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THE CONTRIBUTION OF CITIZEN SCIENCE VOLUNTEERS TO RIVER MONITORING AND MANAGEMENT: INTERNATIONAL AND NATIONAL PERSPECTIVES AND THE EXAMPLE OF THE MORPH SURVEY

Running heading: Citizen Science River Monitoring

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ABSTRACT

The contribution of citizen scientists to worldwide environmental monitoring has increased rapidly, particularly over the last two decades, as initiatives have become increasingly wide ranging in scope and style.

River monitoring and assessment faces many challenges, especially over the longer-term. Difficult decisions are being made over what can be measured and where. Citizen scientists are helping address these challenges by providing information on properties of river ecosystems, in particular biotic and water quality indicators, at lower cost and higher spatial and temporal coverage than would otherwise be possible; and by contributing to data interpretation, especially through their local knowledge. A notable deficit, however, has been the monitoring of physical characteristics and outcomes of physical interventions.

Furthermore, the development of frameworks, such as the Catchment Partnership approach in the UK, within which volunteers, Non-Governmental Organizations, charities, and statutory bodies collaborate to improve understanding of river environments and decision-making, is facilitating the engagement needed to support a new generation of integrated citizen science surveys.

Within the UK, citizen scientists use the Modular River Survey (MoRPh) to record river habitat data at a range of spatial scales to monitor physical changes and complement biological monitoring, notably the Riverfly Monitoring Initiative and associated 'Riverfly Plus' surveys. They also collect geomorphological data and provide data for restoration appraisal. We present and analyse MoRPh data to illustrate how such new-generation, multi-scale,

multi-purpose monitoring methods can extract maximum value from the ever-increasing citizen river science approach.

KEYWORDS

Citizen science, Citizen river science, bio-physical river habitat monitoring, Modular River Survey, Riverfly Plus

INTRODUCTION

Monitoring programmes are key to the effective and sensitive management of river systems by capturing data that inform the setting of objectives, the design and prioritization of actions, and provide the all-important baseline for assessments. However, river monitoring and appraisal faces several key challenges.

Securing funds is a major obstacle especially over the longer-term, leading to difficult decisions over what can be measured. Such limitations can have implications for spatial and temporal resolution and attempts to links physical, biological, and chemical changes.

Although some river monitoring is routinely undertaken to meet statutory obligations these data are unable to meet the demand from an increasing number of improvement schemes, (e.g. restoring river habitats and providing natural flood management), many of which are likely to have project-specific data requirements. In recent years, growing numbers of volunteers are working collaboratively with a range of organizations (Non-Governmental Organizations (NGOs), charities, and statutory agencies) to address the 'monitoring gap' and the engagement of citizen scientists is proving mutually beneficial, creating new and exciting possibilities for river monitoring.

Our paper explores the rise of citizen science, arguably a revolution in how science is undertaken (Roberts, 2016), and considers the opportunities and challenges it provides in the context of river monitoring and management. First, we review the rise of citizen science internationally, defining its nature and scope and then, based on online searches, we present examples of citizen science projects and analyse the nature of published outputs based on citizen river science. Secondly, we examine the contribution of citizen science to river monitoring and management in the United Kingdom, where Catchment Partnership has become a prominent delivery mechanism for river monitoring and improvements. Thirdly, we explore the Modular River Survey (MoRPh) because of (i) its provision of a relatively rare type of citizen science monitoring, biophysical habitat monitoring, which is an important complement to the more widespread water quality and species-based monitoring undertaken by citizen scientists; (ii) its deliberate multi-scale structure, which allows the monitoring data to be used in a wide range of contexts; and (iii) its design to capture geomorphologically-meaningful properties in addition to physical habitat characteristics of the river environment, so that it can support understanding of river morphodynamics. We present an analysis of MoRPh data which illustrates the breadth of surveys collected by citizen scientists so far and, by focusing on a calibration data set collected by the researchers who developed the survey, the depth and potential quality of monitoring data that such new generation, multi-scale citizen science surveys can provide. Finally, we summarise and share some reflections on the future development and use of MoRPh within the context of evolving citizen river science.

THE RISE OF CITIZEN SCIENCE AND CITIZEN RIVER SCIENCE

Definitions, Scope and the Rise of Citizen Science

Citizen science is a broad concept and definitions abound in the literature. At its simplest it is 'the engagement of non-professionals in scientific investigations' (Miller-Rushing et al., 2012). The European Environment Agency (EEA) use a practical working definition (after Bonney and Dickinson, 2012): 'Organized research in which members of the public – who may or may not be trained in science – gather or analyse data' and this can often be '… in collaboration with or under the direction of professional scientists and scientific institutions' (Oxford English Dictionary).

Environmental monitoring by non-professionals has a long history dating back over the centuries, for example, to early weather watchers such as farmers and wine growers keen to make sense of changing rainfall and temperatures and the links with soil conditions and crops (Sheldon and Ashcroft, 2016). However, with the professionalisation of the environmental sciences from the mid-twentieth century, and the establishment of a range of environmental research institutes, these 'amateur experts' (Gura, 2013) were excluded (Roberts, 2016). In recent decades, a renaissance or 'new dawn' for citizen science has been occurring (e.g. Silvertown, 2009; Mackechnie et al., 2011; Miller-Rushing et al., 2012) and is reflected in the rising number of publications on the topic of citizen science (Table 1).

Citizen science initiatives are wide-ranging in scope and operate at local to global scales (Miller-Rushing et al., 2012) but the key distinguishing feature is that participation is on a *voluntary* basis. Individuals report being motivated to participate in citizen science for a variety of reasons (Kragh, 2016). These include *self-directed* motives (e.g. arising from a personal interest in the natural environment and a desire to learn something new) and *altruistic* ones (e.g. a desire to make a difference, contribute to a cause and a scientific programme) and this engagement can occur in a variety of ways. This can be as simple as crowd sourcing or participants can analyse as well as gather data and propose and design research (see Sheldon and Ashcroft, 2016). Reflecting these different ways of engaging, projects have been categorized as: (a) *Contributory*, designed by professional scientists with members of the public primarily contributing data; (b) *Collaborative,* designed by professional scientists with members of the public contributing data, informing the way in which the questions are addressed, analysing data, and disseminating findings; and (c) *Co-created*, designed by professional scientists and members of the public working together with some of the volunteer participants involved in most or all steps of the scientific process (see Bonney et al., 2009; Miller-Rushing et al., 2012; Roy et al., 2012). Understanding the motivations of volunteers (Geoghegan et al., 2016; Wright et al., 2015) and providing opportunities for higher levels of engagement in projects that become collaborative in nature are key to sustaining the longer-term interest of citizen science volunteers in a competing market. Offering training and mentoring to increase skills and expertise, facilitating data sharing through web-based platforms, and use of social media to promote feedback are just some of the ways this can be achieved (see also Newman et al. 2012).

A Global Perspective on Citizen River Science

The total number of citizen science projects and initiatives globally that involve monitoring aspects of the river environment is problematic to quantify and they are far too numerous to attempt to report here but some key features can be recognised (see Table I in Supplementary Materials for selected examples). Alongside on-going projects running successfully for up to 30 years (e.g. StreamWatch and WaterWatch) new initiatives continue to be launched, some with a very targeted focus and short timeframes of days to months (e.g. Caring for Waterhole Creek 2017, Supplementary Materials, Table I). Monitoring encompasses a range of river characteristics including biota, physical habitat, water quality, water levels, and litter, but projects with a focus on biota (especially macroinvertebrates) and water quality dominate (see Hecker et al. (2018) and Kullenberg & Kasperowski (2016) for analyses of European citizen science projects). In terms of the geographical coverage of projects, examples can be found on all continents and across a range of scales from the local / catchment level through to national and international but they are most numerous in North America, Europe and Australia (Roy et al., 2012; Pocock et al., 2019). Citizen science is notably more limited in developing countries (Araya et al., 2009; Pocock et al., 2019).

The wide availability of smartphones, tablets, desktop computers and easy access to the internet in more developed countries is enabling the public to record environmental data in many more locations and at finer timescales, complementing professional monitoring programmes. In contrast, citizen science projects reliant on technology, including access to the internet and mobile coverage, have limited success in resource-poor countries where they have to compete with other priorities for scarce resources (Beza et al., 2017; Braschler, 2009). Although some notable examples exist (see Supplementary Materials, Table I), the primary barriers to citizen river science in less developed countries include: limited awareness of opportunities; limited organisational capacity, including planning, leadership and co-ordination; lack of appreciation of the value of citizen science from decision-makers; lack of skilled participants; inadequate funding; and limited incentives (see Pocock et al., 2019). To access valuable local knowledge citizen science projects also need to be designed to capture and synthesize information from indigenous societies with different knowledge systems (Hecker et al., 2018; Vitos et al., 2013) and Pocock et al. (2019) have called for "culturally-relevant citizen science" that aligns with the UN's Sustainable Development Goals and benefits participants and end-users. Less known best practice examples include Thai Baan research led by the Living River Siam Association (previously Southeast Asia Rivers Network) on the Mekong River dating back to 2003 where villagers successfully fought the blasting of rapids and destruction of important habitat for local fishing stocks and the endangered Mekong Giant Catfish (Herbertson, 2012). Citizen river science projects also vary in terms of the training required for participants ranging from no training to online guidance and/or dedicated courses, and they also show different levels of engagement which we have categorised as contributory, collaborative, and co-created (after Bonney et al, 2009; Roy et al, 2012). Based on a sample of 174 European Citizen Science projects, Hecker et al. (2018) show that over two thirds of projects are either contributory or collaborative and an estimated 1.2 million people have participated at least once in a project.

