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Seeking river restoration appraisal best practice: supporting wider national and international environmental goals

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Abstract

With growing investment in river restoration, we increasingly need to justify costs by demonstrating success and wider benefits of measures. To aid practitioners, the UK River Restoration Centre (RRC) has worked with experts to develop a practical monitoring guidance (PRAGMO) that links objectives to specific monitoring to demonstrate achievable outcomes. Feedback, however, via an on-line questionnaire highlighted the need to rationalise the guidance contents for a new growing audience, taking advantage of new developments and incorporating the evaluation of social and economic aspects of river restoration. With these potential improvements, it is hoped that practitioners will follow this guidance, improve the quality of monitoring undertaken and share evidence of success and lessons learnt. This paper outlines how this guidance has been adopted as best practice. We discuss why we need to embed this guidance into wider monitoring protocols that can feed into national and international environmental policy and targets.

Keywords: evaluation, monitoring, PRAGMO, impact assessment, prioritisation

Introduction

Restoration of fluvial geomorphological processes is increasingly used to address degradation of riverine ecosystems (Smith *et al*. 2014). Unfortunately, many schemes are poorly appraised (Roni and Beechie 2013) meaning the demonstration of ecological benefit remains limited (e.g. Palmer *et al.* 2010; Feld *et al*. 2011), despite some successes (e.g. Kail *et al*. 2015). Notwithstanding this uncertainty, an increasing number of restoration projects are undertaken and the call for effective evaluation continues (Angelopoulos *et al*. 2017). In

2016, the River Restoration Centre (RRC) UK National River Restoration Inventory contained over 2800 completed projects with only 21% stating some degree of monitoring. Of the 179 projects added in 2017, only 5% of the projects specifically reported any monitoring outcomes (RRC unpublished data). These data demonstrate a greater recognition of the need to monitor (in 2010, 10% of projects stated some degree of monitoring). Nonetheless, demonstrable integrated successful outputs remains patchy.

Historically, monitoring has frequently evaluated one particular aspect such as morphology (e.g. Downs and Brookes 1994), macro-invertebrates (e.g. Friberg *et al*. 1998), macrophytes (e.g. Pedersen *et al*. 2006) or fish (e.g. Gortz 1998). Increasingly, the need for multi-assessments to determine success has been recognised (e.g. Muhar *et al.* 2016). A key challenge is to establish an appropriate monitoring strategy that includes physical parameters that link to ecological responses and focus on processes rather than habitats or species (Beechie *et al*. 2010; Gurnell *et al*. 2016a).

Wohl *et al.* (2005) recognised a lack of identified generic criteria to support strategic monitoring, although Palmer *et al*. (2005) simultaneously suggested five elements:

1. an image of the dynamic state to be restored
2. recognition of measurable improvements to the ecosystem
3. an increase in resilience
4. assurance that there is no lasting harm
5. inclusion of ecological assessment.

Other authors advocated a pragmatic approach (e.g. Woolsey *et al*. 2007), yet what remained missing, was a detailed and systematic explanation of how the appraisal process should be shaped to ensure specific questions can be answered. The process, it was argued, needed to be easily accessible to practitioners and stakeholders. In response, the RRC enlisted its supporting organisations and UK national experts to help develop monitoring guidance.

Development of a monitoring protocol

To ensure a strategic approach, a conceptual model was developed that targets limited resources to maximise the information gained. The approach ensures that the monitoring effort focusses on projects with the most risk and/or potential to learn. The concept behind the model is that small-scale projects, using established techniques, are generally more predictable and therefore present a lower risk, so may need less or simpler monitoring (England *et al.* 2008). In contrast, large scale projects, and techniques applied in new situations or using novel approaches present greater risk, provide more opportunity to learn and therefore warrant detailed scrutiny. This concept was presented at an invited-audience meeting of academics and practitioners, who agreed that developing an integrated monitoring approach was desirable and that both pre- and post-project monitoring are essential to achieve robust scientific conclusions about the success or failure of river restoration projects (RRC 2006). This integrated approach and the setting of clear project objectives was considered essential to give confidence that appraisals can demonstrate

project effects. The outputs of this workshop, and a subsequent development workshop (RRC 2007), led to the formulation of a decision-making process linking measurable objectives to appropriate monitoring based on the scale, complexity and cost of a project within "Practical river restoration appraisal guidance for monitoring options (PRAGMO)" (RRC 2011).

Practical River Restoration Appraisal Guidance for Monitoring Options (PRAGMO) - an overview.

PRAGMO (RRC 2011) provides pragmatic guidelines to help practitioners, from government agencies to community groups, determine the necessary level of monitoring. The guidance is broken down into a series of questions, summarised in this section.

1. Do you understand your river?

Before making any decision about what river restoration is appropriate and what to monitor, the practitioner must have a good understanding of their river in its catchment context. Understanding hydrology, sediment load and water quality is critical in terms of setting realistic objectives and determining a monitoring strategy (Addy et al. 2016, Angelopoulos *et al.* 2017).

