MoRPh: A citizen science tool for monitoring and appraising physical habitat changes in rivers

Lucy J. Shuker[1], Angela M. Gurnell[2], Geraldene Wharton[2], David J. Gurnell[3], Judy England[4], Brishan F. Finn Leeming[5] & Ellie Beach[6].

[1] Geomorphology Technical Service, Environment Agency, Hertfordshire, AL10 9EX, UK; [2]School of Geography, Queen Mary University of London, UK; [3]Untyped Ltd, Brighton, UK; [4]Environment Agency, Wallingford, Oxfordshire OX10 8BD, UK; [5]Department of Biological and Environmental Sciences, University of Aberdeen, UK: [6]Department of Human and Environmental Sciences, Geography, Environment and Agriculture, University of Hertfordshire, UK.

Abstract

The MoRPh survey is designed to enable citizen scientists to monitor physical habitat mosaics and human pressures within short (up to 40 m) river reaches called modules. MoRPh underpins a multi-scale Modular River Survey, providing local information, which when collected across 10 contiguous modules, delivers a MultiMoRPh river sub-reach survey up to 400 m in length. This, in turn, contributes to a HydroMoRPh assessment of reaches extending to tens of kilometres of river length, based on secondary data sources.

A six month trial on chalk streams, demonstrates that indices calculated from MoRPh surveys can detect notable differences in hydraulic, sediment, physical and vegetation habitat characteristics across this single river type. Further tests will evaluate applicability to other river types and ability to detect temporal changes. Development of aggregate indices for MultiMoRPh sub-reaches will aid interpretation of contemporary morphological dynamics, complementing longer term changes extracted at the reach scale by a HydroMoRPh analysis.

Key words: Public participation, Environmental Assessment, Catchment Management, Habitat, Geomorphology, Rivers, Surveys.

Why do we need MoRPh?

The need for monitoring and assessment of river restoration activities is well documented (e.g. England *et al*. 2008; Mainstone and Wheeldon 2016) and yet is often not undertaken. As an important element in applying the adaptive management approach in river restoration (Summers *et al*. 2015),these needs were echoed in a recent review of river restoration activities within the UK and Republic of Ireland, undertaken for the UK National Committee of the International Union for Nature Conservation (Addy *et al.* 2016). The recommendations within the report included:

- Promote and carry out simpler and cost-effective monitoring methods that can be applied across all sites.
- Use citizen science to provide useful information while also reconnecting people with their river environments.
- Use all monitoring evidence to evaluate projects objectively and help contribute to the design of others.

The role of volunteers is becoming increasingly recognised in environmental research (Jasanoff 2004; Silvertown 2009; Roy *et al*. 2012) with the rise of citizen science being regarded by many as a research revolution (Roberts 2016).

In river science and management, a range of survey techniques and opportunities have been developed to engage citizen scientists, mainly concerned with assessing water quality. Some examples of these include methods that directly monitor water quality, such as Thames River Watch (www.thames21.org.uk/project/thames-river-watch/) and Freshwater Watch (Loiselle 2016); others provide indirect assessment methods using macroinvertebrates (the Riverfly Partnership, www.riverflies.org; Di Fiore and Fitch 2016) and algae (RAPPER, Kelly *et al*. 2016). A recent guide produced by the Rivers Trust (2016) illustrates how environmental monitoring by the voluntary sector is providing a fundamental contribution through the development of a Catchment-Based Approach (CaBA) to understanding rivers (see also Starkey and Parkin 2015). This type of localised participatory approach to environmental data collection and monitoring, aims to raise awareness, fill important knowledge gaps, and engage all sectors of society in identifying and delivering solutions to water management issues in ways that both protect and enhance the freshwater environment. In particular, this occurs at the level where impacts are experienced and observed first hand. However, there remains a need for a standard citizen science approach to assess river physical habitats, summarizing their character and dynamics, identifying stretches in need of restoration and monitoring any ensuing change (Smith *et al*. 2014; Huddard *et al*. 2016). In particular, while existing popular citizen science methods are in wide use, there is currently no method for volunteers to record the accompanying physical habitat at a scale that complements biological and water quality sampling.