A Google Scholar search using a variety of search terms in combination with *Citizen Science* revealed some interesting publication trends on different aspects of river monitoring (Table 1). Decadal increases in publications occurred in all search areas from the 1970s. Publications on citizen science monitoring of river ecosystems increased significantly at the start of the 1990s mirroring the earlier and more widespread engagement of citizen science volunteering in biological and ecological (especially biodiversity) monitoring commented on by several authors (see for example Roy et al., 2012). Over the following decade (2000-2009), large increases in publications on *river monitoring* and *river habitat monitoring* occurred, reaching levels comparable to those on *river ecosystems monitoring* and publications continue to remain at the same high levels in all these three areas in the current decade. Publications on citizen science and river monitoring that specifically mention *geomorphology* are c. 50% fewer but have sustained increases over the past five decades and the 8630 publications since 2010 reflect vibrant activity. Interestingly, publications on citizen science monitoring specifically referring to *hydromorphology* only appear post 1990, probably because of the term's widespread use since then in the context of monitoring for the EC European Water Framework Directive (WFD; Council of the European Communities, 2000) implementation. Although numbers are very low, they are also increasing.

Opportunities, Benefits and Challenges of Citizen River Science

Using novel and more affordable technologies and engaging with citizen science initiatives, the public are also becoming better connected and more informed about their local environment (Wals et al., 2014). Stakeholder engagement with its partnership and polycentric approach to monitoring and data collection is improving decision-making (Buytaert et al., 2016) by bringing local knowledge to help in the resolution of local environmental problems (Aceves-Bueno et al., 2015; Kragh, 2016; Overdevrest et al., 2004) and represents a collaborative and inclusive model of governance (Mert, 2015; United Nations Development Programme, 2016).

Set against the long list of benefits linked to citizen science initiatives (see Roy et al., 2012 for a summary) are concerns over the precision and accuracy of data collected by volunteers. Several studies have been undertaken to assess the performance of volunteers engaged in river monitoring compared to professionals (e.g. Crall et al., 2011; Fore et al., 2008; Gollan et al., 2012; Pocock et al., 2014). The studies provide strong evidence that citizen science volunteers can collect reliable data (Gollan et al., 2012) and with training they can make stream assessments comparable to professional scientists (Fore et al., 2008). Crall et al. (2011) also advocate volunteer certification on completion of training to provide a sense of accomplishment, demonstrate commitment, and improve retention. If data are collected appropriately following clear protocols without subjective measures and are subject to quality assurance, they can be used by government agencies for regulatory purposes (Fore et al., 2008; Pocock et al., 2014). In the USA, for example, monitoring of watercourses is undertaken by volunteers following Environmental Protection Agency (EPA) protocols to meet regulatory requirements (Nerbonne and Nelson, 2004). Furthermore, the growing number of citizen science projects to monitor water and air quality is recognised and actively supported by the EPA through metadata and tools such as www.citizenscience.gov (https://www.epa.gov/citizen-science/citizen-science-projects-supported-epa accessed 03/02/2019). In the UK, 7 out of the 26 headline biodiversity indices rely on data collected by volunteers (Defra, 2012). Online tools for screening and validating data gathered by large numbers of people with varying levels of expertise (e.g. the novel system developed by Bonter and Cooper (2012) for Project FeederWatch) offer enormous potential and the possibility of even more widespread use of citizen science surveys. With the ever-increasing numbers of citizen science projects, web-based initiatives that register projects and have search facilities play an important role in recruiting and retaining volunteers, sustaining projects, and sharing best practice. Examples include the US National Science Foundation funded project SciStarter (https://scistarter.org) and the Australian Citizen Science Project Finder (https://www.ala.org.au/biocollect).

THE CONTRIBUTION OF CITIZEN RIVER SCIENCE TO RIVER MONITORING AND MANAGEMENT IN THE UNITED KINGDOM

A long tradition of stakeholder interest in the health of rivers exists in the UK from anglers, landowners, naturalists and local community groups (Orr et al., 2007).

In the absence of a formal structure for this engagement the Catchment Based Approach (CaBA) launched by Defra in 2013, supports integrated management and objectives delivery including EU WFD Regulations (Defra, 2003; Natural England, 2015; Vlachopoulou et al., 2014). CaBA aligns with the UK's adoption of the Ecosystem Approach (Defra, 2007) to provide a framework under which different river-focused interest groups can come together at a local level through Catchment Partnerships (CPs). Over 100 CPs currently operate across England and Wales, 77% of which work with citizen scientists and volunteers (https://catchmentbasedapproach.org/ accessed 26/1/19). River trusts are key host organizations within CPs and the 60 trusts across the UK engage with 11,575 volunteers in a wide range of activities (https://www.theriverstrust.org/ accessed 26/1/19).

Recognising the benefits of a collaborative partnership model, the Environment Agency is currently trialling an 'agile' approach to monitoring for evidence-based investigations across England with five catchment host organisations (Environment Agency, 2018). These 'catchment prototypes' will test ways of using 'a broader range of information' to solve problems, make decisions, and categorise improvement activities. They are considered ideally placed to implement a range of monitoring methodologies including post-restoration assessments or rapid deployment, for example at the time of environmental incidents or events (Environment Agency, 2018).

To date, there has been a strong focus on water quality and biological monitoring within citizen river science (see also Supplementary Materials, Table I). In the UK the Anglers' Riverfly Monitoring Initiative (ARMI) (http://www.riverflies.org/) is an exemplar of a highly co-ordinated collaborative initiative launched in 2004 following concerns over the environmental quality of the UK's rivers. Trained volunteer groups monitor water quality by recording the abundance of pollution-sensitive invertebrate groups, seven of which are riverflies. If abundances fall below site 'trigger' levels the groups alert the relevant statutory body for further investigation. In this way the initiative also informs statutory responses by providing an early warning system (Di Fore and Fitch, 2016).

Since its establishment the Riverfly Partnership has expanded to over 100 organisations bringing together anglers, conservationists, entomologists, and government agencies to protect rivers (Davy-Bowker and Menzies, 2016). The network facilitates more regular monitoring (usually monthly) at a finer spatial resolution than the statutory monitoring of UK regulatory agencies. This citizen science partnership is particularly advantageous in pollution detection and has led to the successful prosecution of polluters (England and Peacock, 2010). The presence of volunteers on the river also acts as a deterrent to would-be polluters (Huddart et al., 2016).

The ARMI initiative has been the catalyst for other complementary freshwater-focused citizen science. These 'Riverfly Plus' schemes have developed in response to demands from existing network members wanting to further understand their river ecosystem or address specific issues. Through collaborations with statutory bodies or academic institutions the capabilities and commitment of ARMI groups effectively complements and informs decision making and research (Riverfly Partnership, http://www.riverflies.org/ accessed 16.1.19).

In the context of citizen river science, 'Riverfly Plus' schemes demonstrate an innovative example of a suite of tools developed at appropriate spatial scales for their joint application at a monitoring site, including a tool to monitor channel and riparian morphology and vegetation physical structure – the Modular River Survey (MoRPh). Such a suite of tools is essential to build an integrated understanding of how river environments function and vary across time and space and could be further complemented by flow data whether from professional sources or collected by citizen scientists (e.g. Crowdwater, Supplementary Materials, Table I). Furthermore, Catchment Partnerships involved in delivering hydromorphological improvements, often require monitoring to assess their outcomes but accessible methods to assess physical change as an underlying control on other attributes have been limited. MoRPh, which was specifically developed in response to river enthusiasts wanting tools to assess physical habitat quality at a range of spatial scales to match biological monitoring, helps to identify morphological degradation, and appraise the success of river restoration activities (Huddart et al., 2016; Shuker et al., 2017).

THE MODULAR RIVER SURVEY (MoRPh)

MoRPh as a Tool for Citizen Scientists engaging in River Assessment

The MoRPh survey is a tool for citizen scientists to monitor river channel and riparian physical habitats at scales that can complement biological surveys. In gathering data using MoRPh, citizen scientists both capture valuable evidence whilst also engaging directly with and learning about the changing physical character of their local river systems. We focus on MoRPh as an exemplar of a new-generation citizen science survey tool because:

(i) It supports citizen scientists in delivering a relatively rare but important type of river survey that characterises the physical structure of the river channel and vegetation. Many citizen science surveys are concerned with biological or water quality aspects of rivers, leaving the characterisation of physical structure as a major missing link in their investigations.

