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RESTORATION OF A CHALK STREAM USING WOOD: ASSESSMENT OF HABITAT IMPROVEMENTS USING THE MODULAR RIVER SURVEY

Judy England, Lukasz Dobbek, Brishan Finn Leeming, Angela Gurnell, Geraldene Wharton

ABSTRACT

The installation of large wood and sediment berms to narrow the overwide channel of the River Bulbourne, Hertfordshire, aimed to restore geomorphological processes, improve channel habitat diversity, and increase the amenity value of the park in which the river is located. The Modular River Survey provides a framework and suite of tools for river managers and volunteers to monitor and assess restoration activities. Applying this technique to the River Bulbourne before and after restoration demonstrated that the works increased physical habitat and vegetation complexity. The restored section was narrowed, substrate composition changed, and the range of instream vegetation morphotypes increased. The initial slight improvement in riparian habitat complexity immediately following the restoration is expected to increase further over time as the riparian vegetation develops and the restored section of channel matures. A public perception and recreational use survey reviewed how visitor experience and use of the park changed following restoration.

KEY WORDS

Large wood, restoration, River Bulbourne, Modular River Survey, habitat, public perception

INTRODUCTION

Freshwaters occupy only 0.8% of the surface of the Earth yet they are disproportionately diverse relative to their habitat area (Dawson, 2012). Human modifications of river systems and changes to flow regimes have altered their natural character impacting on the diversity of the biota they support (Demars *et al.,* 2012). To address the degradation of aquatic systems in Europe the Water Framework Directive (WFD; European Commission, 2014) was introduced to promote sustainable management of the water environment. Achieving the required Good Ecological Status or Potential relies on the water body's physical condition, as defined by the hydromorphological quality elements, and reflects the fluvial geomorphic state. Degradation of hydromorphological quality is one of the main reasons for waterbodies failing the WFD requirements (European Environment Agency, 2012).

River restoration is increasingly used to redress habitat modification impacts upon riverine biota (Addy *et al*., 2016). Addy *et al*. (2016) define river restoration as *"the re-establishment of natural physical processes (e.g. variation of flow and sediment movement), features (e.g. sediment sizes and river shape) and physical habitats of a river system (including submerged, bank and floodplain areas)."* This focus on restoring natural processes to create characteristic, self-sustaining, dynamic physical habitats is referred to as *process-based restoration* (Beechie *et al*., 2010) and allows rivers to respond to future disturbances (such as climate change) enabling ecosystems to evolve and continue to function (Addy *et al.,* 2016). Living and dead wood are natural components of healthy functioning river systems (Gurnell *et al.,* 1995; Gurnell, 2013) and have been introduced in a variety of river systems to help restore these natural processes, increase habitat diversity, and improve ecological status (Kail *et a*l., 2007; Chin *et al*., 2008; Pilotto *et al*., 2016).

The aim of this study was to appraise the restoration of a chalk stream which used wood to improve biophysical habitat and support morphological features created from sediments released by bank reprofiling. The immediate aim of the restoration was to narrow the over- widened river channel, increase its morphological complexity, and improve the connectivity between the river and its floodplain. These support the longer term aims of helping to restore local river processes and increase in-channel and, eventually, riparian habitat diversity. The newly-developed Modular River Physical (MoRPh) survey (Shuker *et al.,* 2017) was used for the first time to appraise the hydromorphological condition of a river pre and post restoration. The appraisal was based on the five main integrative indices (channel habitat complexity, riparian habitat complexity, channel vegetation complexity, riparian vegetation complexity, and average bed material size) that are automatically generated when a survey is uploaded into the MoRPh information system and that were designed to track broad physical habitat changes through time and across space. The indices are each derived from a sub set of the observations collected during a MoRPh field survey (Shuker *et al*., 2017) and their derivation is fully described in the 'MoRPh Indices' document which is downloadable from https://modularriversurvey.org/documents/. While these five indicators were the main focus of the present analysis, a range of other indices are automatically generated by the information system when a survey is entered, and other indicators could be added should monitoring and appraisal of river schemes require different aspects of biophysical habitat to be evaluated in the future. A public perception and park user survey contributed to the overall evaluation of the restoration scheme.

The study addressed three research questions:

(1) Have the restoration measures increased the biophysical habitat quality of the chalk stream? Specifically, we tested the null hypotheses that the restoration had not resulted in any increase in (a) channel habitat complexity, (b) riparian habitat complexity, (c) channel vegetation complexity, (d) riparian vegetation complexity, and (e) average bed material size when compared to the conditions observed at the beginning of the period and prior to restoration.