The power of large data sets generated by volunteers, to improve understanding of river systems and to aid their more sustainable management, is enormous (Shuker *et al*. 2012; Leonard *et al*. 2015; Roberts 2016). This is because the spatial (and in many cases temporal) coverage of such data sets can exceed monitoring by other means by several orders of magnitude. However, the quality of the generated data depends upon using simple methods that are sufficiently clearly-defined and quality-controlled that operator variance is reduced to acceptable levels (Bird *et al*. 2014). To have the greatest effect, the scale and style need to be flexible, enabling participants to contribute at a level that feels 'comfortable' (Wiersma *et al*. 2016). Methods designed to help volunteers undertake field monitoring usually focus upon very short river reaches (a few to tens of metres long) and use standard, simple and robust equipment (e.g. water quality monitoring devices) with simple, clear keys (e.g. biological monitoring). Crowd-sourcing of collected data is further enabled by advancing technological developments involving web or mobile ‘apps’, which in many cases not only assimilate the volunteer data but also provide data visualization opportunities and the ability to download the data for more detailed analysis (Sheldon and Ashcroft 2016).

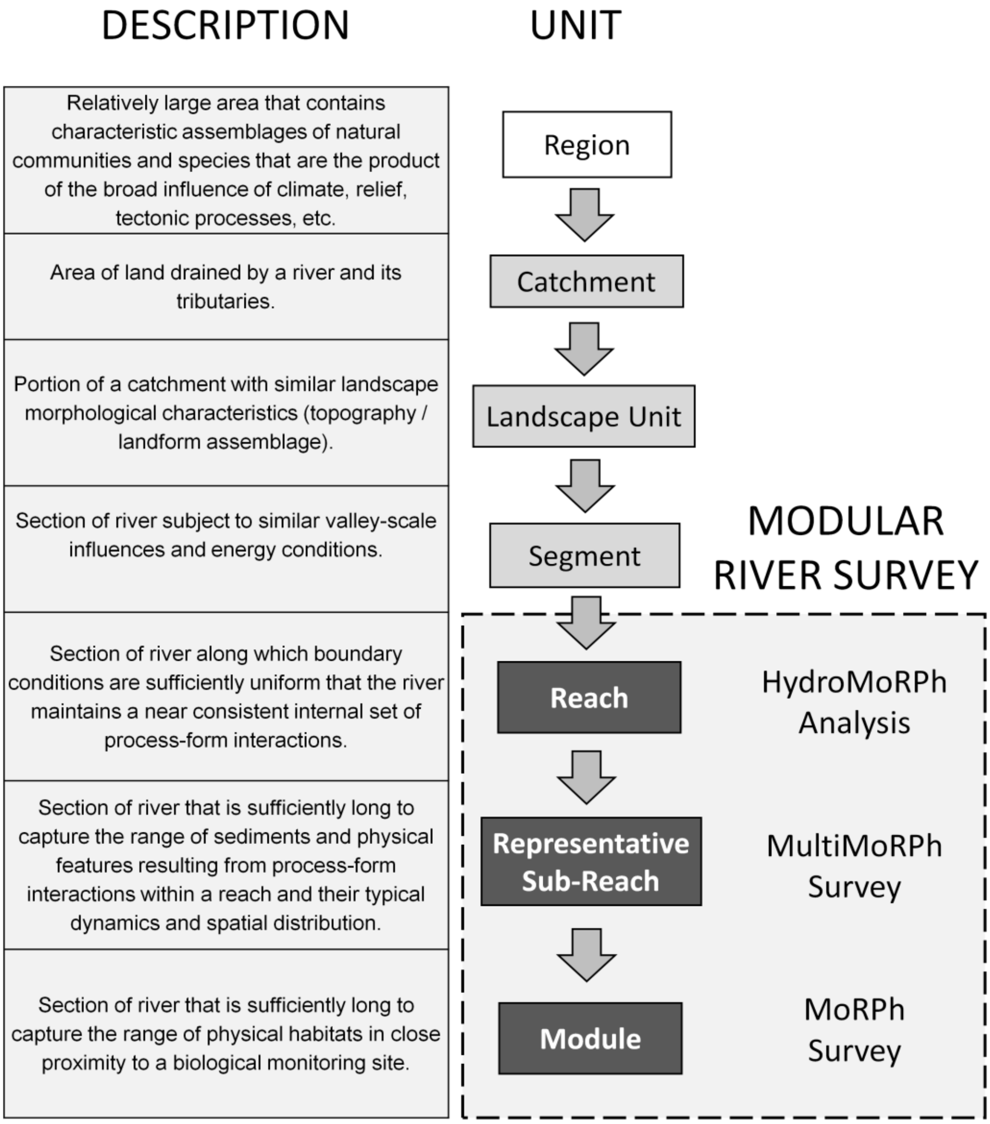

Figure 1: A hierarchy of spatial units for hydromorphological survey and assessment, illustrating how MoRPh and the Modular River Survey contribute to investigating physical habitat and hydromorphology from biological monitoring site to river reach scales. For further details refer to the MoRPh Technical Manual which can be obtained from www.modularriversurvey.org.

The form of river reaches and how this changes through time, expresses the dynamic physical habitat mosaic that provides for the biota inhabiting or passing through a river reach. The physical functioning of river reaches depends on factors and processes that operate at multiple spatial and temporal scales (England and Gurnell 2016, Figure 1). While such factors and processes can be investigated at larger spatial scales (catchment, landscape unit, river valley segment) through desk studies of available data sets collected by professional river scientists, studies at the reach and finer scales require inputs from field surveys. Importantly, field surveys provide data that cannot be obtained from remotely-sensed sources, including features that are smaller than the spatial resolution of the available imagery; ‘vertical’ features such as river banks that cannot be seen from a high viewing point; and any bed, bank and riparian features that are obscured by overhanging vegetation and structures, particularly in small river channels. Repeat field surveys can also capture detailed temporal changes in, for example, physical habitats or river bed sediments, where these features are a concern at particular locations or as part of post-restoration monitoring (Shuker *et al*. 2012).