2. Will your aspirations improve the river given the current conditions?

The knowledge gained under question 1 enables a better understanding of how a watercourse may respond to restoration and any limits to ecological recovery. The importance of catchment processes in understanding trajectories of change are well documented and their importance to river management noted (Kail *et al.* 2015; Gurnell *et al.* 2016b). These processes shape river reaches and determine if restoration measures are likely to be sustainable. For example, installation of boulders and gravel into a lowland river system where there is excess fine sediment input is not sustainable unless the source of the fine sediment is also managed (Mueller *et al*. 2014).

3. Can you define "SMART" project objectives?

Each project needs clear objectives against which success can be judged. Adopting the "SMART" (Specific, Measureable, Achievable, Realistic and Time-Bound) approach ensures sound objectives are set (Roni and Beechie 2013; Angelopoulos *et al.* 2017).

4. Can the monitoring needs be defined based on project risk and scale?

Determining the risk of a project considers the degree to which a specific technique has been used successfully elsewhere and whether it is suitable for the type of river being restored. The user is taken through a series of steps to help identify the project risk and scale to determine the necessary monitoring level. Published reviews of river restoration effectiveness (e.g. Kail *et*

al. 2015; Smith *et al*. 2014; https://reformrivers.eu/home) can help identify gaps in evidence which need to be addressed.

5. Can "SMART" monitoring objectives be confidently set?

Monitoring objectives need to assess measures of success both spatially and temporally. These differ from project objectives that establish overall aspirations, but they must relate back to them to demonstrate project success. Monitoring objectives should consider how morphology will be affected by the restoration measures and how biota will respond, thus helping predict expected timescales of change. Clearly, this is not a simple task, since recovery following restoration is one of the main areas of uncertainty and response time will vary depending on geomorphic processes (Beechie *et al*. 2010; Gurnell *et al.* 2016b), biological colonisation processes (Li *et al*. 2016; Stoll *et al*. 2016), and hydrological conditions (Groll 2017).

6. Prioritise monitoring

Identifying what is possible or desirable to monitor is often restricted by available resources and pre-project data, therefore limiting comprehensive long-term monitoring. In reality, different stakeholders and funders will have different priorities, so it is important that their views are considered during this process (Angelopoulos *et al*. 2017).

7. Select monitoring techniques to demonstrate project performance related to objectives

Where a project has been identified as a priority for in-depth monitoring, the strategy should produce robust data that can be analysed with appropriate statistics to improve confidence in the outcomes. Techniques are likely to be quantitative and include replication, necessitate pre-project data and follow a BACI (Before-After-Control-Impact) approach (Kail *et al*. 2015). However, there is still a wealth of information that can be gathered from simpler or smaller projects, providing a robust monitoring strategy is applied (Shuker *et al*. 2017).

Steps 6 and 7 comprise an iterative process since costs and resources will affect what is achievable within the constraints of a project. To help with this process, the RRC developed a monitoring planner (RRC 2014) which can be used to review and prioritise monitoring in a systematic way, using a series of structured questions. The agreed strategy can be implemented as an integral part of the project delivery.

8. Sharing the results.

The final step is to ensure that the results of the monitoring programme are communicated both to the stakeholders and the wider scientific community to ensure that we learn from successful schemes (Angelopoulos *et al*. 2017) and that we learn from the experiences where projects have not progressed as planned (Salant *et al.* 2012).

Is PRAGMO fit for purpose?

PRAGMO is currently a well accessed document, with around 200 downloads per month (RRC unpublished data). How to manage and use data is a significant current topic. In January 2019 the Organisation for Economic Co-operation and Development (OECD, 2019) recognised the impact of biodiversity loss and called for better measuring and monitoring of the environment. Whilst in the UK the Government's 25-year plan (Defra, 2018) identifies, amongst others within its targets, thriving plants and wildlife, resources from nature, engagement with the natural environment, reduction of pollutants and clean and plentiful water. To demonstrate these goals will inevitable require a range of data sources and approaches that will collectively be able to explain benefits. Ensuring that this guidance remains relevant and useful is therefore essential. Incorporating current best practice such as the Modular River Survey, a citizen science technique (Shuker et al. 2017), remote sensing as a tool to track geomorphic change (e.g. Bentley et al. 2016) and the application of ecosystem service approaches (e.g. Large and Gilvear 2015) will help to support these wider aspirations, within the context of river restoration, and support much needed 'grass root' appropriate and robust monitoring. Equally, it is critical to ensure that this guidance continues to reflect the increase in river restoration evidence, so that users have all the information they need to create sound monitoring assessments. To target future development, the RRC undertook an on-line survey to provide an overview of what practitioners find most and least useful within the current version and what they would like to see in any update.