(2) Is MoRPh a suitable method for detecting and evaluating changes in hydromorphology as a result of restoration schemes?

(3) How has the public reacted to the restoration scheme?

STUDY SCHEME – *BRINGING BACK THE BULBOURNE*

The restoration scheme and study reaches are located on the River Bulbourne, a chalk stream within the River Thames catchment, England (Figure 1). Chalk streams support a diverse range of flora and fauna with a broad specialist species range (Buglife, 2013). Over 80% of the world's chalk streams are found in the UK and most are in England (Mainstone, 1999). Many, including the Bulbourne, have become degraded due to human pressures (Chapman *et al.*, 2014) with only 25% estimated to be at Good Status under the WFD (The Wildlife Trusts, n.d.). Projects aimed at restoring their physical structure and ecological function, and studies to evaluate the impacts of restoration activities are therefore critical to reverse these declines and deliver WFD targets.

Prior to restoration, the River Bulbourne at Box Moor Park displayed a wide, deep, and morphologically simple channel with limited habitat diversity and heavy siltation across extensive areas of the channel bed (Chilterns AONB, 2017), probably as a result of past flood defence and land drainage activities. In addition, unrestricted grazing of the banks by cattle and horses had contributed to bank erosion, channel widening, and reduction of marginal vegetation. The *Bringing Back the Bulbourne* restoration scheme was undertaken in January 2017 with the aim of restoring natural processes within a 1 km stretch to create a characteristic chalk stream and enhance the river corridor for people and wildlife.

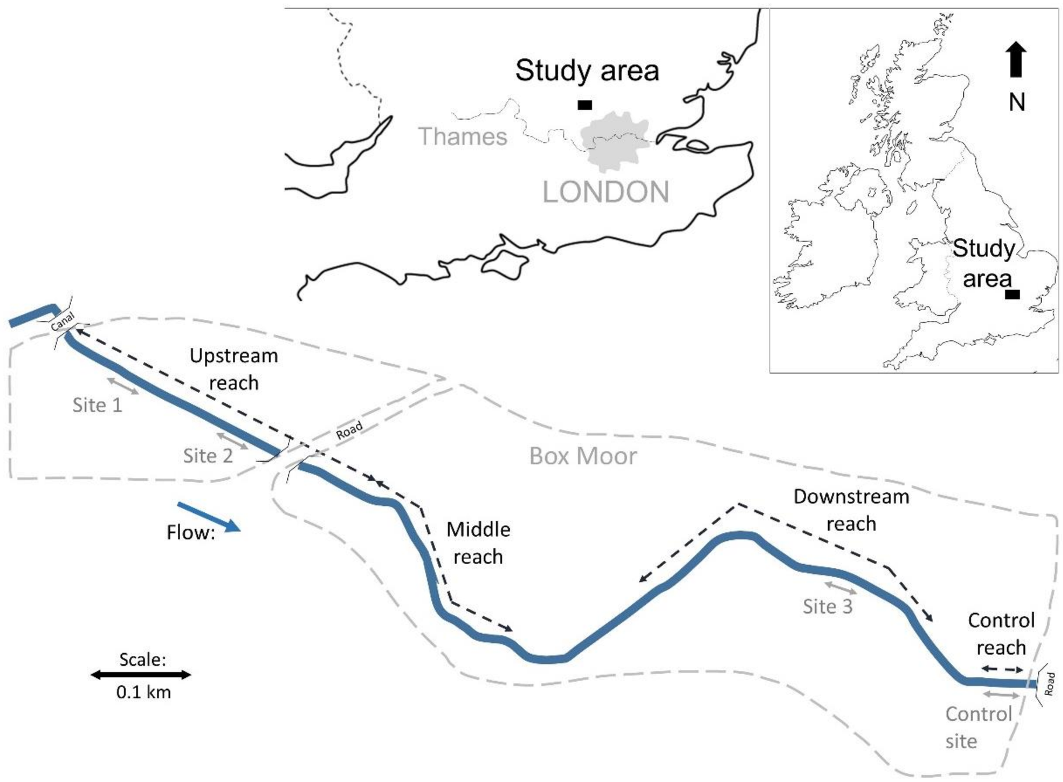

Figure 1 Location of the *Bringing Back the Bulbourne* river restoration scheme at Box Moor in Hemel Hempstead. Multi-MoRPh Surveys were undertaken within the 3 restored reaches (Upstream, Middle, and Downstream) plus the Control reach and detailed habitat mapping was undertaken at the Sites 1-3 and the Control site.