(ii) Although the MoRPh tool was originally devised to complement Riverfly surveys, it can be applied flexibly by citizen scientists at different spatial scales to complement biological surveys of species displaying different levels of mobility and styles of habitat usage and also to investigate river responses to different hydrological events and human interventions.

(iii) In addition to capturing information on physical habitat, MoRPh also allows citizen scientists to capture sufficient geomorphological information to assess the degree to which a river of a particular type displays the relevant geomorphic features and also to collaborate with researchers in inferring some aspects of river morphodynamics. These constitute larger space and time insights into how a river is functioning and may be changing

MoRPh was developed in 2016 and has been gradually adopted across England, Wales and, most recently, the Republic of Ireland. The survey method has been described by Shuker et al. (2017). The MoRPh manual, field guide, survey forms and indicator formulations are freely available in the public domain and downloadable from https://modularriversurvey.org/. An overview of the composition of the survey is provided in Table 2 and information on the indicators extracted from it is provided as Table II in the Supplementary Materials.

The MoRPh tool enables citizen scientists to record properties of the river bed, bank faces and bank tops up to 10m from the channel edge (Table 2). It is applicable to small (typically up to 20 m wide) single thread to transitional rivers which characterise almost 100% of the river length in the United Kingdom. MoRPh surveys are carried out by citizen scientists at three spatial scales (Figure 1) to meet the interests and objectives of local groups. At the smallest scale, for capturing and monitoring physical habitat around a macroinvertebrate monitoring site, a 'module' of river, approximately 2 channel widths in length, is surveyed. A MultiMoRPh survey of 10 contiguous MoRPh modules (subreach length approximately 20 channel widths) captures the range of habitats available to more mobile species such as fish. By accessing open source data and aerial imagery, a HydroMoRPh desk study of extended reaches (e.g. 10+ km) can be also be undertaken by citizen scientists interested in the wider river system, enabling them to link field-surveyed geomorphological features with the type of river under consideration.

At its simplest, a HydroMoRPh analysis estimates a river type from the river and valley slope, river planform and degree of valley confinement of an extended reach within which the MultiMoRPh subreach is located. Information on bed material gained from the MultiMoRPh field survey data also contributes to assigning a river type. The degree of natural geomorphic function can then be assessed by investigating whether the MultiMoRPh subreach displays the appropriate types/abundances of geomorphic features expected for the river type and the human interventions (e.g. reinforcement, in-channel structures) that may be disturbing natural function. Thus, detailed knowledge of a river system and its current condition may be gained by individuals or groups of citizen scientists by combining the different spatial scales captured by the Modular River Survey methodology.

The MoRPh single module survey captures information on physical habitat, vegetation structure, sediments, geomorphic features, and human interventions and pressures (Table 2). Because the survey is designed with non-specialist citizen scientists in mind, geometric/visual guidance is provided to identify the limits of the channel bank tops, bank faces and bed, sediment calibre classes and also certain features (e.g. bars, berms, benches, islands). In addition, abundance is recorded using a count or a simple four-class abundance scale (A = absent (0%), T = trace (<5%), P = present (5 - 33%), E = extensive (>33%)). These aspects aim to maximise consistency in recording, but also need to be recognised in interpreting survey data.

When a citizen scientist uploads a survey into the web-based Modular River Survey information system values of 14 indicators are calculated (Supplementary Materials, Table II) and mapped. Eleven indicators synthesise natural properties and 3 concern anthropogenic influences. Citizen surveyors can see mapped results from all surveys and are able to download any of the indicators, raw survey data and photographs held in the MoRPh data base.

Currently there are over 350 active citizen surveyors and approximately 2300 MoRPh modules have been surveyed, mainly during 2018. Figure 2 locates the sites surveyed by these surveyors within England and Wales at the end of 2018. Figure 3 presents frequency histograms of 6 of the main synthetic indicators derived from all the surveys conducted by citizen scientists so far. Although most surveys have been conducted in lowland areas of relatively high population density, these frequency histograms show varied indicator scores across their potential ranges (represented by the length of the horizontal axes), illustrating the variability observed across predominantly lowland rivers and also the space for surveys from upland rivers to populate the less frequently occurring scores for some of the indicators.

An analysis of Modular River Survey observations collected from 10 rivers of different type to address Two Questions:

A calibration data set was collected by the researchers who developed the Modular River Survey. This encompassed the range in river gradient or energy displayed by rivers across

England and Wales at sites subject to minimal human interventions and pressures (Figure 2, black dots; Table 3) and thus allowed testing of the effectiveness of the survey across this range. MultiMoRPh surveys were conducted by the researchers at these sites to address two main questions. The first relates to the broad physical character of these surveyed river reaches and thus the suites of recorded physical characteristics underpinning these indicators that can be interrogated to investigate the availability of habitat for target species and their life stages. The second explores some of the geomorphic information that is collected and the degree to which it describes the expected assemblages for rivers of different types:

> Question 1: Do the indicators that are derived from MoRPh surveys allow discrimination of differences in the overall physical structure of river channels, channel margins and their vegetation across relatively unmanaged rivers of different type?
>
> Question 2: Do the raw field observations of geomorphic features obtained during MoRPh surveys describe expected gradients across the surveyed river gradients and types?

HydroMoRPh analysis

Following the citizen science methodology, a simple HydroMoRPh analysis of longer reaches containing each MultiMoRPh subreach used information extracted from images in Google Earth (Table 3) coupled with estimates of bed material properties from the MultiMoRPh field surveys to establish the river type (Table 3, following Rinaldi et al., 2016). Each selected longer reach was determined by (i) absence of major tributaries, (ii) broad consistency in river planform-confinement, (iii) absence of major structures (e.g. dams). Sinuosity (river length: valley length) was classified as straight, sinuous or meandering using threshold values of 1.05 and 1.5. River and valley slope were calculated using the lowest local elevation at each end of the reach (Google Earth DEM). Level of confinement was estimated from the proportion of the river bank length that appeared to be in contact with valley side slopes (confined (C) reaches - >90% river bank length in contact; unconfined (UC) - <10% in contact; partly confined (PC), 10% to 90% in contact). Table 3, which lists the 10 river reaches in order of their valley gradient, displays reasonably consistent changes in channel gradient, average bed material size class and coarsest bed material with decreasing valley gradient and assigns a river type based on confinement, planform and bed material. The steepest 5 reaches are straight or sinuous and confined or partly confined (A to E), whereas the least steep 5 reaches are sinuous or meandering and unconfined.

MoRPh indicators and Question 1

Figure 4 displays values of 9 MoRPh indicators, which synthesise suites of the properties surveyed. Figure 4 illustrates some distinct changes as river valley slope declines but also shows internal variability within MultiMoRPh subreaches, suggesting that MoRPh is capturing progressive changes both within and between MultiMoRPh subreaches. The hydraulic (Figure 4 v and vi), sediment (Figure 4 vii to ix) and channel physical habitat (Figure 4 i) indicators display systematic changes with decreasing gradient across the 10 MultiMoRPh subreaches. The number of aquatic vegetation morphotypes (Figure4 iii) also increases across subreaches of intermediate to low gradient, reflecting the ability of aquatic plants to survive in lower energy streams (Gurnell et al., 2011), while riparian physical habitat (Figure 4 ii) shows fairly consistent values, but with the highest values at subreaches of intermediate slope.

To investigate this variability in more detail, the observations for the 9 indicators illustrated in Figure 4 were subjected to a Principal Components Analysis (PCA) using XLSTAT 2019 software. The categorical data presented in Figures 4vi and 4vii, were converted to numbers by assigning values of 1 to 8 to the highest energy (free fall) to lowest energy (no perceptible flow) flow types and values of 1 to 6 for the coarsest (bedrock) to finest (silt) bed material. The PCA was performed on a rank correlation matrix because several variables were integer or had a restricted range in their possible values. The first two PCs explain over 70% of the variability in the data set (Figure 5ii). PC1 explains almost 58% of the variability and, based on the highest indicator loadings (Figure 5ii), describes a gradient of decreasing hydraulic complexity (high negative loading on number of flow types and high positive loading on the highest energy flow type, whose value increases with decreasing flow type energy), decreasing bed material size (high positive loadings on coarsest bed material and average alluvial bed material size in phi units, both of which increase in value with decreasing particle size), decreasing channel physical habitat complexity, and an increasing number of aquatic vegetation morphotypes. The MoRPh modules are arranged along PC1 approximately in subreach order (Figure 5i) but with overlap indicating how individual MoRPh modules may display quite widely varying characteristics within a MultiMoRPh subreach. By far the highest loading on PC2 (0.678) is on the riparian physical habitat complexity indicator, and the loading vector for this variable (Figure 5ii) indicates that this is a feature of subreach E and some modules of F and G (Figure 5i), which are the intermediate gradient subreaches in the calibration data set.