This paper introduces a new method that volunteers and river professionals can use for monitoring the physical habitat mosaic and human interventions and pressures within short river reaches (10 to 40 m length). This survey method complements those undertaken by UK river professionals (for a review see England and Gurnell 2016) and is designed to fit within the framework illustrated in Figure 1, and thus to provide data that can be investigated at larger spatial scales and over longer periods of time. MoRPh forms part of the novel, hierarchical Modular River Survey where field information from MoRPh modules can be aggregated to characterize MultiMoRPh sub-reaches (100 to 400 m river lengths), in which morphological patterns and dynamics are investigated across sets of at least 10 contiguous MoRPh modules. Information from MultiMoRPh sub-reach sets can fit into reach-scale assessments of hydromorphology (HydroMoRPh), which integrate the MoRPh and MultiMoRPh field data into a desk-based historical and contemporary analysis of physical forms, adjustments and processes within the river and its floodplain (Figure 1).

How does MoRPh work?

The MoRPh survey is applied to ‘modules’ of river, which can be centred on a biological or water quality monitoring site, to characterize the local physical habitat mosaic and human interventions and pressures. The MoRPh survey module extends 10 m back from the bank tops on both sides of the river and the length of the module is scaled to the width of the active river channel. Thus in rivers with active channel widths of (i) up to 5 m, (ii) 5 to <10 m, (iii) 10 to <20 m and (iv) 20 to < 30 m the MoRPh module length is (i) 10 m, (ii) 20 m, (iii) 30m and (iv) 40 m respectively. The survey is not suitable for application to larger rivers.

By constraining the module length using the channel width, the survey covers a sufficient area to place a biological or water quality monitoring point into its physical habitat context. However, additional adjacent upstream and downstream MoRPh surveys provide information on other habitats at a greater distance from the sampling point. Furthermore, a contiguous set of at least 10 MoRPh surveys should capture the range and diversity of physical habitats available along a river reach and thus provide habitat information relevant to highly mobile species. It should also allow the longitudinal pattern of physical forms and sediments to be investigated as well as human interventions, providing a foundation for interpreting any contemporary geomorphological dynamics.

