest associations being apparent in the Materials classes and the weakest in the Vegetation classes), they can be used to explore the consequences of changed engineering, and the influence of scenarios of vegetation and water quality management can be additionally explored in relation to the Vegetation classification.

INTRODUCTION

River surveys are undertaken by river managers for a variety of purposes including (i) the establishment of inventories of particular features and changes in those features through time, (ii) the collection of data to underpin the classification of river types or to assess resources according to particular criteria, and (iii) the identification of sites that have particular qualities or may require particular types of management. The survey approach is driven by the purpose for which it is undertaken including its spatial scale (e.g. based on surveys of point locations, river reaches, or sectors of river networks), the degree to which it is monumented to allow precise repeat surveys, and the nature of the river properties that are recorded.

River habitat surveys

In a freely adjusting environment, fluvial processes (river discharge and sediment transport regimes) generated from upstream subcatchments and sectors of the river network interact with the local channel boundary materials

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(sediment calibre, vegetation cover) to generate a river channel of particular size and form (e.g. Wharton, 1995). The frequency of geomorphological features, such as pools and riffles, is scaled to the channel dimensions (Leopold and Wolman, 1957; Leopold *et al*., 1964), influencing the structure, stability and composition of the physical habitat mosaic. Thus, channel geomorphology at the reach scale should underpin any classification of river habitats (McEwen *et al.*, 1997), and should contribute to the formulation of rehabilitation plans for degraded rivers. The conviction that the geomorphological features found within the river channel can be used to assess the ecological potential of the river system has led to the development of a variety of geomorphological assessment methodologies including those proposed by Kellerhals *et al.* (1976), Thorne (1998: the Stream Reconnaissance Survey) and RSPB *et al.* (1994: the River Channel Morphology Assessment).

To provide a more integrated approach to channel assessment, habitat surveys have been developed which attempt to detail both the geomorphological characteristics and the ecological composition of the channel and the surrounding riparian zone. Examples include Meador *et al.* (1993), Petersen (1992: the Riparian, Channel, and Environmental Inventory, RCE), two current European methodologies developed for assessing the conservation status of French (SEQ-MP: Systèm d'Evaluation de la Qualité du Milieu Physique) and German (LAWA-vor-Ort: Länderarbeitsgemeinschaft Wasser) rivers (Raven *et al.*, 2002), and the River Habitat Survey (RHS), developed by the Environment Agency England and Wales between 1993 and 1995 (Environment Agency, 1997; Fox *et al.*, 1998), which is the recognized reach-scale habitat assessment technique for the UK.

River habitat classification

Early attempts at river classification reflected the perception of the river as a longitudinal continuum from source to mouth (Petts, 1984). In the last two decades, river habitat classification systems have increasingly adopted a hierarchical structure that places habitat within a reach or stretch, network and catchment context. Warren (1979) produced one of the first attempts, defining 11 spatial units, from the regional scale ($>10\,km^2$) to the microhabitat ($<1\,m^2$), using five key variables: substrate, climate, water chemistry, biota and culture. Frissell *et al.* (1986) produced a conceptual hierarchical framework of five spatially nested river units, within a temporal and evolutionary context. Each of the hierarchical levels is important for characterizing the river system, and information from all levels is required if a robust classification system is to be developed. This type of hierarchical approach has been adopted for use in a variety of contexts, including frameworks for describing river processes (Petts and Amoros, 1996), integrated river corridor classifications (e.g. Harris, 1988), stream classifications (Cupp, 1989; Beechie and Sibley, 1990; Wadeson and Rowntree, 1994), and the assessment of riparian and floodplain characteristics of river channels (Corkum, 1990, 1999). Hierarchical schemes have also underpinned the geomorphological assessment and classification of rivers (e.g. Whiting and Bradley, 1993; Rosgen, 1994; Nanson and Knighton, 1995; Brierley and Fryirs, 2000).

Although approaches to river habitat classification have progressively incorporated anthropogenic impacts, they provide most discrimination in relation to relatively natural, predominantly rural rivers. For example, within the UK, the RHS has been designed to assess rivers for their conservation value (Raven *et al.*, 1997) and two scoring systems have been developed for use with the RHS (Raven *et al.*, 1998). The Habitat Quality Assessment (HQA) assigns a score for each natural attribute recorded within the reach, according to the extent of each feature within the channel, whereas the Habitat Modification Score (HMA) assesses the level of human impact upon the channel. A second example, the River Invertebrate Prediction and Classification System (RIVPACS), is a computer-based tool for biological classification that predicts the list of macroinvertebrate taxa that should be found at any given site according to the physical and chemical conditions within the channel (Wright *et al.*, 1984, 1993).

Urban river surveys and classifications

Very few survey methodologies have been developed specifically for urban or heavily engineered rivers (Newson, 2002). Notable exceptions include Anderson (1999), Suren *et al.* (1998) and RSPB *et al.* (1994). Fluvial processes and channel form and structure interact within most river reaches, but a particular feature of urban river channels is that they have often been subject to significant engineering intervention, which may have constrained channel size and reinforced channel boundaries so that process and form can no longer interact freely and longitudinal patterns become disguised by local hydraulic controls. As a result, physical assessment of urban rivers must place emphasis on the characteristics of channel engineering and must also record physical habitat features in some detail so that subtle distinctions between different reaches of river can be highlighted. Indeed, Brooks (RSPB *et al.*, 1994) suggested that his channelized river morphology survey should be undertaken over a length of uniform channel management, emphasizing the importance of management in controlling river channel characteristics. In this paper, we present a survey methodology designed specifically for urban rivers that is applied to reaches of river of a single engineering type. Fortunately, such detailed survey can be relatively straightforward and can usually be applied with good precision when surveying reaches of a single engineering type, because such reaches tend to have a more uniform character than their rural counterparts.

Because current river classification systems tend to group urban rivers into a single homogenous category of 'bad' or 'poor' quality, the urban river has become undervalued and understudied. However, the EC Water Framework Directive defines a category of 'modified water bodies' (which includes urban rivers) and advocates that reference conditions should be developed for such water bodies to establish river restoration aims (Pollard and Huxham, 1998). The fact that current classification systems cannot readily discriminate between urban rivers means that if sustainable rehabilitation of urban rivers is to be achieved, new classification systems are required especially for the urban river. Here, we are concerned specifically with the reach-scale habitat survey of urban rivers, although for effective management such reaches need to be placed in their catchment and network context (Davenport *et al*., 2001). At the reach scale, we describe (i) a method of Urban River Survey (URS); (ii) some synthetic indices that can be derived from URS survey data to provide a quantitative description of urban river reaches; and (iii) three different classifications of urban river reaches to reflect the character of their boundary materials, physical habitats and vegetation characteristics.

AN URBAN RIVER SURVEY

The Urban River Survey (URS) has been developed specifically for the survey of urban rivers. To maximize its utility, its design is essentially an extension of the RHS, so maintaining compatibility with the RHS whilst providing more detail of features that may aid discrimination between rivers within an urban environment. This section provides a brief description of the RHS and then elaborates upon the major additional features of the URS.

A brief description of the RHS

The current operational habitat survey technique applied at the reach scale in the UK is the Environment Agency's River Habitat Survey (RHS). Fox *et al.* (1998) provide a detailed review of the RHS methodology, but a brief description is provided here to support discussion of the URS. The RHS is applied to 500 m stretches of river and comprises four basic components: (i) background measurements; (ii) spot-check measurements; (iii) once-only measurements; and (iv) cumulative measurements.