In summary, Figures 4 and 5 provide the answer to Question 1. Noteable differences in the MoRPh 'natural' synthetic indicators are observed within and between MultiMoRPh subreaches, suggesting changes in the suite of observed characteristics that underpin them. Within-subreach variations illustrate why it is necessary to conduct a MultiMoRPh survey if the range of available habitats are to be captured. Between-subreach contrasts capture distinct changes as gradient and river type change. Overall, MoRPh module and MultiMoRPh surveys are capable of capturing major and minor differences between and within the surveyed subreaches.

MoRPh geomorphological features and Question 2

Figures 6 and 7 show, respectively, the presence, count or abundance of channel bed and channel margin physical features that were recorded in the MoRPh calibration surveys, and illustrate examples of a tiny subset of the raw data that is collected during a MoRPh survey. Each graph displays MoRPh module data in a downstream sequence within each of the

MultiMoRPh subreaches, which are arranged in order of decreasing valley slope and changing river type.

The channel bed features (Figure 6) show that waterfalls, steps, cascades, exposed bedrock and boulders are confined to the steepest subreaches (Figure 6 i, ii, iv, v). Riffles, pools and mid-channel bars occur more widely (Figure 6 iii, vi), although riffles and unvegetated bars are not observed in the lowest gradient subreaches. This MoRPh data reveals the expected geomorphological transition in bed features from steep channels with waterfalls, steps-pools and cascades, through intermediate slope riffle-pool subreaches to low gradient subreaches with relatively featureless beds.

The channel margin features (Figure 7) show that extensively eroding banks are largely confined to steeper subreaches, and when they occur in lower-gradient subreaches, they are confined to a single river bank within a MoRPh module (Figure 7 i). Vegetated side bars increase in frequency and extent as subreach gradient declines (Figure 7 iii), whereas unvegetated side bars are mainly observed in subreaches with a high to intermediate gradient (Figure 7 ii). Berms and benches occur across all subreaches but are most frequently recorded as extensive in intermediate to lower gradient subreaches (Figure 7 iv). Although a less clear geomorphological pattern than for the bed features, an expected transition is observed from steep to intermediate subreaches displaying actively eroding bank profiles and unvegetated side bars to increasingly vegetated side bars, berms and benches as the gradient decreases.

In answer to Question 2, it seems that despite the rather simple MoRPh abundance scale, designed for ease of use by volunteer citizen scientists, geomorphological features are recorded in the positions and abundances that would be expected. Furthermore, the lightly managed rivers of different type are being attributed with appropriate suites of geomorphic features.

SUMMARY AND CONCLUSIONS

Analysis of international publications indicates that the recent rise in Citizen Science dates back at least to 1970 but has expanded dramatically since 2000, and now initiatives operate at local to global scales. Furthermore, our literature review and analysis of MoRPh data provide evidence that citizen scientists collect extremely valuable data. In relation to the MoRPh tool, the collected data summarises the physical structure of rivers that can complement observations of water quality and the species present that, to date, have been more frequently captured by citizen river scientists.

At a time when river monitoring and appraisal is increasingly important, citizen science volunteers are making major contributions to improved river management by:

- increasing the spatial and temporal collection of data;
- providing information on numerous properties of river ecosystems including those required at a local level in relation to specific environmental issues;
- interpreting data and often enhancing interpretation with local knowledge;

- actively informing and participating in decision-making.

Where frameworks exist for citizen scientists to work with regulators and NGOs, such as the UK Catchment Partnerships, these provide a setting in which:

- truly collaborative projects evolve with many co-created elements reflecting local knowledge;
- the many contributions of citizen scientists are amplified;
- integrated citizen science monitoring initiatives can promote a deeper understanding of river ecosystem structure and function.

One such integrated monitoring initiative is 'Riverfly Plus' in which the Modular River Survey (MoRPh) provides:

- an approach for citizen scientists to capture river physical habitat data to develop an integrated understanding of river functioning; enabling citizen scientists to combine knowledge of species, water quality and physical habitat.
- a nested, multi-scale tool for capturing physical habitat information that can complement the scales of different biological monitoring approaches, allowing joint, contemporaneous, compatible surveys of habitat and biota to be conducted.
- a hierarchical framework for characterising river geomorphic features and dynamics by linking and interpreting information across spatial scales and through time.

The Modular River Survey (MoRPh) provides an example of a new generation of citizen science tools which supports integrated, multi-scale monitoring to ensure that the maximum value is delivered by citizen river science endeavours. The survey is being widely and successfully used by citizen scientists within the UK following one day of training and early indications are that it is transferable for application to rivers of appropriate size across the humid temperate zone. However, robust recommendations for its wider application need to be based on further research.

Nevertheless, the Modular River Survey provides an example of emerging new generation tools that can enable citizen scientists to make increasingly fundamental and far-reaching contributions to integrated river ecosystem understanding and more sustainable river management.

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Geoff Petts was internationally recognised for his integrated approach to understanding river ecosystems. He was an enthusiast for citizen river science in general and for the Modular River Survey in particular. Indeed, he was keen to become a MoRPh surveyor, an ambition that was undermined by his final illness. We incorporated the Old Mill Stream, a beautiful steep, Devon stream, in our calibration data set, because Geoff intended it to be the site for his first MoRPh surveys.

DATA AVAILABILITY STATEMENT

Modular River Survey Data: Authors: trained MoRPh surveyors; Year: 2015 to present, Data repository: www.modularriversurvey.org (click on the relevant locations on the MoRPh map to display the data in a side-bar). The data for the 100 MoRPh Surveys analysed in detail in this article and collected by A.M. Gurnell and L. Shuker; Year is available as an Excel spreadsheet on request to a.m.gurnell@qmul.ac.uk.

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FIGURES

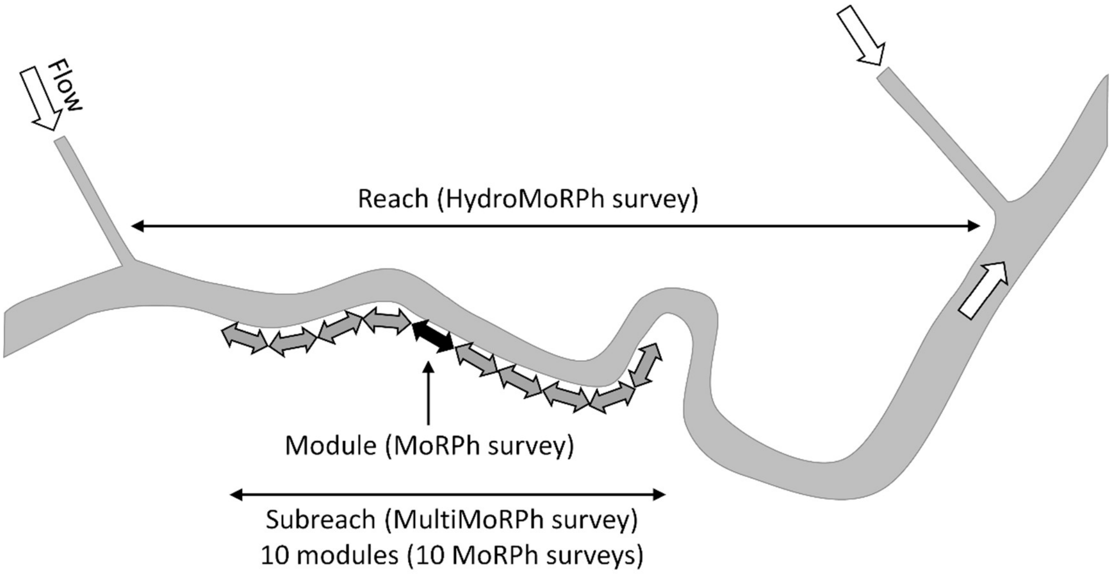

Figure 1. Schematic illustrating the relationship between a MoRPh module, MultiMoRPh subreach and HydroMoRPh reach.