In line with other industry standard survey techniques (see England and Gurnell 2016), the MoRPh survey captures morphological and flow features, river channel and riparian sediment, vegetation extent and structure. As a further development, MoRPh records additional detail on material characteristics such as direct modifications and other human pressures within the 10 to 40 m length survey module (Table 1 provides a summary) enabling insights into habitat quality in the context of anthropogenic factors. MoRPh survey data and accompanying photographs are entered into a database via a web site (www.modularriversurvey.org). Surveyors gain a log-in following completion of one day of training. Through this log-in, all trained MoRPh surveyors can upload survey data to the MoRPh database. A small number of designated personnel assess the completeness and apparent data quality and either approve the survey or send queries to the surveyor. These designated personnel include the main national trainers (currently 4), and a rapidly increasing number of regional trainers (currently 10 but scheduled to be over 30 by the end of 2017), who have attended a trainers training course, usually as members of a regional river or wildlife trust. Surveyors can only edit their own surveys, but they can view or download any of the surveys that have been collected. Searches of the database can be made according to a range of criteria including surveyor name, survey entry date, river name and river location. Updates on any survey refinements and developments, survey forms, a Field Guide and full Technical Manual are downloadable from the Modular River Survey website.

Table 1. Broad categories of materials, physical features and vegetation properties, including human pressures and direct modifications that are characterized by a MoRPh survey.

	Bank top-Floodplain	**Bank face-Channel (and established island) Margins**	**Channel bed**
Materials		Natural materials Reinforcement materials	Channel bed natural materials, including degree of siltation Channel bed reinforcement materials
Physical features	Water-related features Artificial-managed ground cover	Natural and modified bank profiles Natural physical features of the bank face, toe and channel margin Artificial physical features	Natural physical features Water surface flow patterns Artificial physical features
Terrestrial (Riparian) and Aquatic Vegetation	Terrestrial vegetation structure Tree and large wood features Non-native invasive plant species	Terrestrial vegetation structure Tree and large wood features Aquatic vegetation at the channel margin Non-native invasive plant species	Aquatic vegetation Terrestrial vegetation, large wood and other organic matter interacting with the wetted channel Non-native invasive plant species

The Modular River Survey web site maps the raw data and fourteen indices extracted to summarise the flow patterns, sediments, physical habitats, vegetation, human pressures and interventions within each surveyed module (Table 2). The indices represent the weighted sum of the abundances and types of surveyed features or characteristics. Each index increases in value with an increase in the magnitude, complexity or severity of the property being indicated, and the potential minimum and maximum values of each index provide a basis for interpreting individual values from particular modules. In the future, the fourteen indices may be fine-tuned and expanded to provide differently weighted estimates of the current indices, to extract additional summary indices from each MoRPh survey, and to add one or two synthetic indices of overall quality or human pressure, probably at the MultiMoRPh rather than the MoRPh scale. An important strength of the current indices is that, when compared with uploaded photographs of each MoRPh module, they enable a rapid check of the apparent quality of the survey data.

Table 2. The 14 indices currently estimated from each MoRPh survey

Index type	Index number and name
River channel characteristics	INDEX 1: Number of flow types INDEX 2: Highest energy extensive flow type INDEX 3: Number of bed material types INDEX 4: Coarsest extensive bed material particle size INDEX 5: Average bed material size INDEX 6: Average bed material particle size class INDEX 7: Extent of bed siltation INDEX 8: Channel physical habitat complexity INDEX 9: Number of aquatic vegetation morphotypes
Riparian (bank face and top) character	INDEX 10: Riparian physical habitat complexity INDEX 11: Riparian vegetation complexity
Human pressures and impacts	INDEX 12: Degree of human pressure imposed by land cover on the bank tops INDEX 13: Channel reinforcement INDEX 14: Extent of non-native invasive plants

Some early results

Following initial testing and fine tuning, MoRPh was launched in late spring 2016. In the first six months, 233 MoRPh surveys were conducted on groundwater-fed, chalk streams of which 212 were located on rivers draining the Chiltern Hills to the north-west of London. Of these, 100 provide information on 10 MultiMoRPh sub-reaches. This emerging data set on chalk streams reflects early engagement with the Riverfly Partnership in the River Chess catchment and provides a timely opportunity to evaluate the performance of the MoRPh survey on a single river type.