Restoration activities involved regrading the river banks throughout the restored section to narrow the channel within its existing course and allow the river to reconnect with its floodplain. This was coupled with fencing along the restored river channel and margins to protect them from grazing and allow marginal wetland habitat to develop. Locally sourced wood and sediment from bank regrading were used to achieve the restoration. This included the placement of individual pieces of large wood and mattresses of dead and living large wood (*Salix* species) to provide habitat and at the same time reinforce the regraded bank sediments. The mattresses were arranged to emulate natural berms (Figure 2). The restoration was implemented slightly differently within the Upstream, Middle, and Downstream reaches of the scheme, with greater narrowing and wood installation in the Upstream and Downstream reaches, which had suffered greater widening in the past.

Figure 2. The River Bulbourne before (A) and after restoration (B). Photographs taken within the Upstream reach where large wood has been incorporated as a flow deflector.

METHODS USED TO EVALUATE THE RESTORATION SCHEME

The restoration scheme was evaluated through pre and post project assessments of its hydromorphology and habitat using both reach-scale and patch-scale survey techniques (Figure 1).

At the reach scale, observations in three restored reaches (Upstream, Middle and Downstream reaches) were compared with observations in a Control reach (Figure 1). Our selection of a control reach was constrained by the limits of the restoration scheme park, and the locations of a canal and road crossings. The only section available for use as a control was a short section downstream of the restoration scheme, constraining the length of river available for data collection and raising a potential problem of some responses induced by the upstream restoration. Although not ideal, this reach was far less degraded than those that were restored and so it had the advantage of indicating a habitat template that restoration could aim to achieve upstream.

At the patch scale, observations were confined to four 15m lengths of river (called *sites*, Figure 1), where changes in the percentage cover of different habitat types were monitored. One site was located in the Control reach and the other three sites were located in the Upstream (sites 1 and 2) and the Downstream (site 3) reaches to coincide with the placement of large wood.

Public perception of the scheme and the changing use of the river and park were captured through an on-site questionnaire survey.

Reach-scale assessment: the Modular River Physical (MoRPh) survey

The newly-developed MoRPh survey, which is designed to enable citizen scientists to characterize local physical habitat mosaics and human pressures within short river sections, was employed at the reach scale. MoRPh surveys focus on river 'modules', the smallest unit within the multiscale Modular River Survey (Shuker *et al.,* 2017; England and Gurnell, 2016). Surveys of a contiguous set of 10 MoRPh modules (known as a MultiMoRPh survey) capture the range and diversity of physical habitats available along a river reach and allow the longitudinal pattern of physical forms and sediments to be investigated.

Briefly, a single MoRPh survey systematically records general site information, physical features, vegetation properties, and human modifications on the bank tops (within 10m of the channel), bank faces and channel edges, and the channel bed of a length of river that is approximately twice the channel width (Figure 3), using a combination of feature types and codes and a simple abundance scale [A=Absent, T=Trace, (<5%), P=Present (5% - <33%) and E=Extensive (>33%)]. The key principle is to "record WHAT YOU SEE not what you know". Survey data are uploaded to an on-line data base https://modularriversurvey.org/ and, once approved, fourteen indices are calculated automatically and mapped to summarize the sediments, physical habitats, vegetation, human interventions and pressures within each surveyed module (Shuker *et al.,* 2017).