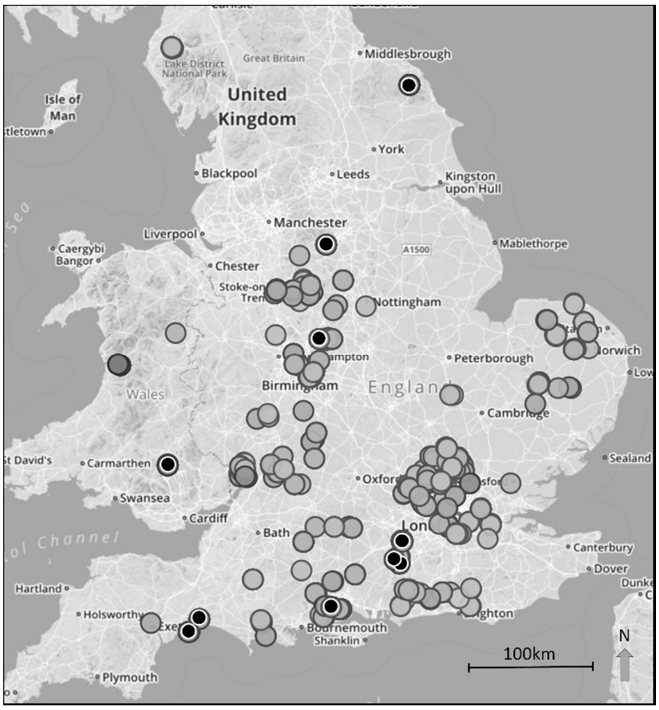

Figure 2. The distribution of MoRPh surveys across England and Wales at the end of 2018 (grey dots) and the distribution of the 10 MultiMoRPh surveys selected to represent the range of river types found across England and Wales (black dots)

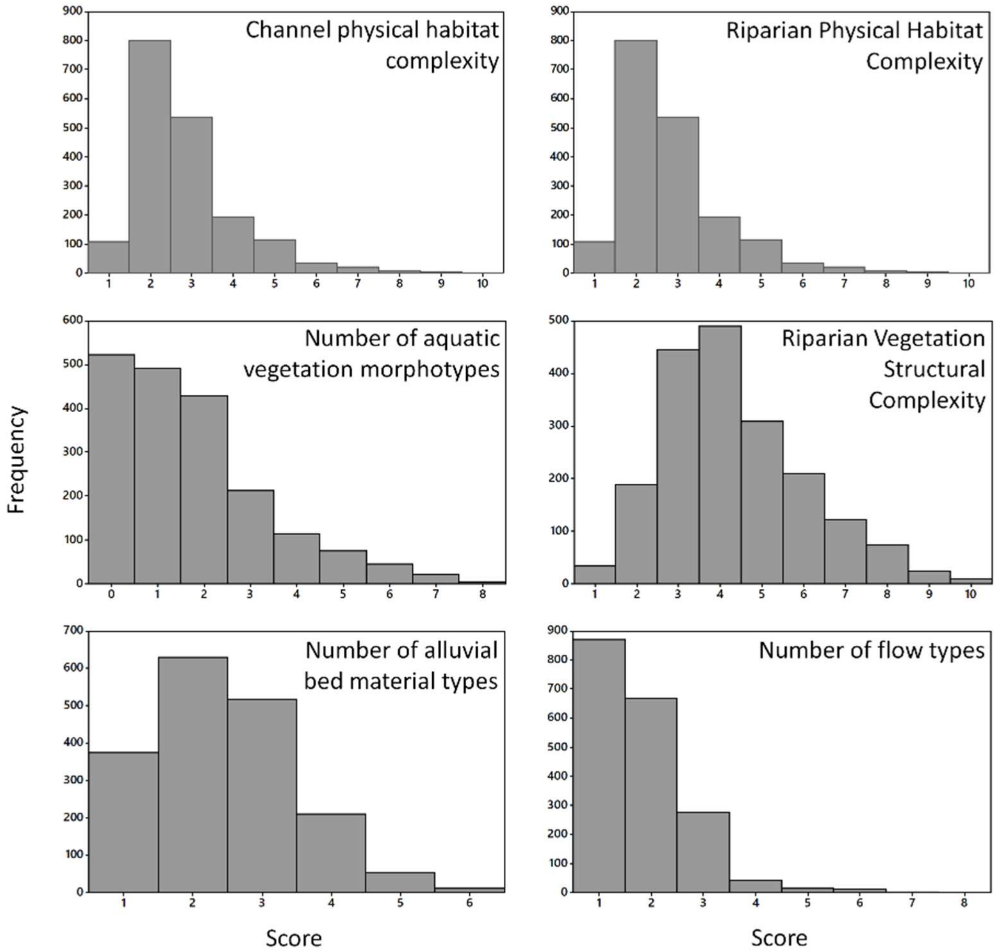

Figure 3. Histograms of the values of six indicators estimated from all MoRPh surveys conducted before the end of 2018.

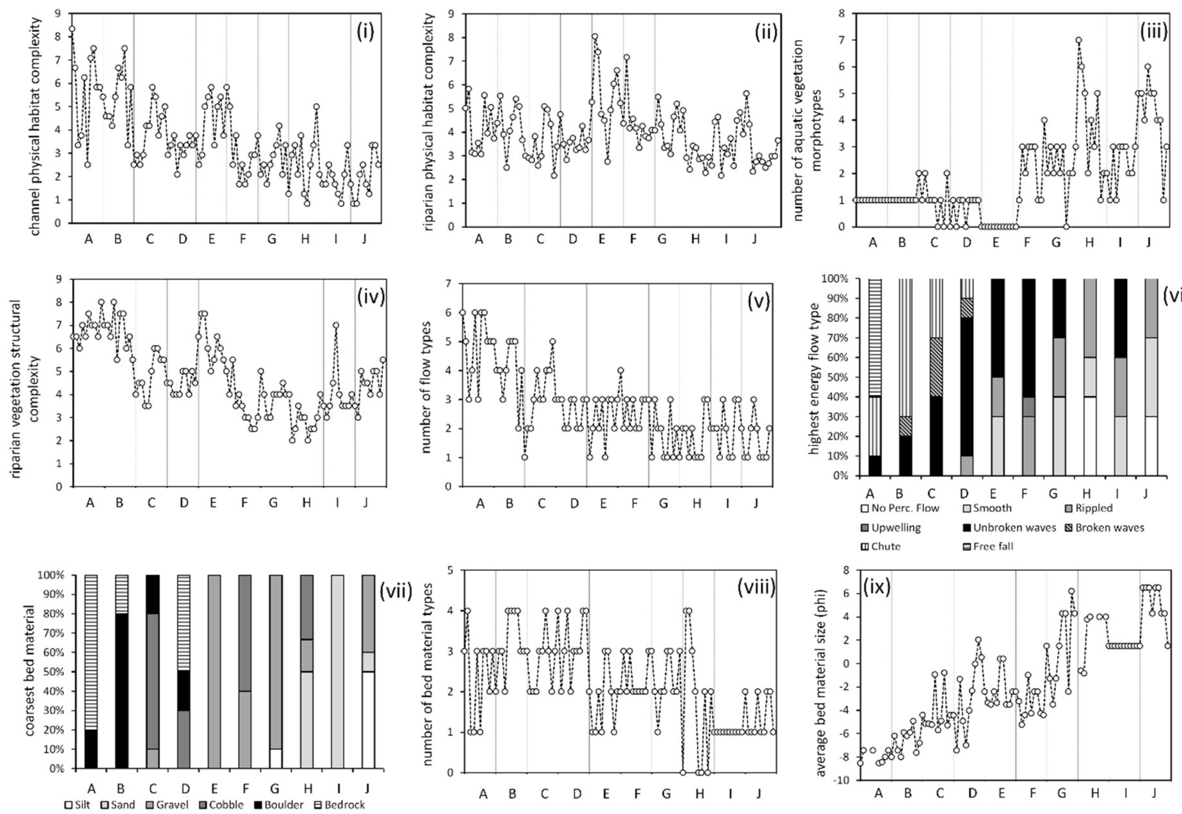

Figure 4. Values of 9 indicators displayed by the 10 MultiMoRPh surveys of relatively unmanaged streams. (i). Channel physical habitat complexity, (ii) Riparian physical habitat complexity, (iii) Number of aquatic vegetation morphotypes, (iv) Riparian vegetation structural complexity, (v) Number of flow types, (vi) Highest energy flow type, (vii) Coarsest bed material, (viii) Number of bed material types, (ix) Average alluvial bed material size (phi units). Graphs (i) to (v), (viii) and (ix) display indicator values for each MoRPh module plotted from upstream to downstream within each of the 10 MultiMoRPh subreaches. Graphs (vi) and (vii) display proportional bars for values observed across the 10 MoRPh modules within each of the MultiMoRPh subreaches.