Figure 2 shows graphs summarizing 233 values of several of the indicators. The frequency histograms (indices 1, 5, 8 to 13) summarize values in the context of the potential range of each index, which is represented by the numerical range of the horizontal axis. The frequency distributions (Figure 2) illustrate the rather low physical habitat complexity of the channel (index 8) and riparian margins (index 10) but high complexity of the aquatic (index 9) and riparian vegetation (index 11) within the potential range of values of these indices. The histograms also indicate that the channels are hydraulically simple (few flow types covering >10% of the water surface area) and the average bed material size (index 5) is rather fine, being mainly sand and silt, although some sites have an average gravel-pebble bed material size. The two bar graphs (Figure 2, indices 2 and 4) support these conclusions. The first bar graph (index 2) illustrates that the majority of the highest energy flow types observed that also cover at least 10% of the water surface area are rippled or smooth, with a very small number showing unbroken standing waves, and the remainder showing no perceptible flow or a dry channel bed. The second bar graph (index 4) shows that the coarsest bed material observed covering at least 10% of the river bed is gravel-pebble, with the second most frequent being silt. The final two frequency histograms show that most of the surveyed modules have no reinforcement of their bed and banks (index 13) and, in most cases, the adjacent land use presents relatively little hydrological or morphological pressure on the river (index 12).