The questionnaire was made available on the RRC website, a link sent to all RRC members and advertised in the RRC newsletter. It featured questions on the usefulness and ease-of-use of PRAGMO and suggested improvements. A total of 47 people responded to the questionnaire over a 3-month period. The majority (55%) of respondents used PRAGMO regularly or occasionally with only 13% stating they had never used it (Figure 1A). The largest group of respondents belonged to regulatory bodies, matched by non-profit organizations (NGOs) reflecting the increase in restoration activity undertaken by these organisations (Figure 1B). User focus of interest (there could be more than one per respondent) varied from geomorphology (51%) to hydrology (35%), biology (40%), fisheries (35%) and social well-being (19%) as well as engineering and planning (14%).

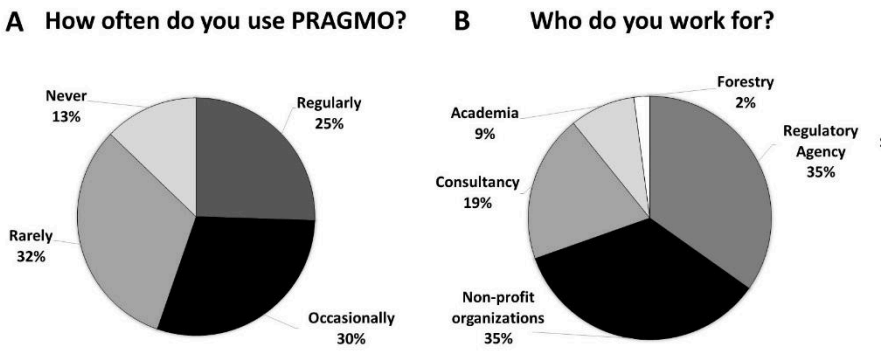

Figure 1 – Responses to the *Practical River Restoration Appraisal Guidance for Monitoring Options (PRAGMO*) use questionnaire on the frequency of use and audience.

The main reasons for respondents using PRAGMO (multiple choice question; Figure 2A) was setting monitoring objectives, identifying monitoring intensity, developing monitoring protocols and setting and prioritising monitoring objectives. This focus on monitoring objectives, application and timescales is also reflected in the top five sections used (multiple choice question; Figure 2B). Also popular are the sections which link biological and morphological processes possibly emphasising the increased interest in process-based restoration (Addy et al. 2016) and the need for integrated assessments (Angelopoulos *et al*. 2017). Nearly 36% of respondents recognised the value in helping set SMART objectives. The least used sections highlighted in the survey (multiple choice question; Figure 2C) were the appendices about water quality and the Water Framework Directive, and information on data and costs. These sections are not the main focus of the PRAGMO guidance and their lack of popularity may reflect that this information and data is held elsewhere in a more accessible format.