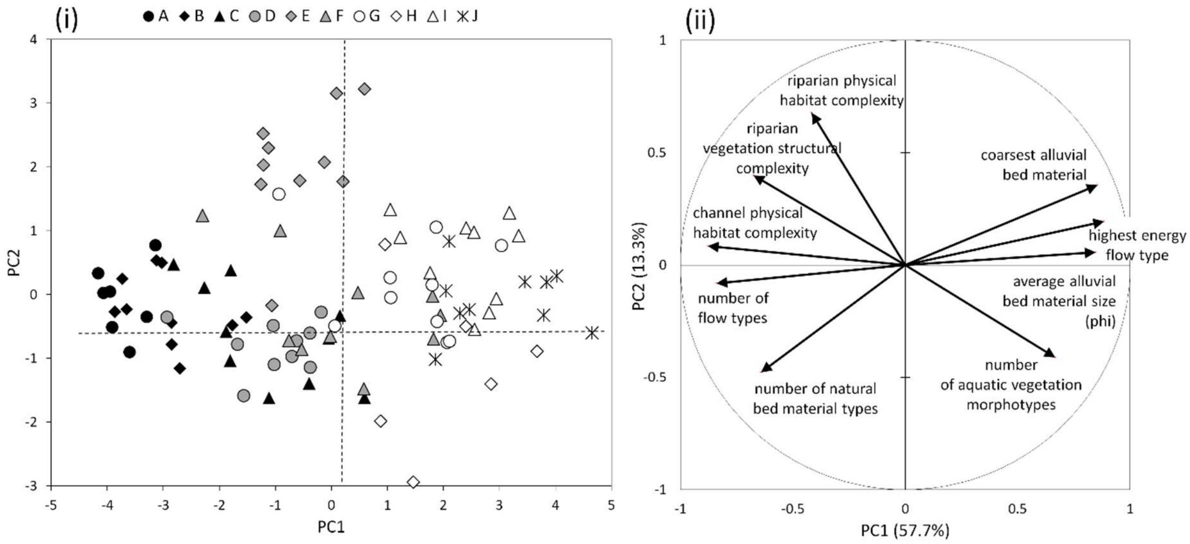

Figure 5. (i) MoRPh module scores and (ii) MoRPh indicator loadings on the first two PCs of a PCA applied to the values of 9 MoRPh indicators observed on 100 MoRPh modules in 10 MultiMoRPh subreaches.

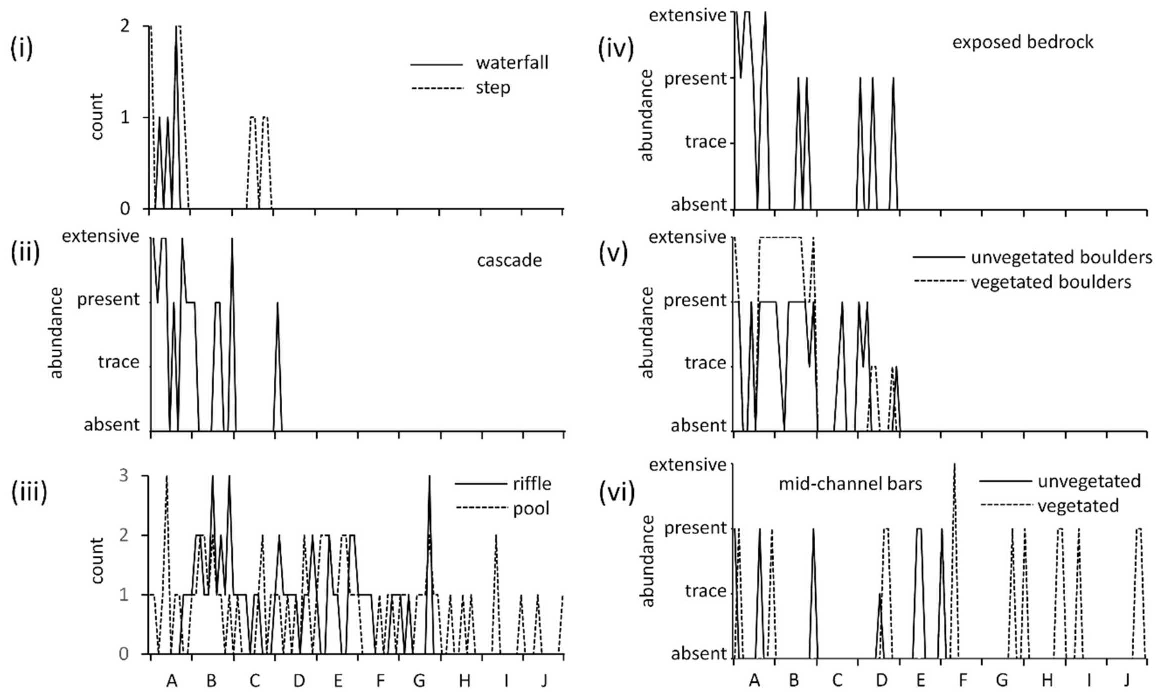

Figure 6. Variations in the number or abundance of channel bed physical features displayed by the 10 MultiMoRPh surveys of relatively unmanaged streams. (i) waterfalls and steps, (ii) cascades, (iii) riffles and pools, (iv) exposed bedrock, (v) unvegetated and vegetated boulders, (vi) unvegetated and vegetated mid-channel bars. The six graphs display values for each MoRPh module plotted from upstream to downstream within each of the 10 MultiMoRPh subreaches.

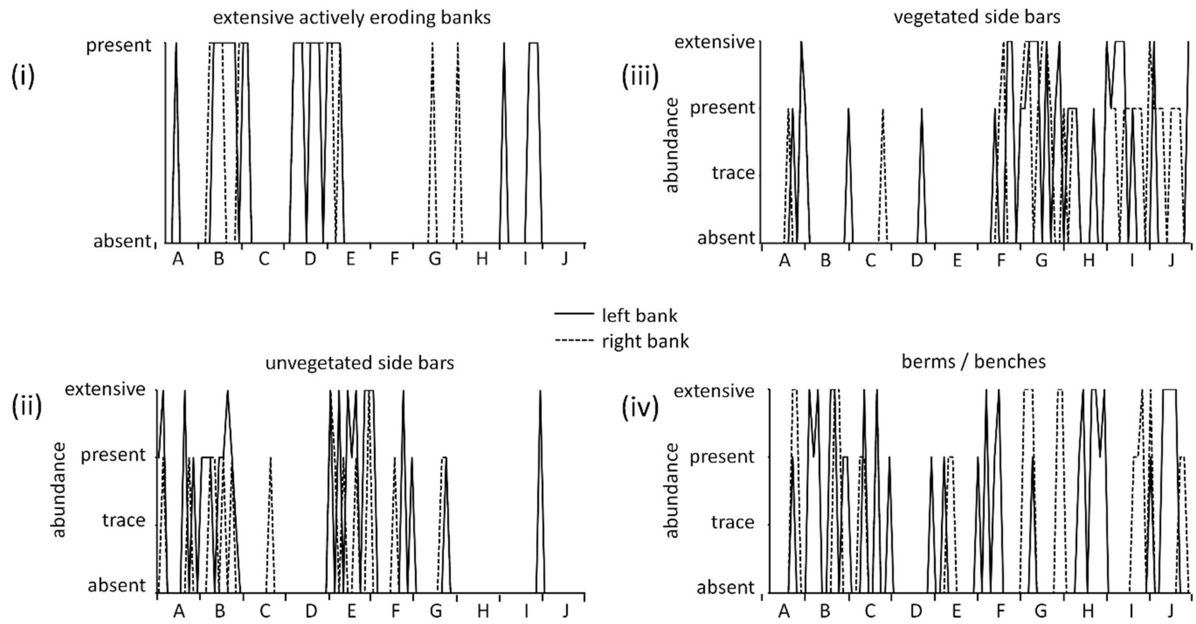

Figure 7. Variations in the presence or abundance of channel margin physical features displayed by the 10 MultiMoRPh surveys of relatively unmanaged streams. (i) extensive actively eroding banks (i.e. bank profiles that are vertical including with an overhang, undercutting or a toe), (ii) unvegetated side bars, (iii) vegetated side bars, (iv) berms or benches. The four graphs display values for each MoRPh module plotted from upstream to downstream within each of the 10 MultiMoRPh subreaches.

TABLES

Table 1: The rise of citizen science publications

Google Scholar search terms and date ranges	**1970-1979**	**1980-1989**	**1990-1999**	**2000-2009**	**2010-2019**
Citizen Science*	25000	48100	133000	636000	688000
Citizen Science plus					
Environmental monitoring	3130	5630	16700	44200	46100
Ecosystems monitoring	3700	6670	18100	19000	17200
Ecological monitoring	4890	8290	18100	19700	17500
River monitoring	1440	2560	8230	19200	21200
River habitat monitoring	1020	2190	9910	17700	16800
River ecosystems monitoring	1020	2190	14400	17800	17000
River geomorphology monitoring	126	323	1030	4470	8630
Hydromorphology monitoring	No matches	No matches	12	178	585

Source: Google Scholar search (17.01.2019) for all publications on Citizen Science followed by search terms in combination with *Citizen Science* to explore different aspects of river monitoring. Note: Google Scholar was the world's largest academic search engine in January 2018 with an estimated 80-90% coverage of all articles published in English (see Khabsa and Giles, 2014; and Jensenius et al., 2018). *When no date boundaries were applied the search identified publications totalling 2,350,000 referring to *Citizen Science*.