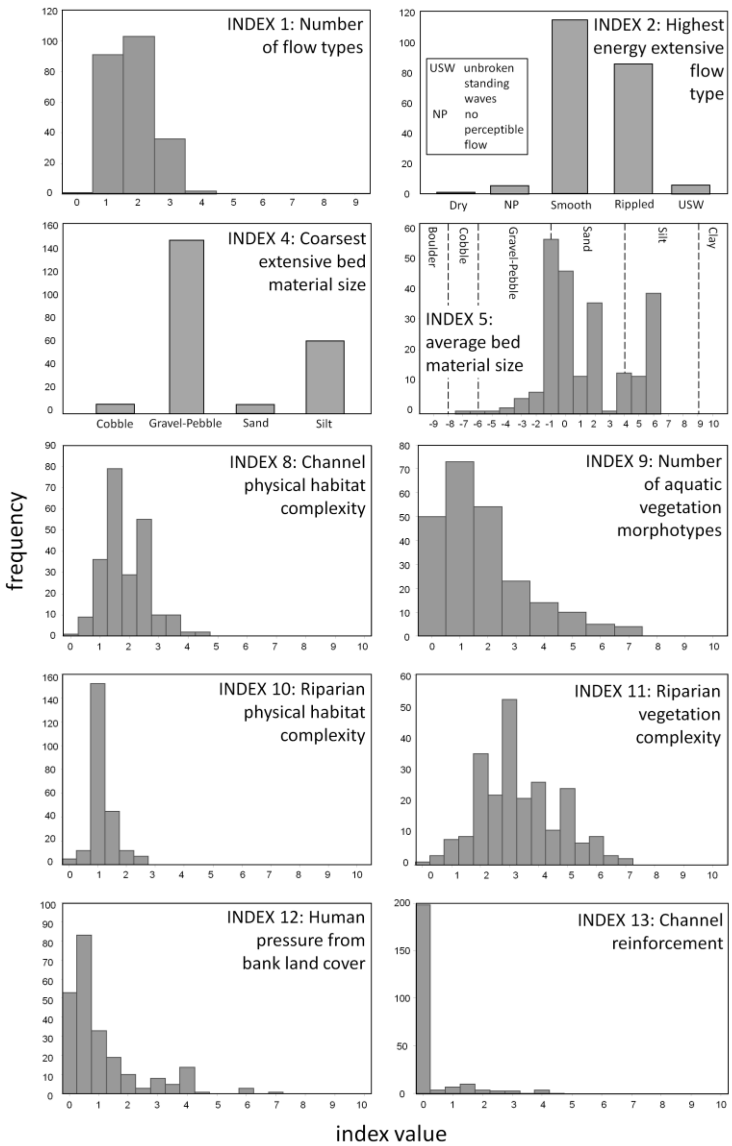

Figure 2. Frequency distributions for indices 1, 5, 8 to 13 illustrate the index values obtained from 233 MoRPh surveys. Note that each graph is plotted to show the observed data in relation to the maximum potential range of each index (the potential ranges are shown on the horizontal axes). Bar graphs for indices 2 and 4 illustrate the frequency with which particular index categories were observed.

Figure 3 illustrates how a selection of the indicators fluctuate across 10 contiguous MoRPh modules within 10 separate MultiMoRPh sub-reaches. The four illustrated indices relate to in-channel conditions, and in this Figure the values are plotted within a range (vertical axis) that highlights their variability rather than their magnitude with respect to the potential range of index values. The degree of index variability exhibited within each set of 10 contiguous MoRPh modules is often large, illustrating how the range of recorded hydraulic, sediment, morphological, and vegetation habitats can increase rapidly with an increase in the length of river surveyed. Across all 10 MultiMoRPh sub-reaches, the selected indices allow differentiation of each sub-reach through the different combinations of the physical character and quality indicators. For example, within the MoRPh survey data, MultiMoRPh sub-reach 1 illustrates high local variability in bed siltation (index 7) and a downstream increase in average bed sediment size (index 5): ranging from silt (+6) to relatively fine gravel-pebble (-2), calculated as decreasing values in phi units($-\log_2 D$, with particle size (D) measured in mm). MultiMoRPh sub-reach 2 shows one of the coarsest as well as variable average bed material size (index 5: +3 is sand to -4 is relatively coarse gravel-pebble) and the highest, although also very variable, channel physical habitat complexity (index 8). In contrast MultiMoRPh sub-reach 5 has more homogeneous and finer average bed material size (index 5: mainly 6, which is silt) and MultiMoRPh sub-reach 6 has the highest number of aquatic vegetation morphotypes (index 9) throughout its 10 MoRPh modules.