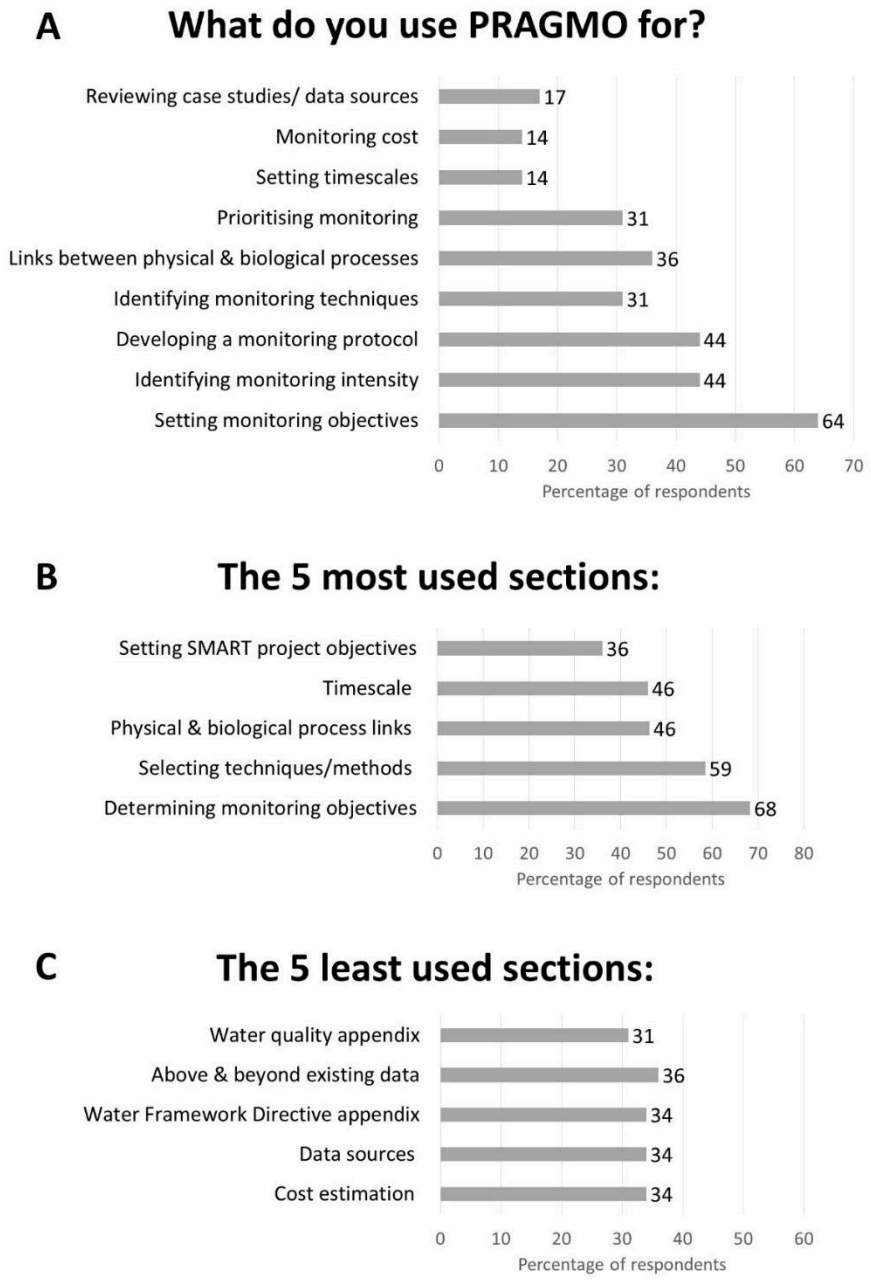

Figure 2 – Responses to the *Practical River Restoration Appraisal Guidance for Monitoring Options (PRAGMO)* use questionnaire on why people accessed the guidance and which were the most and least used sections. (SMART = Specific, Measurable, Achievable, Realistic and Time-Bound).

When asked if PRAGMO should be updated, 81% of respondents said yes, only 2% said no and the remaining 17% were undecided. Comments were made on the size of the document (320 pages) and the need to make it shorter and more interactive, with links to more detailed guidance as needed.

Respondents also expressed wishes for new sections with an emphasis on decision support, data analysis, Natural Flood Management (NFM), and both simpler and more detailed guidance on methodologies. This need for technical guidance may potentially reflect the growing base of non-expert users and the lack of structured or easily available guidance elsewhere. The most sought-after additions (multiple choice question; Figure 3) were for desk-based assessments, tools to aid decision support, data analysis, statistics and additional guidance on monitoring techniques. There was also interest in adaptive management strategies and more informal sources of help such as access to a help line, a discussion forum or Question and Answer sections, which may reflect the uncertainty of understanding the success of restoration measures. There were requests in the free text questions to add guidance material on NFM monitoring.

The results of the survey provide credence for the need to update PRAGMO in the context of improved understanding and to incorporate new technology and innovation.

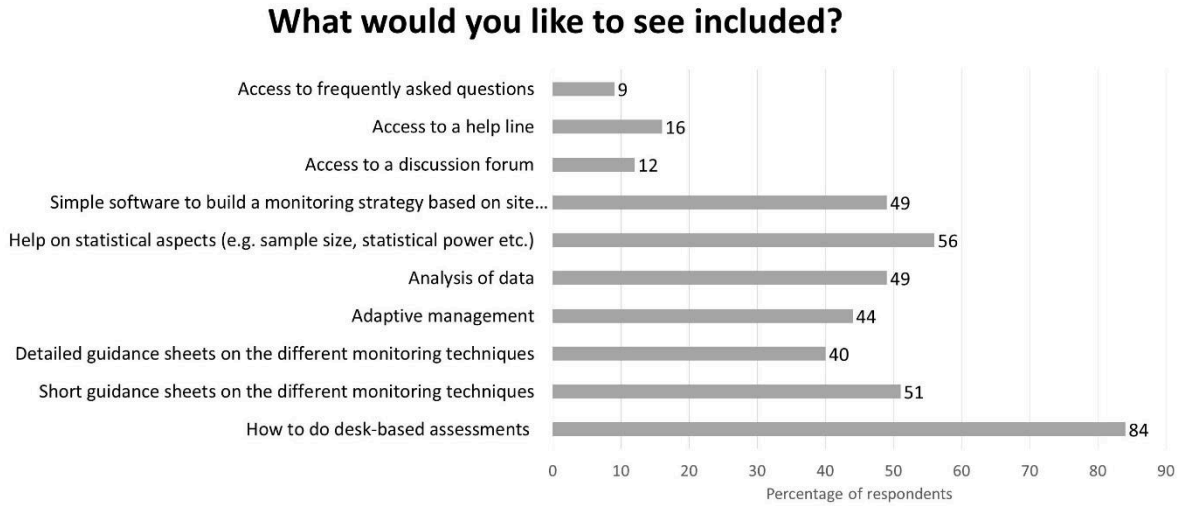

Figure 3 – Responses to the *Practical River Restoration Appraisal Guidance for Monitoring Options (PRAGMO)* use questionnaire on what people would like to see included in an updated version.

PRAGMO for the future

The frequent access to PRAGMO demonstrates its continued use to the UK practitioner community. However, the results of the questionnaire indicated some limitations in its use. Essentially, users felt that the manual would benefit from being streamlined and their wish for decision help in the shape of a software with simple step-by-step procedures and specific guidance on potential techniques was clear.