'*Background measurements*' include the date, time of the survey, grid reference, and general conditions for the assessment (adverse weather, and channel bed visibility). Properties that relate the stretch to its catchment provide a context for the survey and can be derived mainly from secondary sources (e.g. altitude, geology, distance from source, slope) or a brief assessment in the field (e.g. valley form). '*Spot-check measurements*' are recorded within 1 m and 5 m wide transects across the channel located every 50 m along the stretch (ten spot-checks per 500 m stretch). The attributes associated with each spot-check are assessed by eye and include the physical attributes of the channel (channel substrate, bank materials, in-stream features such as bars, flow types, and forms and modifications of the channel and banks), in-channel macrophytes, the bank vegetation in terms of its structure, and immediate land use (5 m from the bank top). '*Once-only measurements*' are assessed once within the stretch. They include bank and channel width, water depth, bank-top and bank-full height, and embanked height. '*Cumulative measurements*' comprise a continuous assessment along the 500 m stretch of a range of attributes including the presence of trees and their associated features, bank profile types, land use, channel features, artificial features, special features and management attributes.

Urban river stretches

The size of urban channels is frequently a product of channel engineering and these channels often contain artificial structures and materials which have significant hydraulic impacts, influencing sediment dynamics and the

Table I. Subdivisions of river channel planform character, cross-section character and bed and bank reinforcement that can be combined to define the engineering type for a stretch of urban channel

(i) Alterations to the river's planform	(ii) Re-engineering of the channel cross-section	(iii) Reinforcement of the channel bed and banks
Semi-natural	Semi-natural	No reinforcement
Straight	Restored	Bed only
Meandering	Cleaned	One bank only
Recovered	Enlarged	Bed and one bank only
	Two-stage	Both banks only
	Resectioned	Full

creation of particular habitat types such as bars and pools. Thus, urban channels may not display the number or pattern of physical habitats that are encountered in less heavily impacted channels and physical assessment must emphasize channel engineering. Since channel engineering is fundamentally composed of three components—(i) alterations to the planform of the river; (ii) engineering of the channel cross-section; and (iii) reinforcement of the channel bed and banks—these provide the basis for identifying the engineering type of the stretch of river to be surveyed. Table I lists the separate subdivisions of components (i) to (iii) that can be combined to identify 144 potential engineering types ranging from semi-natural to heavily engineered types. In spite of this large number of theoretically feasible types, urban rivers typically display only a relatively small subset of types. Channels subject to single types of engineering can range in length from a few metres to several hundred metres. Since a 500 m reach of river is adopted for the RHS, surveys of a standard 500 m reach length of a single engineering type are adopted for surveys of urban rivers and are hereafter called urban river stretches.

The URS and RHS compared

The URS comprises the same four basic components as the RHS.

'*Background measurements*' include properties that enable the stretch to be placed in its catchment context (e.g. the codes for the catchment and network sector in which the stretch is located, the river name and the grid reference) and the engineering type of the stretch. Other records are essentially the same as those recorded in the RHS. When available, local indices of river quality (e.g. the General Quality Assessment (GQA) of chemical quality and biological quality (Nixon *et al.*, 1996), the RIVPACS target values of the faunal parameters including number of taxa, Biological Monitoring Working Party (BMWP) score and Average Score Per Taxon (ASPT: Wright *et al.*, 1993)) are also recorded.

'*Spot-check measurements*' when combined with a final 50 m sweep-up category represent the frequency and pattern of the features found within the river channel. Table II compares the properties recorded within the RHS and URS. The key differences are found in detailing the physical characteristics of the channel at each spot-check. Bank protection in urban rivers is a fundamental component of the channel structure. The frequency of different types of protection, and the mosaic of types found along each bank greatly influence flow hydraulics and the type of habitats found within the stretch. The composition of the banks influences the durability of each type of protection. The URS records both the underlying 'natural' bank materials in a separate category using the classes of sediment calibre adopted in the RHS (e.g. cobble, gravel/sand, clay etc.), while the bank protection is recorded using descriptors derived specifically for the URS (e.g. gabions, rip-rap, sheet piling etc.). Both bank modifications and some channel modifications are implicit in the definition of the urban stretch, and so inclusion of these attributes within the spot-check section of the survey is unnecessary. Measurements of other bank and channel modifications and features (e.g. 'natural' bank and channel features such as bars and eroding cliffs) are included in the cumulative measurements of the URS because they are usually relatively rare in urban channels and so require assessment along the entire stretch rather than just at the ten spot-check sites.

Measurements of flow type, bank face and bank-top structure, and channel substrate are all important components of urban rivers but their measurement is the same as in the RHS. However, where artificial substrates occur,

Table II. Comparison of spot-check and cumulative measurements incorporated in the RHS and URS

RHS spot-check parameters	URS spot-check parameters
Bank materials	Bank materials
Bank modifications	Bank protection
Bank features	
Channel substrate	Channel substrate
Flow type	Flow type
Channel modifications	
Channel features	
Bank top structure	Bank top structure
Bank face structure	Bank face structure
Bank top land use (5 m)	Bank top land use (5 m)
Channel vegetation	Channel vegetation
RHS cumulative measurements	**URS cumulative measurements**
Land use (within 50 m of bank top)	Land use (within 50 m of bank top)
Bank profiles	Bank profiles
Trees and associated features	Trees and associated features
Channel features	Habitat features
Recent management	Recent management
Features of special interest	Features of special interest
Choked channel	Choked channel
Nuisance plant species	Nuisance plant species
Alders	Alders
Overall characteristics	
Number of riffles, pools and point bars	
Artificial features	
	Wildlife species present
	Extent of pollution
	Bank protection
	Other information

the calibre of mobile material overlying the artificial materials is recorded because of its potential to form features such as riffles and bars which may affect the ecological diversity of the channel.

The dominant land use on the bank top is included at a greater resolution than in the RHS. A two-tiered classification of land-use proposed by Anderson *et al.* (1976) and modified by Meador *et al.* (1993) is employed. Level 1 allocates the land use to six broad categories (urban, agricultural, rangeland, forest land, wetland, and barren land) in a similar manner to the RHS, but these broad categories are then subdivided into 21 land use types. For example the urban category is subdivided into residential, commercial, industrial, industrial/commercial, transport, sewage treatment works, landfill/refuse deposits, derelict land and contaminated land.

Channel vegetation in the urban environment is important for (i) ecological integrity, (ii) its effect on flow patterns and channel conveyance, and (iii) its impact on dissolved oxygen within the water column (Pitcairn and Hawkes, 1973; Kirk, 1994). Therefore, the RHS method for measuring channel vegetation, which records one of 11 possible categories, has been enhanced by recording the spatial extent of each vegetation type.

'*Once-only measurements*' of channel dimensions (bankfull width, water width, water depth, bank-top height, embanked height, trashline height, and location of measurement) are retained from the RHS because, although they may not always be able to adjust freely in response to fluvial processes in urban rivers, they nevertheless impact on the geomorphological features that are found within the channel. For example, depositional berms and marginal bars might be expected in overwidened channels, whilst reinforced–straightened or narrow–overdeepened channels might produce fewer geomorphological features of a coarser sediment calibre than natural channels with a similar flow and sediment transport regime.