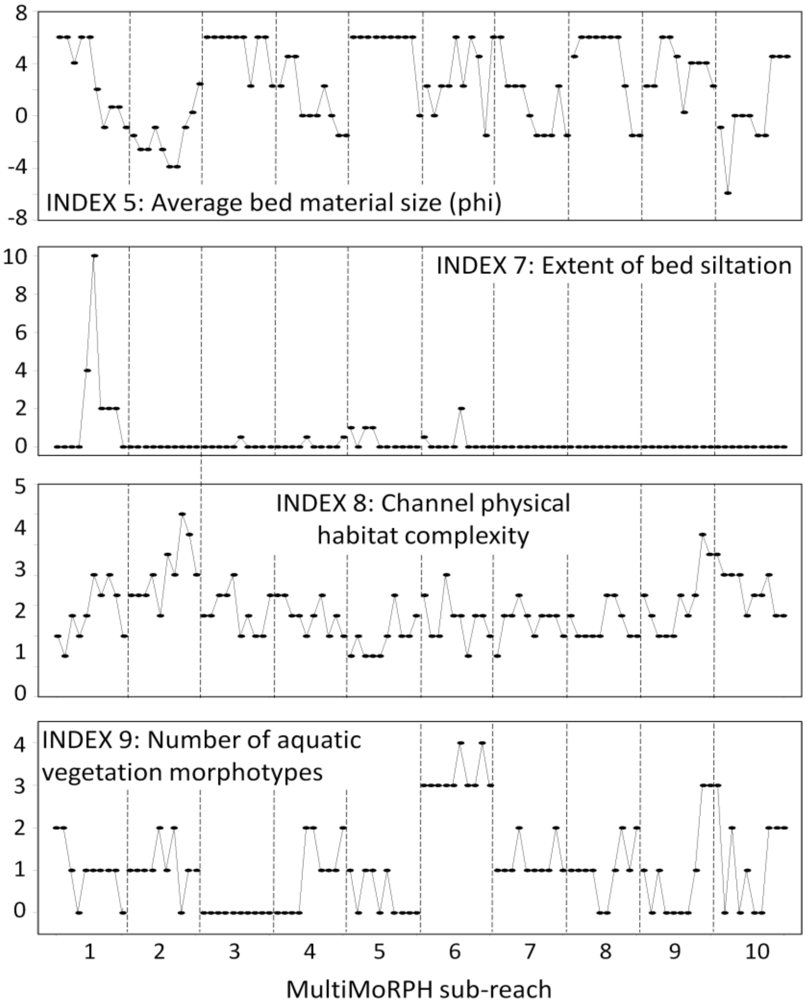

Figure 3. Upstream to downstream sequences of observations of four channel indices (5, 7, 8, 9) along 10 MultiMoRPh sets of 10 contiguous MoRPh surveys, illustrating the variability of some indices within a sequence of adjacent MoRPh modules. Note that: (i) the MultiMoRPh sub-reaches 1-10 are geographically unrelated, having been observed on different river systems; and (ii) the scales on the vertical axes have been selected to enclose the range of observed values and not their potential maximum range.

Conclusions

1. MoRPh has been designed for citizen scientists and river managers to provide an efficient tool for monitoring spatial and temporal changes in physical habitat conditions. Significantly, MoRPh can be conducted at a scale that allows physical habitat monitoring to be linked to biological and water quality monitoring. The Modular River Survey website allows surveyors to upload, store, download and map survey data and the indices that are calculated from that data.

2. At this early stage in its application, data have been collected almost entirely from a single river type (chalk streams) and have shown considerable variability between surveyed modules and also within the 10 contiguous modules of MultiMoRPh sub-reaches. This illustrates that the method is sensitive to differences in the hydraulic, sediment, morphological and vegetation habitat characteristics of a single river type, and thus has enormous promise as a spatial monitoring tool. In addition, the method offers substantial potential to capture changes at the same site through time, although this aspect has yet to be tested. Furthermore, the interpretable results produced by these early surveys give confidence that trained surveyors are applying the MoRPh survey in a consistent and reliable fashion.

3. As a means of summarising habitat characteristics relevant to particular organisms, the modular structure of MoRPh allows small modules of river to be investigated and supports interpretation of the distributions of less mobile organisms; but also larger river lengths to be aggregated when more mobile organisms are being considered.

4. The next stage is to develop aggregate indices for MultiMoRPh sub-reaches, which will support interpretation of contemporary morphological dynamics in addition to interpretation of the distributions of organisms living in the river and its riparian margins.

5. It is anticipated that the MoRPh survey with the addition of MultiMoRPh will help to address recommendations highlighted by Addy *et al.* (2016). By working with citizen scientists it is hoped the data will contribute to an improved understanding of the effectiveness of river restoration and catchment actions, especially when used in combination with complementary biological assessments, such as macroinvertebrate monitoring through Riverfly (www.riverflies.org) or algae assessment using RAPPER (Kelly *et al*. 2016).

Acknowledgements

We wish to thank all of the citizen scientists who have undertaken the MoRPh surveys and contributed feedback throughout development of the methodology. Without them this study would not have been possible. The work leading to this paper was partly funded by the Environment Agency. We are grateful also for all contributions in kind for training provided by the Hertfordshire and Middlesex Wildlife Trust, Chilterns Chalk Stream Project, and the Boxmoor Trust. The views expressed in this paper are those of the authors and do not necessarily represent the views of the organizations with which they are associated.