To address these user needs and concerns, the guidance could be re-designed as a decision-support tool to enable the identification of options based on scheme characteristics, and as a repository of techniques with various levels of detail. To achieve this, PRAGMO could be split into three integrated online modules (a knowledge base, a decision support tool and a data repository) which can link to existing evidence and information (Figure 4). The growing knowledge base will be able to feed into other outcome needs such as demonstration of benefits for 25-year plan indicators (Defra, 2018), natural flood management (Environment Agency 2018a) and increasing resilience to climate change (Environment Agency 2018b).

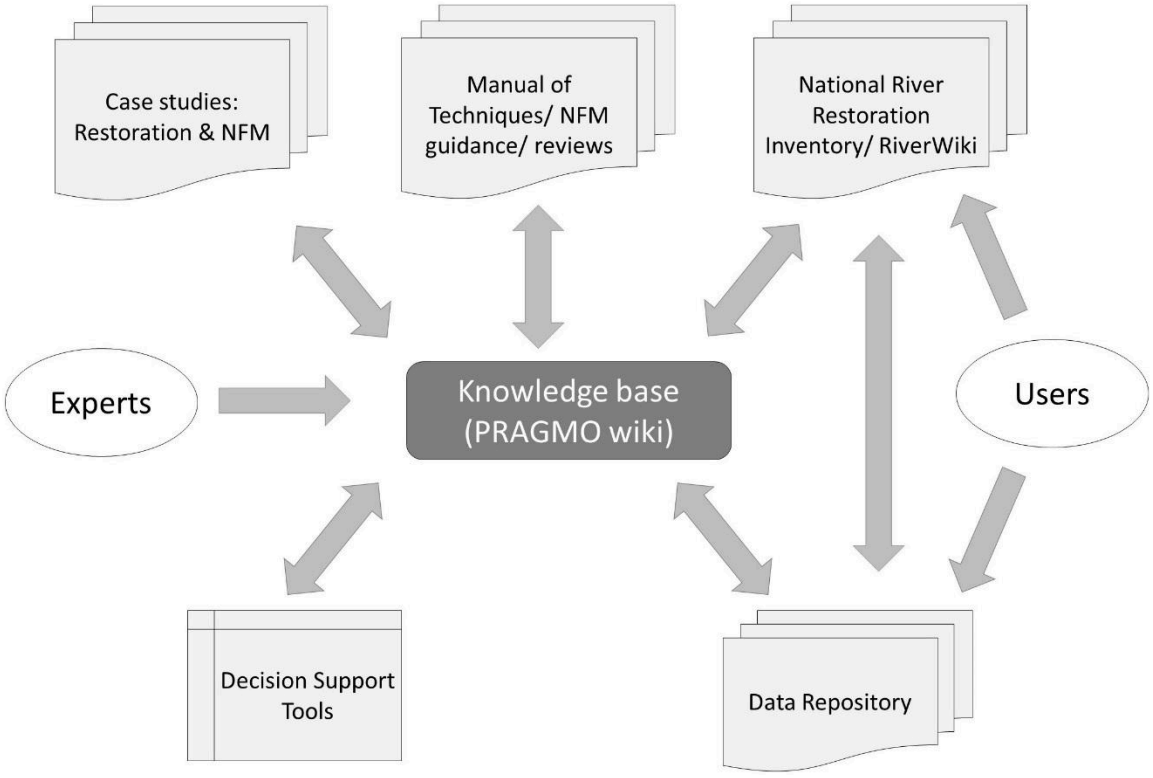

Figure 4 – Conceptual model of a potential revision to *Practical river restoration appraisal guidance for monitoring options (PRAGMO)* in response to a review by users; creating a knowledge base of a benefit to the river restoration community which can support wider goals such as Natural Flood Management (NFM) and climate change adaptation.

1. Knowledge base

The knowledge base would be an online Wiki, containing an updated version of the existing PRAGMO, techniques and methods. Prior to including new information, each section would need to be reviewed and updated based on current knowledge of existing and new techniques. The sections that were considered less useful could be replaced with links to information available elsewhere and additional sections added to address the requests highlighted in the questionnaire (Figure 3). The Evidence Base would have links to other sources of information such as the RRC Manual of Techniques (MOT; RRC 2013), the NFM

evidence directory (Environment Agency 2018b), river restoration and NFM case studies from the National River Restoration Inventory database (NRRI; www.therrc.co.uk/uk-projects-map), the RiverWiki (https://restorerivers.eu/wiki/index.php?title=Main_Page) and reviews of river restoration effectiveness (e.g. Kail *et al.* 2015; Smith *et al*. 2014; https://reformrivers.eu/home).

In addition to the suggestions from practitioners, sections would be included to enable monitoring strategies and design to be supported by statistical evaluations and power analyses. This would include sections on monitoring scales, data management and statistical analysis. Together with establishing standards for the monitoring, this will allow the coordination and collation of the data across multiple projects that will support programme evaluation. Consideration would need to be given to how to incorporate natural capital and ecosystem service assessments and how community monitoring can provide a wider contribution and enhance stakeholder engagement.