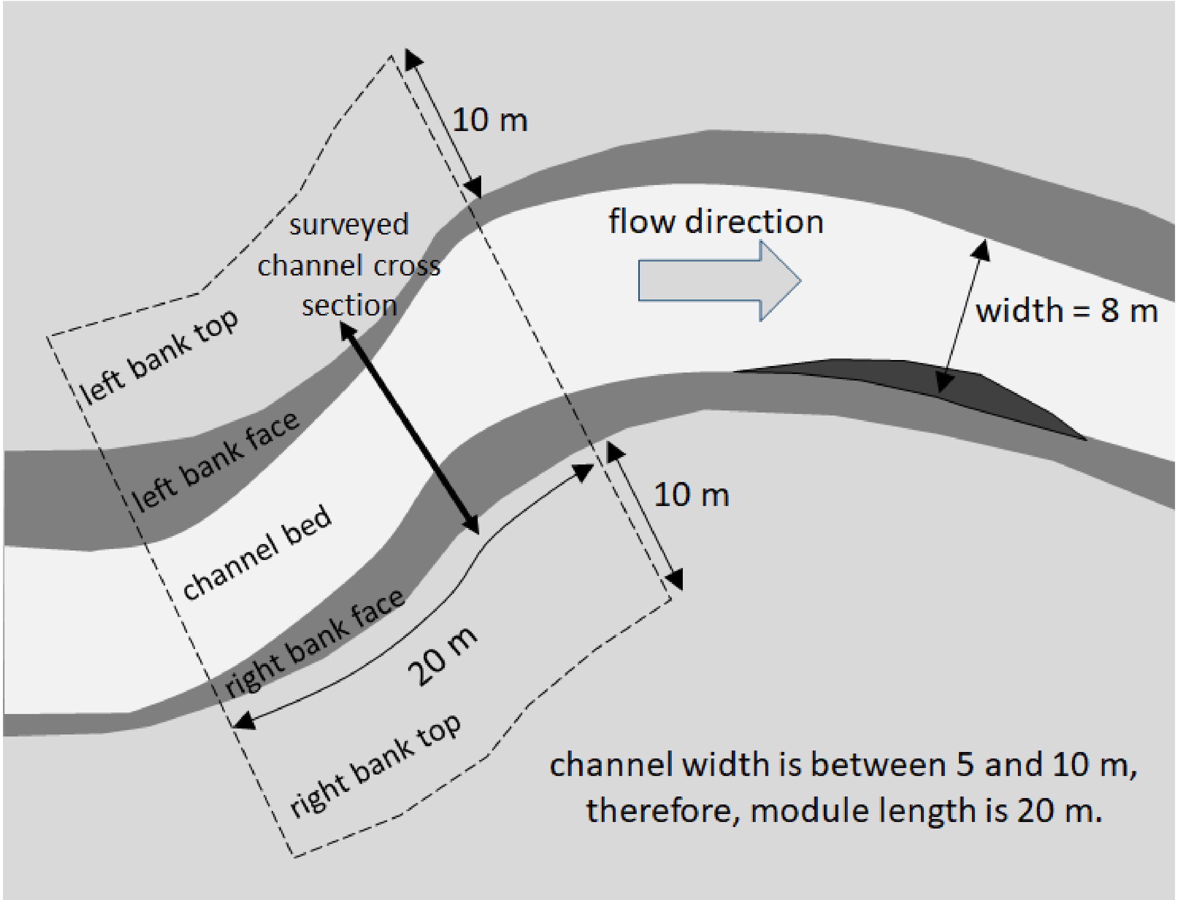

Figure 3. Depiction of the MoRPh survey area, which extends 10m back from the bank tops on both sides of the river. The width of the channel determines the length of the river module.

The appraisal was based on the five main integrative indices (channel habitat complexity, riparian habitat complexity, channel vegetation complexity, riparian vegetation complexity, and average bed material size) that are automatically generated when a survey is uploaded into the MoRPh data base and that were designed to track broad physical habitat changes through time and across space. These indices are each derived from a sub set of the observations collected during a MoRPh field survey (Shuker et al., 2017) and their derivation is fully described in the 'MoRPh Indices' document which is downloadable from https://modularriversurvey.org/documents/.

We investigated the degree to which the five indices showed statistically significant differences between study reaches and their responses to restoration on different survey occasions [i.e. before restoration in September 2016 (2016Spt), shortly after restoration in April 2017 (2017Apr), and in the longer term July 2017 (2017Jly) and September 2017 (2017Spt)]. Therefore, a similar analysis was achieved by estimating multiple linear regression models incorporating dummy independent variables representing the survey occasion, reach, and the interaction between survey occasion and reach to explain each of the five dependent variables. Each dummy variable took the value of 1 (for the specific reach, survey, or reach-survey combination) and otherwise 0. We incorporated survey – reach combinations or interactions because we expected the changes in the surveys to vary irregularly in time and space, depending on the precise nature of the restoration in each reach (the same restoration measures were used but their sizes and layouts were not identical) and the stage of recovery. By considering survey – reach interactions, it was possible to identify whether different behaviour was identifiable in particular reaches on particular survey occasions. Each regression model was initially estimated using a stepwise procedure to select the combination of independent variables that achieved the highest coefficient of determination, adjusted for the degrees of freedom of the model (R^2adj), with alpha=0.15 as the criterion for inclusion or removal of independent variables. This initial model was then refined by removing independent variables whose slope coefficient was not statistically significant ($p>0.05$) until a final model incorporated a set of independent variables which were all statistically significant ($p<0.05$). Each of the selected models showed approximately normally-distributed, homoscedastic residuals. Values for the five indices were extracted from MoRPh surveys conducted during the four survey occasions (2016Spt, 2017Apr, 2017Jly, 2017Spt) at the ten contiguous modules in each of three restored reaches (upstrm, middle, downstrm) and at the two modules in the control reach (control).