Table III. Types of pollution recorded in the URS

Pollution Type	Description
Water odours	Typically sewage effluent odours, but may also include industrial chemical aromas such as ammonia.
Sediment odours	The characteristic odour emitted by anoxic sediments, and can easily be tested by inserting a ranging pole through the surface of the sediments.
Oils	Characteristically seen floating on the water surface, or released from toxic sediments during testing for sediment odours.
Surface scum	Consists of foams caused by the presence of phosphate detergents during surface mixing and is usually seen near sewage outfalls, but may also refer to floating mats of small particles of debris and thin foams forming in slow flowing waters.
Gross pollution	Incorporates larger items of urban trash including shopping trolleys, mechanical parts, and litter.
Clarity	Reflects the concentration of suspended materials, but may also be influenced by the discharge of coloured effluents.
Number of input pipes	Includes sewage and road runoff outfalls, land drainage pipes and small industrial outfalls.
Number of leach points	Often a characteristic of drainage from contaminated land, the leachate may contain ferric matter which can be readily identified by its orange colour.

'Cumulative measurements' provide an overall impression of the quality of the stretch and are particularly important in the URS because they allow greater resolution in the recording of key components of urban rivers, particularly those which are restricted in their spatial extent. Table II illustrates similarities and differences in the recording of cumulative measurements in the URS and RHS.

Within urban rivers pollution is an important consideration since sewage effluent is often a primary component of the river's base flow and industrial effluents and road runoff frequently impact on water quality. The URS should be conducted under 'normal' (not spate) flow conditions during which eight pollution characteristics are recorded (Table III). Five are assessed on an absent/present/extensive (APE) scale (extensive relates to more than 33% of the stretch being affected). Clarity of the water is assessed as being good (water is clear and channel substrate is clearly visible), poor (the channel substrate is not visible due to high turbidity) or average (where the clarity of the water falls between these two extremes) under 'normal' flow conditions. The number of input pipes and leach points, indicative of potential point and more diffuse sources of pollution, are assessed as a total count of each within the stretch.

The structure of the riparian zone is particularly important in the urban environment where rivers may act as wildlife corridors (Goode, 1989). The RHS assessment of tree features (e.g. roots, overhanging branches), the structure of the bank top and face vegetation and the recent management of the riparian zone have been retained. However, the recording of nuisance species is expanded because these species are often a major problem in urban environments where frequent disturbance of the banks and surrounding corridor provides ideal habitats for species such as Himalayan balsam (*Impatiens glandulifera*) and Japanese knotweed (*Fallopia japonica*), allowing them to out-compete native vegetation and degrade the riparian zone. In the URS a simple cover scale reflects the increased extent and potential importance of these species (i.e. absent; single individual (a single plant within the stretch); isolated clumps (a few small clusters of plants within the stretch); frequent (present in 25–33% of the stretch); extensive (>33% of the stretch)).

The presence of habitat features (equivalent to the RHS channel features) is important in the assessment of urban channel quality. Habitat features include flow habitats or types (cascade, rapid, riffle, run, boil, glide, pool, ponded reach, marginal deadwater, stagnant water) and physical features (exposed bedrock, boulder, waterfall, backwater, sand/silt deposit, mature island, unvegetated or vegetated mid-channel or point bars, vegetated side bars, woody debris accumulations). The RHS methodology assesses the presence of habitat features on an absent/present/extensive (APE) scale. However, some types of engineered stretch may produce a relatively homogenous channel in terms of its habitats, and the presence of even small amounts of variation may be sufficient to increase ecological quality. Therefore, a more detailed assessment of these habitats is achieved in the URS by recording flow types as a percentage of the stretch and physical features as a total count within the stretch.

Other measures of channel heterogeneity and recovery are also recorded in more detail than in the RHS by including them in the cumulative measurements. The amount of each bank protection type is recorded as a percentage of the stretch as well as in the spot-check measurements. Two different types of bank profile can be present in a stretch, namely natural and artificial profiles. Artificial bank profiles are particularly significant in urban channels since they provide particular riparian habitats and offer characteristic controls on flow hydraulics. More natural features such as eroding banks and undercutting of the bank toe, may be particularly important in urban channels, where they are indicative of recovery along highly modified stretches and may provide refugia during spate flows. Geomorphological recovery processes allow natural bank profiles to become superimposed upon the artificial profiles and so ‘artificial’ and ‘natural’ bank profiles are grouped separately within the URS, and each bank profile type within these two groups is recorded as a percentage of the stretch, rather than the APE scale used in the RHS. This allows even small amounts of recovery to be incorporated into the survey, whilst still maintaining a reliable overall assessment of the stretch.

Land use 50 m from the bank top is recorded using the two-tier system previously described and by ascribing a percentage cover to each class. Other measures of quality, including recent management, wildlife species present, alders/diseased alders present (required for the national assessment of the incidence of *Phytophthora* root disease), choked channel and other information (i.e. presence of weirs, etc.) are recorded as presence/absence measurements in an identical manner to the RHS.

Data collection

The URS was used to collect data from stretches of the Upper River Tame Catchment in the West Midlands, UK. The catchment covers an area of 805 km^2 and is heavily urbanized, with an urban land cover exceeding 40%. A total of 57 stretches were surveyed in August 1999, and a second full URS survey was completed for 49 stretches during February 2000 to include a more detailed assessment of the extent of physical habitat features such as bars and small sand and silt deposits that could only be identified when macrophyte growth was minimal. Both the August 1999 and February 2000 surveys are used below to develop classifications of urban river stretches.

SYNTHETIC INDICES

The URS provides a wealth of information on urban rivers that can be queried to assess urban river corridor character and change. However, the survey is extremely detailed, with a large number of measurements recorded on three different measurement scales: frequencies, percentages, and other variable-specific scaled measurements. In order to integrate the survey data and to support classification of components of the urban river environment, a series of synthetic indices were developed describing ‘Materials’, ‘Physical Habitat’ and ‘Vegetation’ properties of urban river stretches (Table IV). The indices each describe well-defined components of the urban river environment and provide measures spanning similar numerical ranges (typically 0 to 10). In this way, they have sufficient resolution to detect differences between stretches within the data set and provide useful summary information on urban stretches in a more easily digestible form than the basic URS survey data. In addition, they support the main analytical tool (cluster analysis) used to derive classifications of urban stretches because major variations in the range of values representing the different variables analysed can bias the definition of clusters (Harris *et al.*, 2000; Krzanowski and Marriott, 1994). Within these similar numerical ranges, the values of the indices represent approximately linear variations in the magnitude of the factors that were considered. These scales were adopted for simplicity and to aid the interpretation of the classification results. The indices are explained in the following text and defined in Table IV.

Indices describing materials

Two indices reflect the two components of the channel substrate: immobile materials (concrete, brick, and bedrock) and mobile materials (sand, gravel, etc.). The URS records the predominant mobile substrate at each spot check (ten cross-sections along a 500 m stretch) according to categories compatible with the Wentworth particle size scale and so the SEDCAL index converts these spot-check measurements into an approximate average particle size for the stretch in phi units. The Proportion Immobile Substrate within the stretch is based on the spot-check records.