References

Addy, S., Cooksley, S., Dodd, N., Waylen, K., Stockan, J., Byg, A. and Holstead, K. (2016) River Restoration and Biodiversity, Nature-based solutions for restoring the rivers of the UK and Republic of Ireland. Report of the International Union for Conservation of Nature National Committee (UK). Available at: http://www.crew.ac.uk/publication/river-restoration [accessed 1st December 2016].

Bird, T. J., Bates, A. E., Lefcheck, J. S., Hill, N. A., Thomson, R. J., Edgar, G. J., Stuart-Smith, R.D., Wotherspoon, S., Krkosek, M., Stuart-Smith, J.F., Pecl, G.T., Barrett, N., Frusher, S., (2014) Statistical solutions for error and bias in global citizen science datasets. *Biological Conservation*,**173**,144-154.

DiFiore, D., and Fitch, B. (2016) The riverfly monitoring initiative: structured community data gathering informing statutory response. *Environmental Scientist*,**25**(2),36-41.

England, J. and Gurnell, A.M.(2016) Incorporating catchment to reach scale processes into hydromorphology assessment in the UK. *Water and Environment Journal*,**30**,22-30.

England, J., Skinner, K. S. and Carter, M. G. (2008) Monitoring, river restoration and the Water Framework Directive. *Water and Environment Journal*,**22**,227–234.

Huddart, J.E.A., Thompson, M.S.A., Woodward, G., Brooks, S.J. (2016) Citizen science: from detecting pollution to evaluating ecological restoration. WIREs Water 2016.

Jasanoff, S. (2004) Science and citizenship: a new synergy. *Science and Public Policy*,**31**,90-94.

Kelly, M.G., Krakowski, J. and Harding, J.P.(2016) RAPPER: A new method for rapid assessment of macroalgae as a complement to diatom-based assessments of ecological status. *Science of the Total Environment*,**15**,536-545.

Leonard, P., Gray, R. and Pecorelli, J.(2015) Citizen Crane: An example of Community engagement, helping assess the environmental use of the River Crane, a tributary of the River Thames. SEFS9. Geneva 6.

Loiselle S. (2016) Promoting freshwater sustainability through citizen science. *Environmental Scientist,***25**(2),62-66

Mainstone, C.P. and Wheeldon, J. (2016) The physical restoration of English rivers with special designations for wildlife: from concepts to strategic planning and implementation. *Freshwater Reviews*,**8**,1-25.

Roberts C. (2016) Citizen science – a research revolution? *Environmental Scientist*,**25**(2),2.

Roy H.E., Pocock M.J.O., Preston C.D., Roy D.B., Savage J., Tweddle J.C. and Robinson L.D. (2012) Understanding Citizen Science & Environmental Monitoring. Final Report on behalf of UK-EOF. NERC, Centre for Ecology & Hydrology, Natural History Museum.

Sheldon, D. and Ashcroft, R. (2016) Citizen Science - where has it come from? *Environmental Scientist,***25**(2),4-11.

Shuker, L., Gurnell, A., and Raco, M. (2012) Some simple tools for communicating the biophysical condition of urban rivers to support decision making in relation to river restoration. *Urban Ecosystems*,**15**(2),389-408.

Silvertown, J. (2009) A new dawn for citizen science,*Trends in Ecology & Evolution*,**24**(9),467-471.

Smith, B., Clifford, N. J. and Mant, J. (2014), The changing nature of river restoration. WIREs Water, **1**,249–261.

Starkey, E. and Parkin, G. (2015) Citizen science – a research revolution? A Review of Current Knowledge. Foundation for Water Research.

Summers MF, Holman IP & Grabowski RC (2015) Adaptive management of river flows in Europe: A transferable framework for implementation, *Journal of Hydrology*,**531**(3),696-705.

The Rivers Trust (2016) Citizen science and volunteer monitoring resource pack. Available at: http://www.catchmentbasedapproach.org/volunteer-monitoring [accessed 1st December 2016].

Thames River Watch (www.thames21.org.uk/project/thames-river-watch/) [accessed 28th November 2016]

Wiersma, Y., Parsons, J. and Lukyanenko, R. (2016) Data quality in citizen science – a research study. *Environmental Scientist,***25**(2),75-78.