Patch-scale assessment: detailed habitat extent

Detailed habitat assessment was employed for a patch-scale examination of the changes in response to the restoration measures, allowing subtle changes to be captured which complements the coarser categorical approach employed within MoRPh. By focusing the assessments on four 15m lengths of channel (sites), one within the Control reach and three within the restored reaches (two in the Upstream reach and one in the Downstream reach, to coincide with the placement of large wood, Figure 1), the habitat assessment also allowed the same level of detail to be achieved for the control and restored sites.

The mapping involved visual assessments of the extent and location of the habitats present within the four studied sites. The spatial scale and types of habitat investigated have been variously defined as "mesohabitats" (Pardo and Armitage, 1995), "functional habitats" (Harper *et al*., 1992) and "biotopes" (Newson and Newson, 2000). At each site, a 15m section of channel was defined within which the percentage area covered by different habitats was recorded. The habitat observations used the same plant morphotypes (emergent narrow leaf, emergent broad leaf, submerged broad leaf, submerged fine leaf vegetation), bed sediment (gravel/pebble and cobbles, sand and silt) and wood categories recorded in the MoRPh surveys. Mapping was undertaken by one person at the same times as the MoRPh surveys.

Because only a single site was monitored in the Control reach, with a further three sites distributed across the restored reaches, it was not possible to apply inferential statistics to establish the statistical significance of any observed changes. However, the data are presented as bar graphs and descriptive statistics were used to quantify the observed changes at each of the four monitored sites. The Simpson's diversity index (Simpson, 1949) was calculated for each site to quantify the diversity of habitats on each survey occasion. The resulting absolute and relative values (where all were scaled to a value of 1 on the first survey occasion) of the index are presented as line plots to illustrate absolute and relative changes within and between sites over the study period.

Public perception assessment

To assess people's opinion of the restoration scheme a public perception questionnaire was administered on site during October and November 2017. The survey captured public awareness of the restoration project, recreational useof the area, and individual views of the scheme. People across a range of age groups were asked a series of questions about the project, rating their answers on a five-point scale: Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4) or Strongly Agree (5). The data from 110 respondents provides a baseline of people's reaction to the survey against which future surveys will be assessed.

RESULTS

MoRPh surveys

The final selected multiple regression models relating the five integrative indices (dependent variables) to a set of dummy independent variables are presented in Table 2, which also includes a second model for 'Riparian vegetation complexity'.

Regression models for the two vegetation-related variables have the highest R^2adj values, indicating that the independent variables explain over 30% of the variation in each of these two dependent variables, while models for the two physical habitat related variables have lower R^2adj values, with the model for 'Channel Physical Habitat Complexity' showing only a 2.3% explanation of the variation in the dependent variable. There was no statistically significant model for 'Average bed material size' and so no model is included in Table 2.

In the case of 'Riparian Vegetation Complexity' two models are presented. The first model includes one variable (2017Apr*downstrm) with a slope coefficient that is not quite statistically significant (p=0.067, see underlined variable in Table 2). This model indicates that the Control reach maintains the highest whilst the Downstream restored reach records the lowest values of riparian vegetation complexity throughout the observations. Furthermore, the Downstream and Upstream restored reaches achieve their lowest riparian vegetation complexity in 2017Apr, which is immediately after the restoration treatments and thus before recovery had fully commenced, indicating immediate and ongoing responses to restoration that are not observed in the Control or Middle reaches. If the variable 2017Apr*downstrm is removed from the analysis, a simplified statistically-significant model emerges, showing generally lower values of the dependent variable in 2016Spt and 2017Apr across both control and restored reaches, and thus an improvement in the index through time that cannot be specifically related to the restoration.

The model for 'Aquatic Vegetation Complexity' shows generally lower complexity in the restored reaches compared with the Control, but also notably lower complexity in the Upstream and Downstream restored reaches in September 2016, prior to restoration, indicating some greater improvement in the Upstream and Downstream reaches relative to the Control and Middle reaches following restoration.