Developing the knowledge base as a wiki would ensure that it contains the most current information on techniques, their application and appraisal. It would be informed by inviting editors, specialists in their fields, to edit and contribute evidence. Thus, It would provide the facility to disseminate guidance and information quickly and effectively across practitioners. It would also allow the involvement of the wider community of practice and enable them to feedback and interact.

2. Decision support tool

The decision support tool would need to be developed as a web application or software that contains the decision flow charts and matrices in PRAGMO with additional contextual information on river and floodplain types to help users identify potential monitoring techniques and strategies. It would also include existing tools such as the monitoring planner (RRC 2014). The tool would communicate with the knowledge base, enabling users to cross-reference to techniques and obtain the level of detail required without burdening them with extra information. Worked examples of the decision support tool would also be included within the knowledge database.

3. Data repository

Even when a monitoring strategy is implemented, the results are often not shared or reside within grey literature with limited accessibility. This restricts the more strategic assessments, using a weight of evidence approach to assess particular techniques and approaches or where replication of assessments would be useful. Providing a data repository would ensure that valuable data is not lost and can be made available for integrated assessments.

The data repository would provide a structure for uploading or inputting project records and standardised data and photographs associated with river restoration projects to facilitate archiving, retrieval, assessment and audit. The system would need to link to the NRRI database which contains some 4500 river restoration schemes and is the UK standard for recording river

restoration information. The NRRI database in turn is linked to the RiverWiki database that contains information on schemes across Europe and further abroad.

The secure repository would have different levels of data accessibility levels depending on user requirements. Some of the data and documents uploaded may only be visible to the author, selected user groups or as open data. This would allow it to be used as a practical tool while project assessments are underway, with the ability to make the data available and their release embargoed until user specified dates.

Other advantages of this approach are that it can aid with ensuring data quality and encourage the sharing of data. Standardised approaches to data archiving with the necessary meta-data would ensure that the data can be more readily analysed using statistical tools. It could provide students and academics with access to data, allow them to revisit schemes and facilitate the appraisal of river restoration success over the long-term and build a stronger evidence base.

Future direction

It is essential that any restoration appraisal is well structured and based on sound principles, since poorly planned approaches waste resources and provide meaningless or misleading information (Anderson and Dugger 1998). By using approaches such as PRAGMO and the proposed update, this could be prevented by leading the end-user to adopt an appropriate monitoring protocol that will help to address evidence gaps.

Whilst the spatial extent and period of monitoring represent the bottom line for project managers, the consensus amongst academics is that these must be determined on a case-by-case basis, depending on what aspects are being monitored (Roni and Beechie 2013). Geomorphological effects may be rapid under some circumstances but decades or longer in others (Gilvear *et al.* 2013). Equally, timescales of ecological response will vary (Stoll *et al*. 2016). It is critical that timescales and the trajectories of anticipated change are considered within the restoration process. The framework developed by Gurnell et al. (2016a, 2016b) provides an integrated approach to river systems that can be taken into account when establishing the targets against which restoration activity is assessed (Angelopoulos *et al*. 2017). The importance of understanding these temporal and spatial variations and using them to anticipate restoration success cannot be underestimated. We need to undertake monitoring before restoration work is carried out and afterwards for a sufficient length of time to detect both rapid and longer-term changes (Addy *et al.* 2016). Best practice guidance such as PRAGMO offer the capability to ensure that this notion is considered realistically within any monitoring framework and, hence, work towards a coherent approach to increase the underlying evidence-base. This evidence base is critical to understand how we ensure that we continue to implement restoration techniques that result in environmental, economic and societal benefits and reduction of catchment pressures. The approach presented can underpin these aspirations by making the basic principles of the approach transferable to ecological restoration at an international scale.

Although much of the discussion above has been around environmental and natural physical processes and habitat project goals, we need, as implied above, to understand the social and economic constraints and set goals that provide benefits to society. This will help gain wider support and funding for restoration activities (Addy *et al.* 2016) as river restoration benefits are better understood. The use of citizen science approaches not only provides useful information but also connects people with rivers and improves general understanding (Smith *et al*. 2014). As new techniques and approaches are developed, these need to be incorporated into guidance material. Nonetheless, the need for a robust monitoring programme remains the same. The key is ensuring that there is sufficient flexibility within the system to make sure that new ideas and techniques can be integrated as they evolve. The monitoring guidance outlined in this paper and its potential development provides a robust way of ensuring the most effective and appropriate (relative to project size, knowledge known and budget) monitoring approaches are captured and used within any monitoring process. It can instil confidence of the users that the suite of monitoring they select are more likely to demonstrate change, identifying both restoration benefits and where future adaptive management may be necessary. Furthermore, it can help everyone be part of national and international processes to demonstrate that collectively we can achieve environmental, societal and economic goals and benefits. By publishing on-line, innovative and new effective monitoring practices and analytical techniques can be incorporated alongside the increasing evidence base that more effective monitoring and appraisal can produce.