Table 2: Information captured by a survey of a MoRPh module

Location	Type of information	Summary of Recorded Properties
Channel cross section	Channel dimensions	Left and right bank heights, bankfull width, water width and depth at time of survey
Bank tops within 10m of channel edge (right and left banks surveyed separately)	Artificial ground cover (abundance)	Abundance of: Footpath-pedestrianised, Transport infrastructure, Industrial-commercial buildings, Residential buildings, Storage area, Landfill area, Arable agriculture-allotments, Permanently vegetated agriculture (pasture, orchard), Permanently vegetated recreation (playing fields, parks, gardens), Plantation woodland, Open water (canal, reservoir)
	Terrestrial vegetation	Abundance of: Unvegetated, Mosses/lichens, Short/creeping herbs/grasses, Tall herbs/grasses, Scrub/shrubs, Saplings/trees
	Tree features	Fallen, leaning, J-shaped trees, Branches trailing into river, Large wood
	Water-related features	Disconnected pond, connected pond, side channel, Wetland (i) short non-woody vegetation (ii) tall non-woody vegetation (iii) shrubs and trees
Bank faces and water's edge (right and left banks surveyed separately)	Natural bank profiles	Dominant and subdominant types from: Vertical, Vertical with overhang, Vertical undercut, Vertical with tow, Steep, Gentle, Complex
	Artificial bank profiles	Dominant and subdominant types and abundance from: Resectioned, Two-stage, Embanked, Set-back embankment, Poached.
	Natural bank materials	Dominant and subdominant material types and abundance in upper and lower bank face: Bedrock, Boulder, Cobble, Gravel, Earth, Sand, Silt, Clay, Organic, Peat
	Artificial bank materials	Concrete, Concrete and brick/stone (cemented), Brick/stone (cemented), Sheet piling, Wood piling, Builder's waste, Rip-rap, Gabions, Willow spiling, Planted reeds, Biotextiles, Washed out. Dominant and subdominant types, horizontal and vertical extents
	Bank and channel margin natural features	Abundance of: Unvegetated and vegetated side bars, Berms, Benches, Stable and eroding cliffs, Toe deposits, Nest holes/burrows, marginal backwater, tributary confluence
	Bank and channel margin artificial features	Number and extent of: Pipes/outfalls, Jetties, Deflectors
	Terrestrial vegetation	Unvegetated, Mosses/lichens, Short/creeping herbs/grasses, Tall herbs/grasses, Scrub/shrubs, Saplings/trees
	Tree features	Fallen, leaning, J-shaped trees, Branches trailing into river, Large wood, Exposed tree roots, Discrete organic accumulations

	Aquatic vegetation at bank-channel margin	Abundance of Liverworts/mosses, Emergent broadleaved, Emergent Linear-leaved, Amphibious, Filamentous algae
	Non-native invasive plant species	Abundance of: Himalayan balsam, Japanese knotweed, Giant Hogweed, Floating pennywort
Channel bed	Natural bed materials	Abundance of: Bedrock, Boulder, Cobble, Gravel, Sand, Silt, Clay, Organic, Peat, Continuous thin silt layer, Patchy thin silt layer
	Artificial bed materials	Abundance of dominant and subdominant type from: Concrete, Concrete and brick, Brick, Sheet piling, Wood piling, Builder's waste, Rip-rap, Gabions
	Water surface flow types	Abundance of: Free fall, Chute, Broken standing waves, Unbroken standing waves, Upwelling, Ripples, Smooth, Imperceptible flow, Dry
	Natural physical bed features	Abundance of: Exposed bedrock, Exposed vegetated and unvegetated boulders/rocks, Vegetated/unvegetated mid-channel bars, Islands, Cascades. Counts of: Pools, Riffles, Steps, Waterfalls
	Artificial physical bed features	Abundance of large trash, bridge shadow. Count of large, medium and small weirs, bridge piers. Presence of culverts
	Aquatic vegetation within the wetted channel	Abundance of: Unvegetated, Liverworts/mosses, Emergent broadleaved, Emergent Linear-leaved, Floating leaved, Free floating, Amphibious, Submerged broad-leaved, Submerged linear leaved, Submerged fine-leaved, Filamentous algae
	Vegetation interacting with the wetted channel	Abundance of shade, submerged tree roots, large wood in channel, discrete accumulations of organic material, large wood dam, fallen tree
	Non-native invasive plant species	Abundance of: Himalayan balsam, Japanese knotweed, Giant Hogweed, Floating pennywort

Table 3: Confinement, planform, gradient and bed material characteristics of river reaches within which MultiMoRPh surveys were conducted, and the derived river type

Code	River	Valley confinement	Planform	Sinuosity	Valley gradient (m.m-1)*	Main channel gradient (m.m-1)*	Average alluvial bed material size[1]	Coarsest bed material[2]	River type
A	Caerfanell	C	Straight	1.000	0.0952	0.0952	Cobble	Bedrock	Confined, straight, bedrock-cobble
B	Eller Brook	C	Straight	1.010	0.0211	0.0209	Cobble	Bedrock	Confined, straight, bedrock-cobble
C	Old Mill Stream	PC	Sinuous	1.065	0.0191	0.0179	Gravel	Boulder	Partly-confined, sinuous, boulder-gravel
D	Burbage Brook	PC	Sinuous	1.190	0.0109	0.0092	Gravel	Bedrock	Partly-confined, sinuous, bedrock-gravel
E	Highland Water	PC	Sinuous	1.333	0.0060	0.0045	Gravel	Gravel	Partly-confined, sinuous, gravel
F	Axe	U	Meandering	1.638	0.0038	0.0023	Gravel	Cobble	Unconfined, meandering, cobble-gravel
G	North Wey	U	Sinuous	1.447	0.0024	0.0016	Sand	Cobble	Unconfined, sinuous, cobble-sand
H	Mease	U	Meandering	1.732	0.0016	0.0009	Sand	Cobble	Unconfined, meandering, cobble-sand
I	South Wey	U	Meandering	1.837	0.0011	0.0006	Sand	Sand	Unconfined, meandering, sand
J	Blackwater	U	Sinuous	1.133	0.0005	0.0004	Silt	Gravel	Unconfined, sinuous, gravel-silt

* valley and main channel gradients are estimated from the Google Earth DEM

[1] an abundance-weighted average of all alluvial bed materials (phi units) recorded as present or extensive

[2] the coarsest (bedrock or alluvial) bed material recorded as present or extensive

SUPPLEMENTARY MATERIAL

Table I: Examples of citizen science projects illustrating their key features

Citizen science initiative	**Lead organisation**	**Where?**	**Scale?**	**Training ?**	**Type of survey (level of engagement)**	**When ?**	**Online location**	**What?**
FreshWater Watch;	EarthWatch Institute	UK	Inter-national	Online guide	Contributory	2012 - now	https://freshwaterwatch.thewaterhub.org/ content/your-test-kit	WQ
EarthEcho Water Challenge	EarthEcho International (non-profit organisation)	USA	Inter-national	Online guide	Contributory	2015 - now	http://www.worldwatermonitoringday.org/	WQ
Water level reporter	NOAA	USA	Inter-national	No	Contributory	2018 - now	https://www.citizenscience.gov/catalog/463/#	Water levels
The Boiling River - Citizen Science	The Boiling River Project	Peru	Inter-national	No	Contributory	2016 - now	http://www.boilingriver.org/citizen-science/	WQ
Projecte rius	Habitats Association (Spain)	Spain	National (by regions)	Yes	Contributory	1997 - now	http://www.projecterius.cat/el-projecte/	Biota (macro invertebrate s); WQ; physical habitat
Wasser schafft	Centre for Citizen Science (Austria)	Austria	National	Online guides	Contributory	2015-2017	https://www.zentrumfuercitizenscience.at/ en/p/wasser-schafft	Biota; WQ; Physical habitat
CrowdWater	Zurich University	Switzerla nd	National	Online guides	Contributory	2016 - now	https://crowdwater.ch/en/crowdwater-2/	Water levels
Les sentinelles de la Nature	France Nature Environment	France	National	Online guides	Contributory	2015 - now	https://www.fne.asso.fr/publications/guides- et-ressources-pour-les-sentinelles-de-la-nature	WQ; Water levels
Anglers' Riverfly	Riverfly Partnership	UK	National	Yes	Collaborativ e	2007 - now`	http://www.riverflies.org/rp-riverfly-monitoring-initiative	Biota (macro invertebrate s)