The model for 'Riparian Physical Habitat Complexity' shows that this index was significantly lower in the three restored reaches than the Control reach prior to restoration, indicating some improvement following restoration relative to the Control. Finally, the very weak model for 'Channel Physical

Habitat Complexity' simply indicates an overall increase following 2016Spt in all reaches, which may or may not relate to the restoration.

These five main indicators represent an integration of numerous properties recorded in the MoRPh surveys, whereby variables which did not respond to the restoration within the short post-restoration period may have disguised those that did show a response. Therefore, each contributing property was visualised using Box and Whisker Plots. Feature abundance is recorded in MoRPh using a simple abundance scale (Absent = 0% cover/extent; Trace = $\leq$5%; Present = 5 - $\leq$33%; Extensive = > 33%). To provide quantitative data for the Box and Whisker plots, all of the observations were translated into approximate mid-point percentages for the abundance classes (0%, 3%, 20%, 67%), and, in the case of bank measurements, the two individual bank values were averaged to give a single value for each of the 32 sites surveyed (2 control, 10 for each of three restored reaches), observed on 4 different occasions. Box and Whisker plots for nine variables that appear to show a response to restoration are presented in Figure 4.

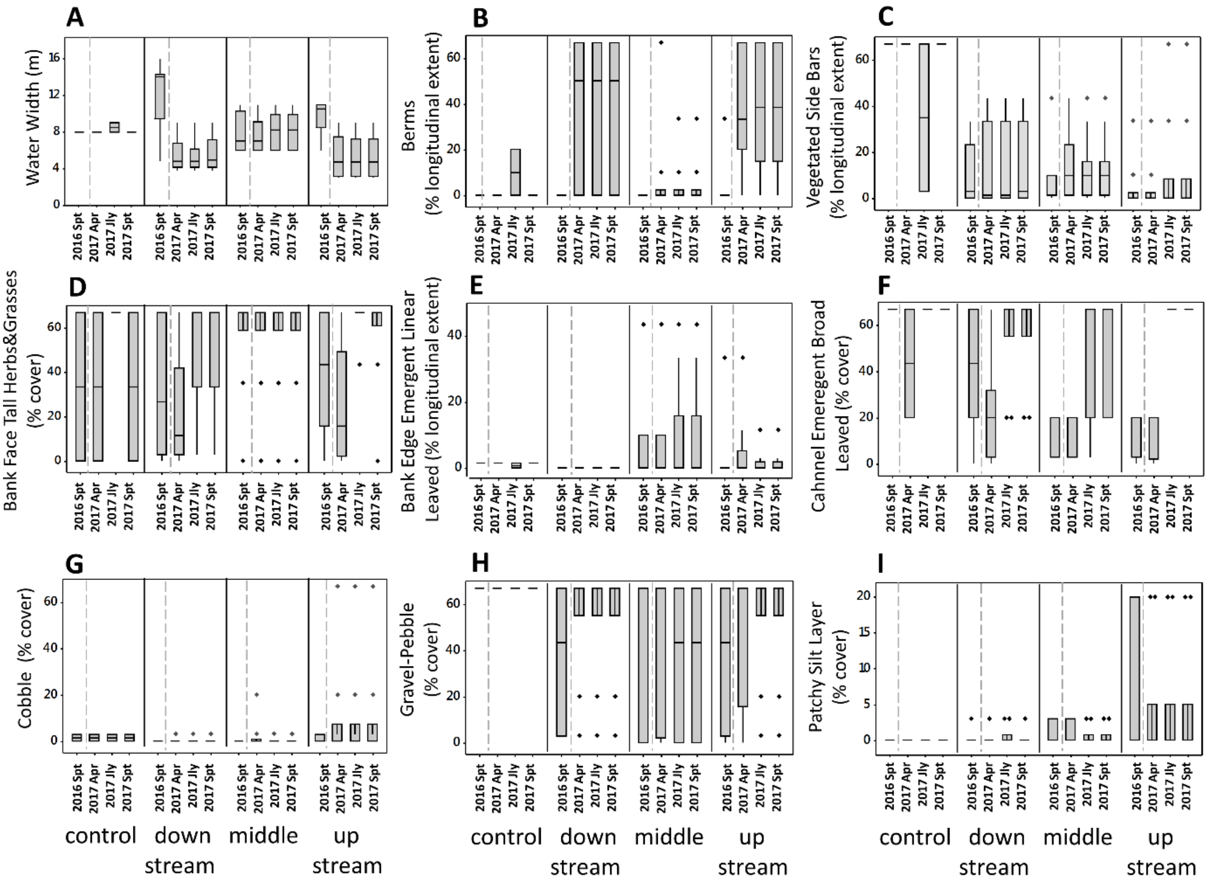

Figure 4. Box and Whisker plots showing the changing extent of selected channel and riparian features among control and restored reaches through time. The vertical solid lines in A, B and C separate the data collected in the control, downstream, middle and upstream reaches, whereas the vertical dashed lines separate the pre-restoration survey data from the three post-restoration surveys undertaken in each reach.