In relation to bank materials, since data are gathered separately for each bank, the synthetic indices are also estimated for both banks, although they can be combined. The URS records similar measurements for mobile bank

Table IV. Synthetic indices derived from the Urban River Survey relating to three different sets of characteristics of urban river stretches: Materials, 'Physical Habitat' and 'Vegetation'

Index name	Index name and description
Materials indices	
SEDCAL Bed Sediment Calibre Index	$= \frac{(-8^{*}BO - 7^{*}CO - 3.5^{*}GP - 1.5^{*}SA + 1.5^{*}SI + 9^{*}CL)}{(BO + CO + GP + SA + SI + CL)}$ where: BO (boulder), CO (cobble), GP (gravel/pebble), SA (sand), SI (silt) and CL (clay) represent the number of spot checks allocated to each sediment calibre class.
Proportion Immobile Substrate	$= \frac{10 \times \text{No. spot-checks with immobile materials}}{\text{No. spot-checks}}$
BANKCAL Bank Material Calibre Index (separate index for each bank)	$= \frac{(-8^{*}BO - 7^{*}CO - 1.5^{*}GS + 1.5^{*}EA + 9^{*}CL)}{(BO + CO + GS + EA + CL)}$ where: BO (boulder), CO (cobble), GS (gravel/sand), EA (earth), and CL (clay) represent the number of bank profiles allocated to each sediment calibre class.
Proportion Immobile Bank Materials (banks estimated separately)	$= \frac{10 \times \text{No. spot-checks with immobile materials}}{\text{No. spot-checks}}$
Proportion No Bank Protection	The proportion of the banks free of bank protection is estimated as a percentage from the cumulative measurements and then divided by 10 to produce an index in an appropriate numerical range.
Proportion Biodegradable Bank Protection	The proportion of the banks occupied by biodegradable bank protection is estimated as a percentage from the cumulative measurements and then divided by 10 to produce an index in an appropriate numerical range.
Proportion Open Matrix Bank Protection	The proportion of the banks occupied by open matrix bank protection is estimated as a percentage from the cumulative measurements and then divided by 10 to produce an index in an appropriate numerical range.
Proportion Solid Bank Protection	The proportion of the banks occupied by solid bank protection is estimated as a percentage from the cumulative measurements and then divided by 10 to produce an index in an appropriate numerical range.
BANKPROT Level and durability of bank protection (separate index for each bank)	$= \frac{(0^{*}NONE) + (1^{*}BIO) + (2^{*}OMP) + (3^{*}SOL)}{(NONE + BIO + OPM + SOL)} \times 3$ where: NONE (No Bank Protection), BIO (Biodegradable Protection), OMP (Open Matrix Protection) and SOL (Solid Protection) represent the number of spot checks allocated to each bank protection type/durability class.
Physical Habitat indices	
Number of Flow Types	A count of the number of different flow types recorded in the spot-checks
Dominant Flow Type	The flow type that is recorded the most times in the spot checks. Where two categories have equal frequency, the cumulative measurements are used to determine the dominant flow type. The index is a numerical value which represents an approximate flow velocity gradient: Free Fall = 1, Chute Flow = 2, Chaotic Flow = 3, Broken Standing Waves = 4, Unbroken Standing Waves = 5, Rippled = 6, Smooth = 7, Upwelling = 8, No Perceptible Flow = 9, Dry Channel = 10.
Number Natural Bank Profiles	The number of different types of natural bank profile are ascertained from the cumulative measurements.
Proportion Natural Bank Profiles	The proportion of the banks occupied by natural bank profiles is estimated as a percentage and then divided by 10 to produce an index in an appropriate numerical range.
Number Artificial Bank Profiles	The number of different types of artificial bank profile are ascertained from the cumulative measurements.
Proportion Artificial Bank Profiles	The proportion of the banks occupied by artificial bank profiles is estimated as a percentage and then divided by 10 to produce an index in an appropriate numerical range.
Number of Habitat Types	A count of in-channel habitats types (not individual habitats), including both the physical habitat features (e.g. bars, islands, sand deposits etc.), and flow type habitats.

(*continues*)

Table IV. *Continued*

Index name	Index name and description
Vegetation indices	
BANKVEG	$= 3(0*B + 1*U + 2*S + 3*C) / (B + U + S + C)$
Bank Vegetation Structure Index (separate index for each bank top and face)	where: B, U, S, C represent the number of bank top and face profiles at which each class of structure was recorded.
Total Tree Score	Tree cover along each bank is recorded on a scale of absent to continuous, The right and left banks are given a score (none = 0, isolated/scattered = 1, regularly spaced = 2, occasional clumps = 3, semi-continuous = 4, continuous = 5) which are added to estimate the index.
Total Tree Feature Score	Tree features (shading of channel, overhanging boughs, exposed bankside roots, underwater tree roots, fallen trees, coarse woody debris) measured on the APE scale are scored 0,1 and 2 respectively and then the scores are summed.
Number Channel Vegetation Types	A count of the number of macrophyte types in the stretch.
Dominant Channel Vegetation Type	The dominant type is the macrophyte with the largest total percentage cover accumulated from the spot checks. The dominant type is then recorded as a number which represents its broad flow resistance in urban channels (none = 0, liverworts/mosses/lichens = 1, free-floating = 2, amphibious = 3, emergent broadleaved herbs = 4, filamentous algae = 5, floating leaved (rooted) = 6, submerged linear-leaved = 7, submerged broadleaved = 8, submerged fineleaved = 9, emergent reeds/sedges/rushes = 10).
Average Channel Vegetation Cover	The percentage cover for all macrophyte types (excluding none and not visible) is summed for each spot check, averaged over all ten spot checks and then divided by 10 to give the appropriate numerical range.
Total Pollution Score	The index accumulates the measures of water odours, sediment odours, oils, surface scum and gross pollution, by attributing each a score of 0, 1 and 2 to represent the APE recording scale
Number of Input Pipes	The total count is converted into a score as follows: 0 pipes = 0, 1 = 1, 2 = 2, 3 = 3, 4 = 4, 5 = 5, 6–9 = 6, 10–14 = 7, 15–20 = 8, 20–30 = 9, >30 = 10.
Number of Leach Points	The total count is converted into a score as follows: 0 points = 0, 1 = 1, 2 = 2, 3 = 3, 4 = 4, 5 = 5, 6–9 = 6, 10–14 = 7, 15–20 = 8, 20–30 = 9, >30 = 10.

materials as for the channel substrate (Table IV), which reflect the Wentworth scale. The BANKCAL index converts these spot-check measurements into an approximate average particle size for each bank in phi units. The Proportion Immobile Bank Materials (concrete, concrete and brick, laid stone, sheet piling, and bedrock) is calculated in the same way as the Proportion Immobile Substrate.

The various types of protection used in urban channels can be placed into different groups according to whether they are absent, biodegradable (e.g. reeds, wood piling, willow spiling), open matrix (e.g. rip-rap, gabions, builders waste) or solid (e.g. concrete, brick, laid stone, sheet piling). These categories are translated from the cumulative measurements into four individual indices reflecting the proportion of the bank with no protection or affected by each of the three protection types. The three protection types are also ascribed a score relating to their durability which is accumulated from the spot-checks to derive the BANKPROT index for each bank.

Indices describing physical habitat features

Two indices help to characterize the hydraulic and morphological diversity of the stretch. The Dominant Flow Type gives an indication of the general character of the stretch and is allocated a numerical value to reflect its position along a flow velocity gradient (Table IV). The Number of Flow Types within a stretch characterizes hydraulic and bed form variability or diversity. These indices based on flow types are complemented by an integrative index which counts the total number of different habitat types (both flow types and physical features) and so represents the overall diversity of habitats within the stretch. The raw URS data characterize the nature and extent of individual habitat types within a stretch.