Monitoring Initiative								
Modular River Survey: MoRPh	QMUL/Cartographer	UK	National	Yes	Co-created	2016-now	www.moduarriversurvey,org	Physical habitat
Thames River Watch	Thames21	UK	Local / catchment	Yes	Contributory	2011 - now	http://www.thames21.org.uk/thames-river-watch/ water-quality-results/	WQ; litter
Operation Otter	Devon Biodiversity Records Centre (DBRC)	UK	Local / catchment	Yes	Contributory	1997 - now	http://www.dbrc.org.uk/operation-otter/	Biota (water-dependent mammals)
Riverkeeper - Citizen Science Water Quality	RiverKeeper (formerly Hudson River Fishermen's Association)	USA	Local / catchment	Online guides	Collaborative	2010 - now	https://www.riverkeeper.org/water-quality/ citizen-data/	WQ
SYRCL River Monitoring program	South Yuba River Citizens League	USA	Local / catchment	Yes	Contributory	2000 - now	https://yubariver.org/	WQ
River and Wetland Watch Volunteering Programme	Asian Institute of Technology	Thailand	Local / catchment	don't know	Collaborative (inferred)	2014-2016	https://www.ait.ac.th/2015/10/ait-co-hosts-river-and-wetland-watch-volunteering-programme-in-nakhon-phanom/	WQ
StreamWatch	Australian Museum Research Institute	Australia	Local / catchment	Yes	Collaborative	1989 - now	https://www.streamwatch.org.au	WQ
MyWater	Fitzroy Partnerhsip for River Health	Australia	Local / catchment	Online guides	Collaborative	2012 - now	https://riverhealth.org.au/report_card/ community/	WQ; Biota (macro invertebrates, fish)
Caring for Waterhole Creek	Environment Protection Authority Victoria	Australia	Local / catchment	Yes	Collaborative (inferred)	Feb-Nov 2017	http://www.epa.vic.gov.au/waterholecreek	WQ; Biota (macro invertebrates, fish); litter

Xiangjang Watcher	Green Hunan	China	Local / catchment	Don't know	Collaborative	2013-2018	http://www.chinadevelopmentbrief.cn/directory/green-hunan/ http://www.enghunan.gov.cn/newscollection/news2018/February2018/201807/t20180713_5052062.html	WQ
River Chief Scheme	China's Ministry of Water Resources	China	Local / catchment	Don't know	Contributory	2016-now	http://english.cas.cn/newsroom/news/201709/t20170908_182915.shtml	WQ; litter
Freshwater For the Future	KOPEL / Forever Sabah	Borneo	Local / catchment	Yes	Collaborative	2012-2016	https://news.mongabay.com/2016/11/_how-citizen-science-is-transforming-river-management-in-borneo/	WQ
Odonata of India	Biodiversity Atlas India	India	National	No	Contributory	2014 - now	https://www.indianodonata.org/	Biota (Odonata)
River Walk Toolkit	Groundtruth	South Africa	Local / catchment	Yes	Contributory	2017 - now	http://www.groundtruth.co.za/river-walk-toolkit	WQ; Biota (macro-invertebrates; riparian zone)
Thai Baan Research	Living River Siam	Thailand	Local / catchment	No	Collaborative	2003-now	https://www.internationalrivers.org/resources/citizen-science-supports-a-healthy-mekong-7759	Biota (fish); physical habitat

Table II: River characteristics included in 14 summary indicators extracted from MoRPh module surveys.

Indicator	Description
1. Number of flow types	The number of flow types recorded as P (5-33% cover) or E (34-100% cover)
2. Highest energy flow type	Highest energy flow type recorded as P or E
3. Number of natural bed material types	The number of bed material types recorded as P or E (Bedrock, Boulder, Cobble, Gravel, Sand, Silt, Clay, Organic, Peat)
4. Coarsest bed material	The coarsest recorded as P or E (Boulder, Cobble, Gravel, Sand, Silt, Clay)
5. Average alluvial bed material size (phi)	= ((-9*Boulder abundance) + (-7*Cobble abundance) + (-3.5*Gravel abundance) + (1.5*Sand abundance) + (6.5*Silt abundance) + (10*Clay abundance)) / (Boulder abundance + Cobble abundance + Gravel abundance + Sand abundance + Silt abundance + Clay abundance), where abundance is recorded as 2% for T, 19% for P and 67% for E
6. Average alluvial bed material class	Calculated from the average alluvial bed material size where ≥ 9 is clay, < 9 to ≥ 4 is silt, < 4 to ≥ -1 is sand, < -1 to ≥ -6 is gravel, < -6 to ≥ -8 is cobble, < -8 is boulder
7. Extent of superficial bed siltation	The sum of abundance scores for Continuous thin silt layer (T=2, P=19, E=67) and Patchy thin silt layer (T=1, P=9.5, E=33.5). The total is divided by 10[1].
8. Channel physical habitat complexity	= (Index 1 + Index 3 + NumBedFeat + NumVegInteraction)/2.4[1] Where NumBedFeat is the number of types of natural bed features. Score 1 for each that is P or E or count>0, from the channel bed list – 'Natural physical bed features' in Table 1. NumVegInteraction is the number of ways in which vegetation is interacting with the wetted channel (from channel bed list in Table 1): score 1 for each that is observed as P or E apart from large wood dams and fallen trees which score 2 if count>0.
9. Number of aquatic vegetation morphotypes	Score 1 for each for every morphotype recorded as P or E (from the channel bed list – 'Aquatic vegetation within the wetted channel', and from the Bank faces and water's edge list – 'Aquatic vegetation at bank-channel margin' in Table 1) but only score each morphotype once.
10. Riparian physical habitat complexity	= (LeftBankWoodHab + RightBankWoodHab + LeftBankTopWatFeat + RightBankTopWatFeat + LeftBankFaceNatFeat + RightBankFaceNatFeat + LeftBankProfile + RightBankProfile)/6[1] Where LeftBankWoodHab and RightBankWoodHab are the total scores for each bank for large wood, fallen trees, exposed tree roots (all P=2, E=4) and discrete organic accumulations (P=1, E=2) recorded in the Bank faces and water's edge list – 'Tree features' and the Bank top list 'Tree features'. The total scores are divided by 1.4[1] LeftBankTopWatFeat and RightBankTopWatFeat are the total scores for every feature recorded as P or E in the Bank tops list- 'Water-related features' (Table 1)on each bank top (score 1 for P and 2 for E) LeftBankFaceNatFeat and RightBankFaceNatFeat are the total scores for each bank top for 'Bank and channel margin natural features' on the Bank tops list (Table 1). Score 3 for tributary confluence, for all other

	features score 1 for P, for animal burrows score 1 for E, for stable cliff score 2 for E, for remaining features score 3 for E. LeftBankProfile and RightBankProfile. Assign a score of 3 for E and 1.5 for P for all natural bank profiles recorded on each bank (Bank faces and water's edge list – 'Natural bank profiles', Table 1)
11. Riparian vegetation structural complexity	The number of riparian vegetation morphotypes (i.e. mosses/lichens, short/creeping herbs/grasses, tall herbs/grasses, scrub or shrubs, saplings or trees, extracted from the Bank tops list – 'Terrestrial vegetation' and the 'Bank faces and water's edge list - 'Terrestrial vegetation') that are P or E. The index is the sum of the scores for each bank divided by 2[1].
12. Human pressure imposed by bank top land cover	The sum of scores on each bank top for the dominant and subdominant type as follows: Transport infrastructure, Landfill area (P=5, E=10); Buildings (commercial, industrial), Buildings (residential), Storage area (P=4, E=8), Arable agriculture / allotments (P=3, E=6); Pedestrianised ' footpath (P=2, E=4); Permanently vegetated agriculture (e.g. pasture, orchards), Permanently vegetated recreation (e.g. playing fields, parks, gardens), Plantation woodland, Artificial open water (canal, reservoir) (P=1, E=1). Divide the total score for the two banks by 2[1]
13. Channel reinforcement	Total score for each bank face and the channel bed according to the extent and dominant type of reinforcement (Bank face and water's margin list – 'Artificial bank materials', Channel bed list – 'Artificial bed materials', Table 1). The type of reinforcement is weighted as follows: Concrete, Concrete and brick / stone (cemented), Brick / stone (cemented), Sheet piling (weighting = 3); Wood piling, Rip-rap, Gabions (weighting = 2), Builder's waste, Washed out (weighting = 1), Willow spiling, Planted reeds, Biotextiles (weighting = 0). For bed reinforcement, the weighting for the dominant reinforcement type is multiplied by reinforcement abundance (T=2, P=19, E=67) For each bank, the weighting for the dominant reinforcement type is multiplied by the reinforcement vertical and horizontal extent (top or bottom reinforcement only score T=1, P=9.5, E = 33.5 for horizontal extent; for fully reinforced score t=2, P=19, E=67 for horizontal extent) Channel reinforcement is estimated as the sum of the scores for each bank and the bed divided by 60[1].
14. Non-native invasive plant extent	4 common 'Non-native invasive plant species' (Himalayan balsam, Japanese knotweed, Giant hogweed, Floating pennywort) are recorded on both banks in the Bank top list, the Bank faces and water's edge list and the Channel bed list (Table 1). Their abundance is scored as T=2, P=19, E=67 in five locations (each bank top, each bank face, the channel bed). The scores are then summed and divided by 420[1].

[1] denominators are introduced to scale the indicators to an approximate range of 0 to 10 or to scale components of each indicator to a similar numerical range so that they have a similar influence on the indicator. These scaling factors were developed based on an assessment of the likely maximum scores and were informed by the actual scores achieved in the surveys recorded so far.