The direct impact of the restoration is illustrated in Figures 4 A and B, where the notable reduction in water width in the Upstream and Downstream reaches from April 2017 (Figure 4A) was achieved by the construction of artificial berms, often stabilised with wood (Figure 4B). Although similar measures were applied in the Middle reach, they were more restricted, as witnessed by no apparent change in channel width and a far smaller increase in the longitudinal extent of berms (Figure 4 A and B). The responses to the major changes in the Upstream and Downstream reaches plus minor changes in the Middle reach can be observed in Figures 4 C to I. Manipulations of the banks are reflected in an increase in the extent of vegetated side bars around the constructed berms (Figure 4C), an increase in the abundance of tall herbs and grasses in the Upstream and Downstream reaches (growing on the constructed berms and on the developing vegetated bars, Figure 4D), and an increase in the Middle reach and appearance in the Upstream reach of emergent linear-leaved aquatic plants along the water's edge (Figure 4E). On the channel bed, there is a marked increase in the cover of emergent broad-leaved aquatic plants in the Upstream and Middle reaches and a recovery beyond the pre-restoration level in the Downstream reach (Figure 4F). Although no statistically significant change was found in the average size of bed material, small exposures of cobbles become apparent in the restored reaches following restoration (Figure 4G) and there is a marked increase in the exposure of gravel-sized deposits in the upstream and downstream restored reaches (Figure 4H), and a marked reduction in overlying patchy silt deposits, particularly in the Upstream and Middle restored reaches (Figure 4I). Overall, this closer inspection of some of the variables that contribute to the integrative indices suggest a response in the channel form (extension of side bars), sediments (increase in cobble and gravel exposure as overlying silt reduces), as well as changes in riparian, aquatic marginal, and aquatic bed vegetation in the first eight months following restoration.

Patch-scale assessment

The changes revealed by MoRPh surveys are complemented by the findings from the more detailed patch-scale habitat assessments at four sites that focus on emplaced wood within the three restored sites. These assessments record the extent of some specific bed sediment and in-stream vegetation types at the four sites (Figure 5A), two in the Upstream reach, one in the Downstream reach and one in the Control reach (Figure 1).

While the mix and extent of habitats present at the Control site remained consistent through the study, apart from some expected seasonal variations in vegetation extent, notable changes occurred at the restored sites. Sand and silt dominated the river bed sediments across the three restored sites in the baseline surveys (Sept16) but this switched to mostly gravel, pebbles and cobbles following restoration. In-stream vegetation became a more important component of the in-stream habitat post restoration with a greater extent and more complex mix of emergent and submerged vegetation. Values of the Simpson's diversity index, estimated from the habitat data at all four sites (Figure 5B), show an increase in the diversity of habitats at each of the restoration sites through the study period, which approach the values for the Control site by the end of the study. In contrast, the Control site shows little change but consistently higher values of the Simpson index as was expected for this less degraded part of the river. The relatively small changes at the control site and overall increases in diversity at the restored sites are even clearer when relative values of the Simpson's index are plotted (Figure 5C).

Overall, clear and progressive responses following restoration were observed at the restored sites but none were observed at the Control site. These are stronger changes than were observed at the reach scale and reflect the fact that the restored sites were deliberately selected to coincide with one of the main restoration measures, the emplacement of large wood, which in turn acted to reinforce the other restoration measure, the creation of artificial berms.