The URS recognizes two different categories of bank profiles—artificial and natural—reflecting the historical management practices and the level of bank profile recovery from past modification. Where the urban channel shows evidence of recovery processes through erosion, natural profile components become superimposed on artificial profiles, giving a potential total of observed profiles of over 100%. Similarly, where an urban channel displays two different types of modification (e.g. two-stage channel and reinforced banks), the total proportion of artificial profiles can exceed 100%. It is important to distinguish channels that show evidence of recovery, in order to explore the effects that different types of engineering may have on the urban channel. To this end, separate indices are developed for natural and artificial bank profiles and in each case the number of different profile types are counted as well as estimating the overall proportion of natural and artificial profiles to give four separate indices (Table IV).

Indices describing vegetation structure and biomass

A characteristic of urban channels is the uniformity of the bank in terms of its vegetation, because tall vegetation tends to be pruned or removed to reduce flow resistance. Three indices express the character of the bank vegetation. The BANKVEG index represents overall bank vegetation complexity. It is based on spot-check observations of bank vegetation structure and, because engineered channels often display different complexities of vegetation between the banks, and between the top and face of the bank, it is applied separately to each of these units. Within the bank vegetation, trees can be a particularly important component of urban river margins because of the shade, bank support and habitat they confer and their widespread management. Therefore, trees are characterized by two indices. The Total Tree Score assesses the extent of tree cover whereas the Total Tree Feature Score assesses the degree to which trees interact with the channel both hydraulically and through the provision of shade.

To fully assess the significance of the aquatic macrophytes within the channel, the measurements taken in the spot-checks are used to derive three important indices. The Number of Channel Vegetation Types indicates the diversity of macrophytes, which in turn can help to indicate water quality. The Dominant Channel Vegetation Type is identified from its cover and is represented by an index score which represents the relative flow resistance of that macrophyte type in comparison with other types within urban channels. The Average Channel Vegetation Cover within the stretch provides not only a simple measure of vegetation extent but may also help to highlight areas where the management of macrophytes is important. It is reasonable to hypothesize that different engineering types will promote different levels of channel vegetation cover and diversity in terms of the macrophyte growth, although this might be confounded by the amount of shading present within different stretches.

Indices that may indicate degradation in water quality were also included in the vegetation list because water quality and vegetation are to some extent related. The Total Pollution Score accumulates observations of odour, oil, scum and other indicators of pollution into a simple overall index, whereas the Number of Leach Points and the Number of Input Pipes indicate potential local inputs of poor water quality.

CLASSIFICATION OF URBAN RIVER STRETCHES

Cluster analysis was used to develop classifications of urban river stretches from the synthetic indices described in the previous section. Because of the similar numerical range in the indices, cluster analysis was applied to the untransformed data. Various clustering algorithms were tested (within-group average linkage, between-group average linkage, centroid and Ward's algorithms). Ward's clustering algorithm was finally selected because it produced distinct, compact clusters of similar size conforming to the view that the algorithm generates 'the most appealing overall results in terms of cluster size, shape (compactness), density and internal homogeneity' (Griffith and Amrhein, 1997, p. 220). Once the cluster analysis was complete and a dendrogram describing the hierarchical agglomeration of the surveyed stretches had been produced, the identification of the number of clusters or classes that best described the data was inevitably somewhat subjective. The dendrogram was inspected to identify agglomerations to approximately three to eight clusters and the number of clusters selected within this range was based on the generation of the most clearly defined groups within the dendrogram and the degree to which the clusters had an interpretable meaning. The validity and meaning of the clusters was assessed by (i) applying non–parametric (Kruskal–Wallis) analysis of variance (ANOVA) to identify which of the individual attributes provided a statistically significant ($P < 0.05$) discrimination between the clusters; (ii) inspecting box-and-whisker plots for each of the discriminatory attributes to identify which clusters were discriminated by each attribute and the strength of the discrimination; and (iii) identifying whether the clusters were composed of any distinct engineering types, which might suggest a causal impact of engineering on cluster characteristics.

Using the indices listed in Table IV, cluster analysis was applied separately to stretch scores on the Materials, Physical Habitat and Vegetation indices. This separation allowed the more direct relationship between engineering type and materials to be investigated separately from the less direct relationship between engineering type and the geomorphological and vegetation features that may be retained or induced. Cluster analysis was performed initially using the August 1999 survey data. A second analysis for Materials and Physical Habitat combined the August 1999 with the February 2000 survey data to provide a more comprehensive analysis, to include any seasonal effects and to assess the robustness of the initial classification. The addition of the February (i.e. winter) information was not appropriate for the analysis of the Vegetation data.

Materials attributes

The indices used within the Materials cluster analysis (Table IV), reflect the character of the natural bed and bank materials and of the artificial materials used to reinforce the channel banks and/or bed. Therefore, the attributes that underpin the cluster analysis reflect the potential susceptibility of the river channel to modification through fluvial processes. Analysis of the August 1999 data distinguished five classes of River Tame stretches (Figure 1A). The analysis was repeated using the combined results of the August 1999 and February 2000 URS surveys of the River Tame, giving a total of 106 stretch surveys (Figure 1B), and five clusters were again distinguished. Kruskal–Wallis non-parametric analysis of variance (ANOVA) was applied to each of the indices to assess which were important for discriminating between the five clusters. Table V lists the Kruskal–Wallis statistic (K) and the associated level of significance (P) for each of the attributes. Table V shows that for both cluster analyses, the proportion of Immobile Substrate and the proportion of Biodegradable Protection are not significant in discriminating between the clusters. In contrast, the calibre of the bank materials (BANKCAL), and the type and amounts of bank protection (BANKPROT, No Bank Protection, Open Matrix Protection, Solid Protection) are important discriminatory attributes. Although details of the engineering type were not included in the analysis, each cluster was found to comprise stretches that possessed distinct types of engineering modification (Table VI), which is reflected in the names given to the clusters (Figures 1A and B, Table VI).

Physical habitat attributes

Cluster analysis of stretches according to their Physical Habitat attributes (Table IV), explored the degree to which channels of similar bank and bed form (reflected by geomorphological features and flow patterns) can be identified. Analysis of the August 1999 survey data identified four clusters (Figure 2A). The inclusion of the February 2000 data suggested five clusters were more appropriate to describe the data (Figure 2B). However, Kruskal–Wallis ANOVA of the Physical Habitat attributes identified similar significant cluster discriminators for both analyses (Table V). In the analysis of the full data set, all indices apart from the dominant flow type were highly significant in discriminating between the five clusters and the clusters were found to be closely associated with distinct types of engineering modification (Table VII). This is reflected in the names given to the clusters (Figure 2, Table VII).

Vegetation attributes

A final cluster analysis was concerned with the characteristics of the bank and in-channel vegetation (Table IV). Only the August 1999 data were analysed and all of the variables included in the cluster analysis showed significant discrimination between clusters with the exception of the number of leach points (Table V). Eight clusters were found to provide good discrimination between different vegetation characteristics (Table VIII, Figure 3). The dominant channel vegetation type (unvegetated channels, algal dominated channels, and vegetated channels) discriminated three large clusters which were also associated with the total pollution score. The highest pollution scores were associated with the vegetated channels and the lowest scores were associated with the unvegetated channels. Further subdivision was driven mainly by the diversity of the in-channel vegetation for the algal-dominated and vegetated groups, although there were also clear differences in bank vegetation