Conclusions

1. Monitoring and appraisal should be an integral part of any river restoration scheme, but effort should be targeted to where we will learn the most.
2. Monitoring and appraisal is only effective if it is well designed and the lessons learnt are shared. This could be aided by decision-support tools, a collated evidence base and data repository.
3. Monitoring guidance is valued by those that use it, but needs to be regularly updated to incorporate new technology and innovation.
4. We need to widen our consideration of restoration effectiveness by incorporating societal and economic benefits.
5. Continuing to develop and update this guidance, which is already being regularly used, can aid in delivering wider environmental national and international goals and enable a pool of information for ongoing decision support purposes.

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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 http://www.crew.ac.uk/publication/river-restoration (accessed 1 December 2016)

Anderson, D.H. and Dugger, B.D. (1998) *A conceptual base for evaluating restoration success.* Transactions of the 63rd North American Wildlife and Natural Resources Conference, Washington DC

Angelopoulos, N.V., Cowx, I.G. and Buijse A.D. (2017) Integrated planning framework for successful river restoration projects: Upscaling lessons learnt from European case studies. *Environmental Science and Policy*, **76**, 12-22

Beechie, T.J., Sear, D.A., Olden, J.D., Pess, G.R., Buffington, J.M. and Moir, H. (2010). Process-based principles for restoring river ecosystems. *Bioscience*, **60(3)**, 209–22

Bentley, S.G., England, J., Heritage, G., Reid, H., Mould, D. and Bithell, C. (2016) Long-reach Biotope Mapping: Deriving Low Flow Hydraulic Habitat from Aerial Imagery. *River Research and Application,* **32**, 1597–1608

Defra (2018) *A Green Future: Our 25 Year Plan to Improve the Environment* OLG Crown Copyright, London. www.gov.uk/government/publications/25-year-environment-plan (Accessed 6 February 2019)

Downs, P.W. and Brookes, A. (1994) Developing a Standard Geomorphological Approach for the Appraisal of River Projects. Pages 299–310 In: Kirby C and White WR (eds) Integrated River Basin Development. John Wiley and Sons, Chichester

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

Environment Agency (2018a) *Working with Natural Processes – Evidence Directory* Environment Agency, Bristol, UK. pp.295. www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk (Accessed 16 January 2019)

Environment Agency (2018b) *Climate change impacts and adaptation* Environment Agency, Bristol, UK. pp.18. www.gov.uk/government/publications/climate-change-impacts-and-adaptation (Accessed 16 January 2019)

Feld, C.K., Birk, S., Bradley, D.C., Hering, D., Kail, J., Marzin, A., Melcher, A., Nemitz, D., Pedersen, M.L., Pletterbauer, F., Pont, D., Verdonschot, P.F.M., Friberg, N. (2011) From

Natural to Degraded Rivers and Back Again: a Test of Restoration Ecology Theory and Practice. In: Woodward, G. (Ed.), Elsevier Ltd., Amsterdam, The Netherlands.

Friberg N.I., Kronvang B, Hansen HO, Svendsen, LN (1998) Long-Term, Habitat-Specific Response of a Macroinvertebrate Community to River Restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 8, 87–99

Gilvear, D.J. Spray, C.J. and Casas-Mulet, R. (2013) River rehabilitation for the delivery of multiple ecosystem services at the river network scale. *Journal of Environmental Management*, **126**, 30-43

Gortz, P. (1998) Effects of Stream Restoration on the Macroinvertebrate Community in the River Esrom, Denmark. *Aquatic Conservation, Marine and Freshwater Ecosystem*s, **8**,115–130

Groll, M. (2017) The passive river restoration approach as an efficient tool to improve the hydromorphological diversity of rivers – Case study from two river restoration projects in the German lower mountain range. *Geomorphology*, **293,** 69-83

Gurnell, A.M., Rinaldi, M., Buijse, A.D., Brierley, G. and Piegay, H. (2016a) Hydromorphological frameworks, emerging trajectories. *Aquatic Sciences,* **78**, 135-138

Gurnell, A.M., Rinaldi, M., Belletti, B., Bizzi, S., Blamauer, B., Braca, G., Buijse, T., Bussettini, M., Camenen, B., Comiti, F., Demarchi, L., Garcia de Jalon, D., Gonzalez del Tanago M, Grabowski, R.C., Gunn, I.D.M., Habersack, H., Hendriks, D., Henshaw ,A.J., Klosch, M., Lastoria, B., Latapie, A., Marcinkowski, P., Martinez-Fernadez, V., Mosselman, E., Mountford, J.O., Nardi, L., Okruszko, T., O'Hare, M.T., Palma, M., Percopo, C., Surian, N., van de Bund, W., Weissteiner, C. and Ziliani, L. (2016b) A multi-Scale Hierarchical Framework for Developing Understanding of River Behaviour to Support River management. *Aquatic Sciences,* **78**, 1–16