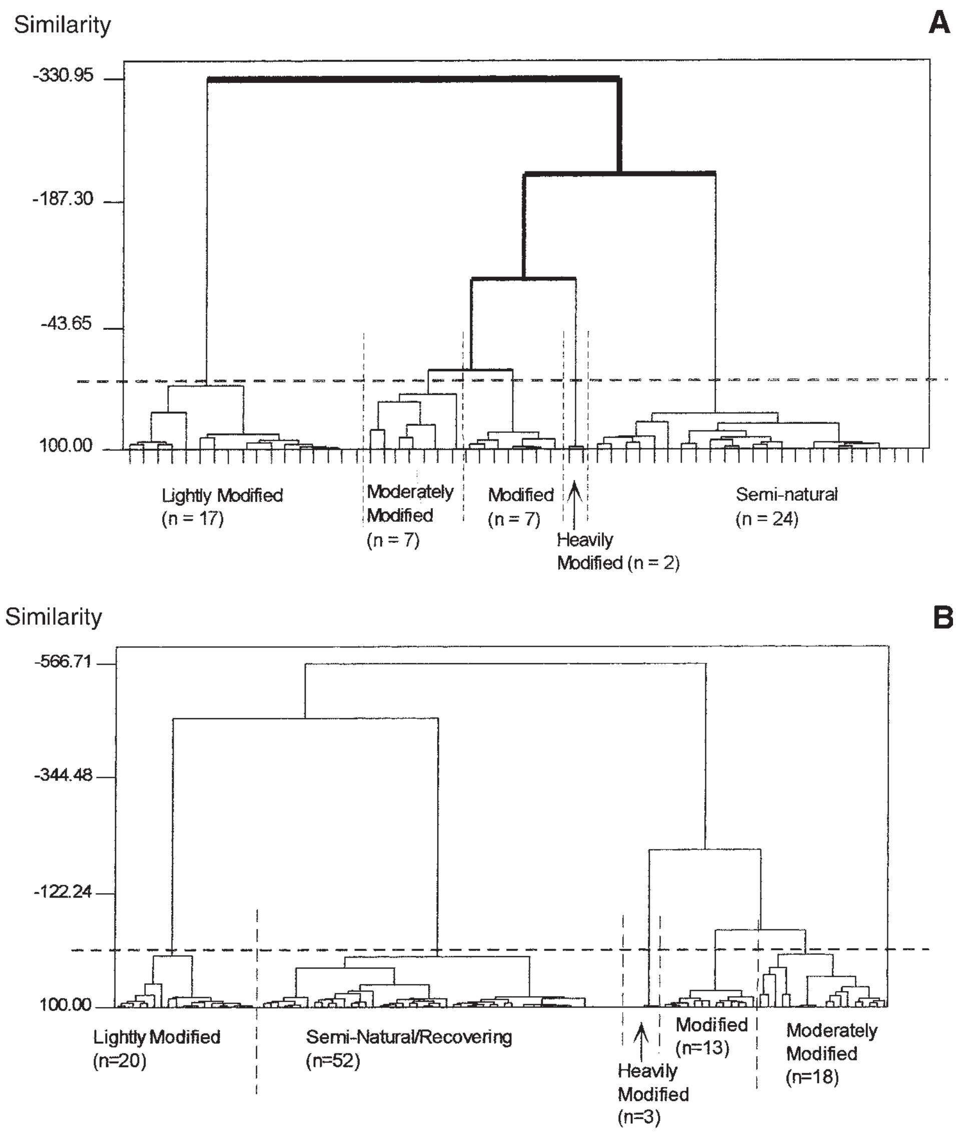

Figure 1. Dendrograms for the cluster analysis of Materials indices: (A) derived from Urban River Surveys of the River Tame undertaken during August 1999; (B) derived from Urban River Surveys of the River Tame undertaken during August 1999 and February 2000

characteristics between groups. Unvegetated channels were subdivided into groups on the basis of very strong contrasts in bank vegetation characteristics. Although the vegetation clusters did not map strongly onto engineering type some associations could be recognized between the three main in-channel vegetation groupings and channel engineering. The vegetated channels tended to possess artificial and predominantly straight planforms, artificial cross-sections, and no reinforcement. The stretches also displayed uniform banks, usually as a result of management practices such as mowing. The high diversity stretches were semi-natural in character but with relatively uniform banks according to their engineering type. The unvegetated stretches tended to display engineering types which possess artificial meandering or straight planforms, artificial cross-sections with a variety of levels of reinforcement. These stretches also displayed simple to complex bank vegetation structure, which would suggest that these stretches, though more engineered than the vegetated channels, were not subjected to regular bank maintenance. The algal-dominated channels comprised two different types of engineering. Algal low complexity stretches were found where there had been full bed and bank reinforcement with concrete, while algal moderate complexity channels were a characteristic of recovering stretches.

Table V. Results of applying Kruskal–Wallis analysis of variance to individual materials, physical habitat or vegetation attributes of urban river stretches surveyed in August 1999 and, for materials and physical habitat in February 2000, grouped according to the 5, 5, 8 'Materials', 'Physical Habitat' and 'Vegetation' clusters (*K* is the Kruskal–Wallis statistic, *P* is the significance level)

	August 1999 survey		August 1999 and February 2000 surveys	
	K	*P*	*K*	*P*
Materials attributes				
Proportion Immobile Substrate	5.80	NS	8.78	NS
SEDCAL	9.23	NS	9.87	<0.05
Proportion Immobile Left Bank Materials	12.18	<0.05	22.23	<0.01
BANKCAL (left bank)	32.71	<0.01	45.75	<0.01
Proportion Immobile Right Bank Materials	6.67	NS	10.67	<0.05
BANKCAL (right bank)	33.60	<0.01	47.00	<0.01
BANKPROT (left bank)	33.25	<0.01	54.22	<0.01
BANKPROT (right bank)	18.45	<0.01	49.69	<0.01
Proportion No Bank Protection (NONE)	35.31	<0.01	72.96	<0.01
Proportion Biodegradable Protection (BIO)	0.70	NS	0.97	NS
Proportion Open Matrix Protection (OMP)	26.59	<0.01	51.44	<0.01
Proportion Solid Protection (SOL)	8.59	NS	20.98	<0.01
Physical Habitat attributes				
Number of Flow Types	6.54	NS	19.82	<0.01
Dominant Flow Type	−57.94	NS	7.51	NS
Number Natural Bank Profiles	28.67	<0.01	62.75	<0.01
Proportion Natural Bank Profiles	42.92	<0.01	81.63	<0.01
Number Artificial Bank Profiles	25.40	<0.01	50.74	<0.01
Proportion Artificial Bank Profiles	47.65	<0.01	93.52	<0.01
Number of Habitat Features	18.12	<0.01	45.62	<0.01
Vegetation attributes				
BANKVEG Left Bank Top	25.86	<0.01		
BANKVEG Left Bank Face	28.86	<0.01		
BANKVEG Right Bank Top	34.39	<0.01		
BANKVEG Right Bank Face	36.20	<0.01		
Total Tree Score	30.81	<0.01		
Total Tree Feature Score	26.06	<0.01		
Number Channel Vegetation Types	26.21	<0.01		
Dominant Channel Vegetation Type	44.42	<0.01		
Average Channel Vegetation Cover	39.54	<0.01		
Total Pollution Score	18.21	<0.05		
Number of Input Pipes	20.77	<0.01		
Number of Input Pipes	4.03	NS		

The above classifications illustrate that there are three broad sets of synthetic indices (Materials, Physical Habitat, Vegetation) which can be used to allocate engineered stretches to five, five and eight different classes, respectively. The classes all appear to be related to the level and type of engineering to some degree, although the strongest associations are with Materials and the weakest are with Vegetation. The similarity in classifications based on Materials and Physical Habitat attributes from two different surveys indicate the robustness of these classifications.

DISCUSSION AND CONCLUSIONS

This paper has described an Urban River Survey, which is based upon, and is compatible with, the Environment Agency's River Habitat Survey, but which includes both additional measurements and also an increase in the resolution of some measurements to highlight some of the important habitat characteristics of urban rivers. The URS generates an enormous range of measurements which describe the surveyed river stretches and provide an ability to identify change between surveys of the same stretch. A series of synthetic indices have also been

Table VI. Five clusters of urban river stretches defined by their materials characteristics

Group name (abbreviation)	Description of discriminating primary (materials) indices	Description of broad engineering characteristics
Semi-natural (SN)	Low levels of bank protection (*c*. 0–10%). Coarser substrates and bank materials.	More natural planforms and cross sections (reflecting natural processes, recovery or restoration).
Lightly modified (LM)	Low levels of bank protection (*c*. 0–10%). Finer substrates and bank materials.	Artificial (mainly straight) planforms, and cross-sections but with limited reinforcement.
Modified (M)	Coarser bed and bank materials. Moderate levels (*c* 50%) of mainly open matrix protection (gabions, rip rap etc).	Artificial (mainly sinuous) planforms, and cross-sections with significant reinforcement.
Moderately modified (MM)	High (*c*. 90–100%) proportions of open matrix protection and moderate levels (*c*. 20–50%) of solid bank materials (concrete, laid stone etc.).	Artificial (mainly straight) planforms and cross-sections with extensive reinforcement.
Heavily modified (HM)	High levels (*c*. 100%) of solid bed and bank materials (concrete, laid stone etc.).	Heavily engineered, straight planforms and high levels of reinforcement.

Table VII. Five clusters of urban river stretches defined by their physical habitat characteristics

Group name; abbreviation	Discriminating habitat characteristics	Description of broad engineering characteristics
Recovering (Re)	High levels of active recovery from engineering intervention 8–10 habitat types.	Moderate proportions of artificial bank profiles (30–60%) and high proportions of natural bank profiles (80–100%).
Uniform active (AA)	5–7 habitat types and a variety of flow types. Evidence of active channel recovery.	High proportions of Artificial Bank Profiles (*c*. 100%), and moderate to high proportions of natural bank profiles (*c*. 20–50%).
Semi-natural (SN)	5–7 habitat types.	Very low proportions of artificial bank profiles and very high proportions of natural bank profiles.
Uniform stable (AS)	Low numbers (1–4) of habitat types, and two major flow types (glides and runs) dominating Little evidence of channel recovery from engineering intervention.	High proportions of artificial bank profiles (*c*. 100%) and low proportions of natural bank profiles (*c*. 0–10%).
Highly artificial (HA)	Low numbers (1–4) of habitat types.	Very high proportions of artificial bank profiles 160–200% (typically two types of bank modification. overlying each other, e.g. 2 stage channels with reinforced banks). Low proportions of natural bank profiles.

proposed which describe the broad characteristics of the Materials, Physical Habitat and Vegetation attributes of urban river channels. The relatively small number of synthetic indices (25) summarize a range of properties of urban channels and also support their classification. Three classifications of urban channels are proposed based on the application of cluster analysis to the values of the summary indices for stretches of the River Tame, West Midlands, UK, that have been surveyed on two occasions using the URS.

The robustness of both the URS methodology and the classifications derived from the URS have been illustrated by the similarity in the classifications for Materials and Physical Habitat generated from one or two surveys. However, analysis of a second summer survey of 59 stretches of the Tame, completed during July 2000, and a survey of 16 stretches of the River Ravensbourne in the Greenwich area of London during August 2000 have provided further confidence in the results presented here. Both the URS methodology and the classifications are currently being fine-tuned as part of an EU Life programme entitled 'Sustainable Management of Rivers and their Floodplains', after which decision-trees will be produced so that newly surveyed stretches can be allocated to urban river classes without the need to rerun the cluster analysis.

In the context of assessing the quality of urban rivers and their potential for enhancement or rehabilitation, the data generated by the URS, the synthetic indices and the classifications provide a range of important indicators. In

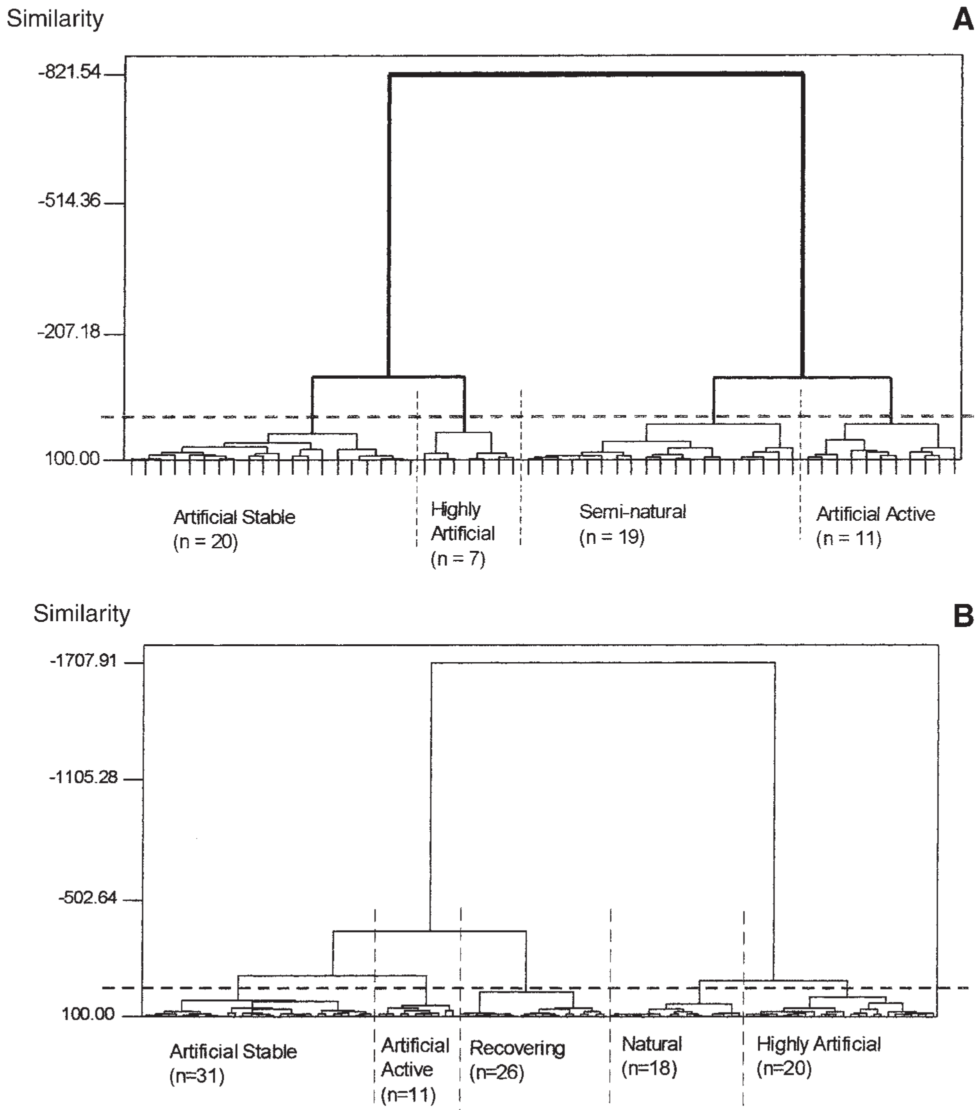

Figure 2. Dendrogram for the cluster analysis of Physical Habitat indices: (A) derived from Urban River Surveys of the River Tame undertaken during August 1999; (B) derived from Urban River Surveys of the River Tame undertaken during August 1999 and February 2000

particular the synthetic indices could be described as primary environmental indicators, describing a variety of fundamental properties of the urban river stretch, and the class to which a stretch is allocated according to its Materials, Physical Habitat or Vegetation attributes could be described as secondary environmental indicators.