Kail, J., Brabec, K., Poppe, M. and Januschke, K. (2015) The effect of river restoration on fish, macroinvertebrates and aquatic macrophytes, a meta-analysis. *Ecological Indicators*, **58**, 311–321

Large, A.R.G. and Gilvear, D.J. (2015) Using Google Earth, A Virtual-Globe Imaging Platform, for Ecosystem Services-Based River Assessment. *River Research and Application,* 31, 406–421

Li, F., Sundermann, A., Stoll, S. and Haase, P. (2016) A newly developed dispersal metric indicates the succession of benthic invertebrates in restored rivers. *Science of the Total Environment,* **569-570**, 1570-1578

Muhar, S., Januschke, K., Kail, J., Poppe, M., Schmutz, S., Hering, D. and Buijse, A.D. (2016) Evaluating good-practice cases for river restoration across Europe, context, methodological framework, selected results and recommendations. *Hydrobiologia,* **769**, 3

Mueller, M., Pander, J. and Geist, J. (2014) The ecological value of stream restoration measures, An evaluation on ecosystem and target species scales*. Ecological Engineering,* **62**, 129-139

Newson, M.D. and Large, A.R.G. (2006) 'Natural' rivers, 'hydromorphological quality' and river restoration, a challenging new agenda for applied fluvial geomorphology. *Earth Surface Processes and Landforms,* **31**, 1606-1624

OECD (2019) *OECD Environmental Performance Reviews: Australia 2019*, OECD Publishing, Paris http://www.oecd.org/publications/oecd-environmental-performance-reviews-australia-2019-9789264310452-en.htm (Accessed 6 February 2019)

Palmer, M.A., Bernhardt, E.S., Allan, J.D., Lake, P.S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C.N., Follstad Shah, J., Galat, D.L., Loss, S.G., Goodwin, P., Hart, D.D., Hassett, B., Jenkinson, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L. and Sudduth, E. (2005) Standards for ecologically successful river restoration. *Journal of Applied Ecology.* 42, 208-217

Palmer, M.A., Menninger, H.L. and Bernhardt, E.S. (2010) River restoration, habitat heterogeneity and biodiversity, a failure of theory or practice? *Freshwater Biology*, **55(1),** 205–22

Pedersen, T.C.M., Baattrup-Pedersen, A. and Marsen, T.V. (2006) Effects of Stream Restoration and Management on Plant Communities in Lowland Streams. *Freshwater Biology,* 5, 161–179

RRC (2006) *Outputs from a Monitoring Seminar, 12th-13th December 2006* www.therrc.co.uk/rrc_themed_workshops.php (Accessed 16 June 2017)

RRC (2007) *River Restoration Monitoring Working Group 12th December 2007* www.therrc.co.uk/rrc_themed_workshops.php (Accessed 16 June 2017)

RRC (2011) *Practical River Restoration Appraisal Guidance for Monitoring Options (PRAGMO)* www.therrc.co.uk/rrc_pragmo.php (Accessed 16 June 2017)

RRC (2013) Manual of River Restoration Techniques www.therrc.co.uk/manual-river-restoration-techniques (Accessed 16 June 2016)

RRC (2014) Monitoring planner www.therrc.co.uk/monitoring-planner (Accessed 16 June 2016)

Roni, P. and Beechie, T.J. (2013) *Stream and watershed restoration, a guide to restoring riverine processes and habitats*. John Wiley and Sons Ltd

Salant, N.L., Schmidt, J.C., Budy, P. and Wilcock, P.R. (2012) Unintended consequences of restoration, Loss of riffles and gravel substrates following weir installation. *Journal of Environmental Management*, **109**, 154-163

Shuker, L. J., Gurnell, A.M., Wharton, G., Gurnell, D.J., England, J., Finn Leeming, B.F. and Beach, E. (2017) MoRPh, a citizen science tool for monitoring and appraising physical habitat changes in rivers. *Water and Environment Journal*, **31**, 418-424

Smith, B., Clifford, N.J. and Mant, J. (2014) The changing nature of river restoration. *Wiley Interdisciplinary Reviews, Water,* **1**, 249-261

Stoll, S., Breyer, P.D., Tonkin, J.D., Früh, D. and Haase, D. (2016) Scale-dependent effects of river habitat quality on benthic invertebrate communities — Implications for stream restoration practice. *Science of The Total Environment*, **553**, 495-503

Wohl, E., Angermeier, P.L., Bledsoe, B., Kondolf, G.M., MacDonnell, L., Merritt, D.M., Palmer, M.A., Poff, N.L. and Tarboton, D. (2005) River restoration. *Water Resources Research*. **41**, 10

Woolsey, S., Capelli, F., Gonser, T., Hoehn, E., Hostmann, M., Junker, B., Paetzold, A., Roulier, C., Schweizer, S., Tiegs, S.D., Tockner, K., Weber, C. and Peter, A. (2007) A strategy to assess river restoration success. *Freshwater Biology,* **52**, 752-769