Because the classifications or secondary environmental indicators allocate a stretch to different classes, and the type of engineering applied to a stretch appears to have a significant influence on the class to which a stretch is allocated (with the strongest associations being apparent in the Materials classes and the weakest in the Vegetation classes), the consequences of changed engineering can be explored in relation to these three classifications, and the influence of scenarios of vegetation and water quality management can be additionally explored in relation to the Vegetation classification. Thus these secondary environmental indicators also provide a means of considering the consequences of changes, primarily in engineering but also in vegetation and pollution management.

However, in considering scenarios of engineering change a set of tertiary environmental indicators, operating at a larger scale (notably at the scale of the sector within which the stretch is located) provide constraints which

Table VIII. Eight clusters of urban river stretches defined by their vegetation characteristics

Group name (abbreviation)	Discriminating habitat characteristics
Vegetated low complexity channels (VLC)	Low diversity of channel vegetation types (2–4 types); low bank face BANKVEG scores (2–3) equivalent to a relatively uniform bank face vegetation structure.
Vegetated moderate complexity channels (VMC)	Moderate diversity of channel vegetation types (3–7 types); moderate to high total tree scores (*c*. 4–7); moderate tree feature scores (*c*. 2–4) and high levels of bank face vegetation complexity (*c*. 5.5–6.5), all of which are higher than for VLC and VHD channels and indicate a more diverse bank vegetation cover; much higher total pollution scores than all of the other vegetation classes.
Vegetated high diversity channels (VHD)	Dominated by reeds sedges and rushes (score = 10); a high diversity of channel vegetation types (7–8 types), higher tree feature scores (*c*. 2–3) and bank face BANKVEG scores (*c*. 3–4) than VLC channels.
Algal low complexity channels (ALC)	Only one channel vegetation type; very low total tree scores (*c*. 2); no tree features; low bank face (*c*. 0–2) and bank top (*c*. 1–3) BANKVEG scores indicating near-bare banks.
Algal moderate complexity channels (AMC)	4–5 different channel vegetation types; moderate total tree scores (*c*. 4–6) and tree features scores (*c*. 4–5); moderate bank face (*c*. 2–5) and bank top (*c*. 2–5) BANKVEG scores.
Unvegetated low tree extent channels (ULT)	3–4 different channel vegetation types with 20–40% average channel vegetation cover; total tree score (3–4) equates to an isolated scattered presence of trees on the banks; moderate tree feature scores (0–3) (both tree scores lower than for UMT and UHT channels). The group is distinguished from UMC and UHC channels by its moderate bank face (2.5–3) and bank top (3–5) BANKVEG scores, suggesting a relatively uniform bank vegetation complexity with some variation produced by the presence of the trees.
Unvegetated moderate complexity channels (UMC)	3–4 channel vegetation types with 20–40% channel vegetation cover (as for ULT) but characterized by moderate total tree scores (7–8) representing occasional clumps/semi-continuous trees, and higher tree feature scores (2–3.5) than ULT; also distinguished by very high bank face BANKVEG scores (*c*. 4–8) coupled with very low bank top BANKVEG scores (*c*. 0–2).
Unvegetated high complexity channels (UHC)	Similar to ULT and UMC channels, this cluster has a low channel vegetation cover, although in some stretches channel vegetation cover reaches 40–60%; mainly discriminated by the highest total tree scores (9–11), representing semi-continuous to continuous cover, and the highest tree feature scores (5–6) of any of the 8 clusters. Stretches display low bank face BANKVEG scores (*c*. 1–2) and high bank top BANKVEG scores (*c*. 6–8) (i.e. the reverse of UMC channels), suggesting that high tree cover on the bank tops may be shading out vegetation on the bank face.

may limit the potential success of any particular option. For example, water quality indicators can support an assessment of whether any genuine in-channel ecological benefit can be gained. If water quality is poor, then no improvement in physical habitat will yield an improvement in the aquatic ecology of the stretch. Under such circumstances, changes in engineering may yield aesthetic benefits and improvements in riparian ecology, but water quality improvement will be essential before the in-channel ecosystem can benefit. In addition, flow-related indicators (e.g. stream power at bank-full stage) can provide an initial assessment of the likely stability of a change in engineering. They may also be of ecological significance in indicating whether low flows will be sufficient to support an enhanced aquatic ecosystem. Moreover, a combination of flow and water quality indices may allow consideration of the consequences of different flow regulation scenarios for water quantity and quality within a stretch. Finally, some simple sector-scale tertiary indicators relating to floodplain land use and floodplain width may indicate whether there are constraints in land availability or land quality that may preclude certain engineering

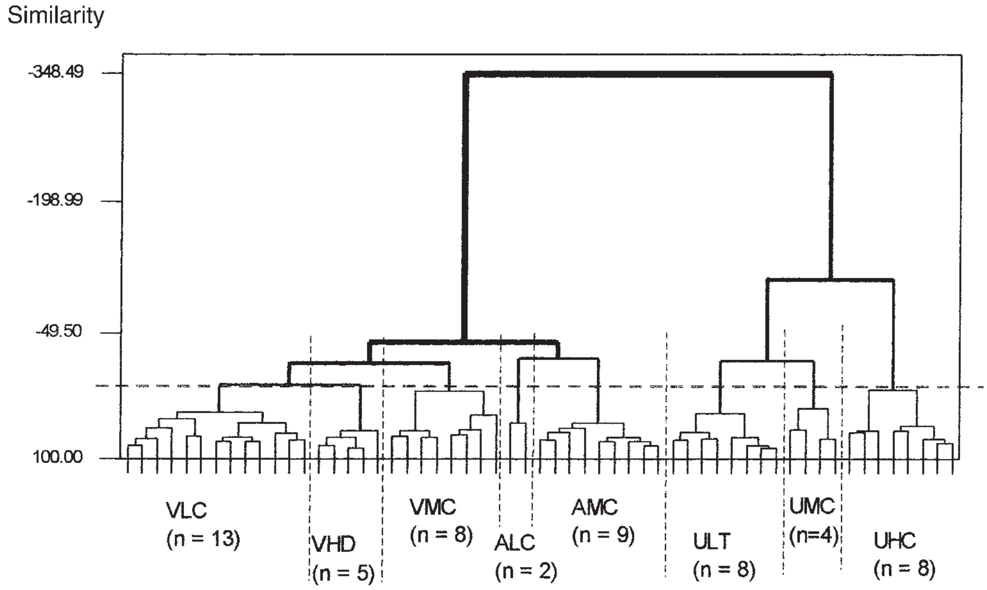

Figure 3. Dendrogram for the cluster analysis of Vegetation indices derived from Urban River Surveys of the River Tame undertaken during August 1999

options. For example, a restricted floodplain or presence of contaminated land could place severe constraints on engineering options that include a change from a straight to sinuous river planform.

Thus the methodology presented in this paper has successfully characterized and classified stretches of urban river, but further refinement and verification are required to ensure a really robust, widely applicable methodology. Then this stretch-scale methodology needs to be placed into its catchment and sector context to provide an integrated approach to the assessment of urban rivers and their rehabilitation potential.

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