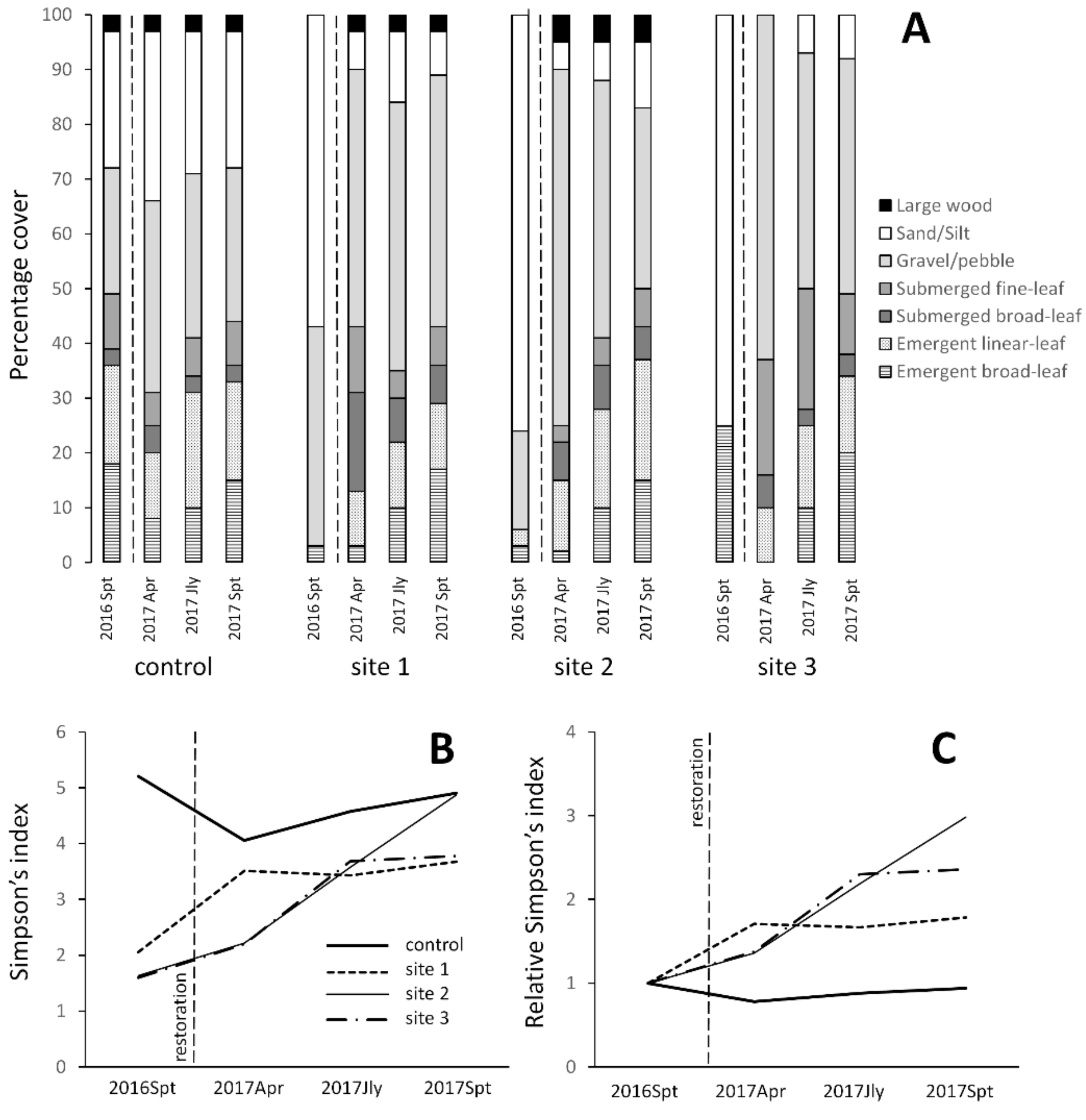

Figure 5. A - Percentage habitat cover recorded at the Control and three restored sites during each survey. B – Changes in Simpson's diversity index at each site across the four surveys. C – Relative changes in Simpson's diversity index at each site across the four surveys (for each site the four Simpson's diversity index values are expressed as a proportion of the pre-restoration value). For locations of the Control site and the restored sites 1, 2 and 3, see Figure 1. The vertical dashed lines in A, B and C indicate the inter-survey period during which the restoration was undertaken.

Public Perception Survey

During the public perception survey 110 people spanning different age groups were interviewed on site, 78% of whom travelled <1 mile to visit to park, 77% visited the park daily, and 89% were aware of the restoration scheme. Most of the people surveyed agreed or strongly agreed that the river and its floodplain have become a better habitat for wildlife since restoration work took place (Figure 6A) and feel that the new state of the river is an improvement over the pre-restoration condition (Figure 6B). People were provided with the project cost (~£64,000) and asked if they thought the scheme was value for money (Figure 6C): 68% of them thought it very good or quite good value; 18% of people did not; and 22% had no opinion or thought it was too soon to tell. Some of the public commented on the disturbance created by the restoration scheme. Overall, these results show that the majority of people are supportive of the scheme, however, others are waiting to see how the river develops before forming an opinion.

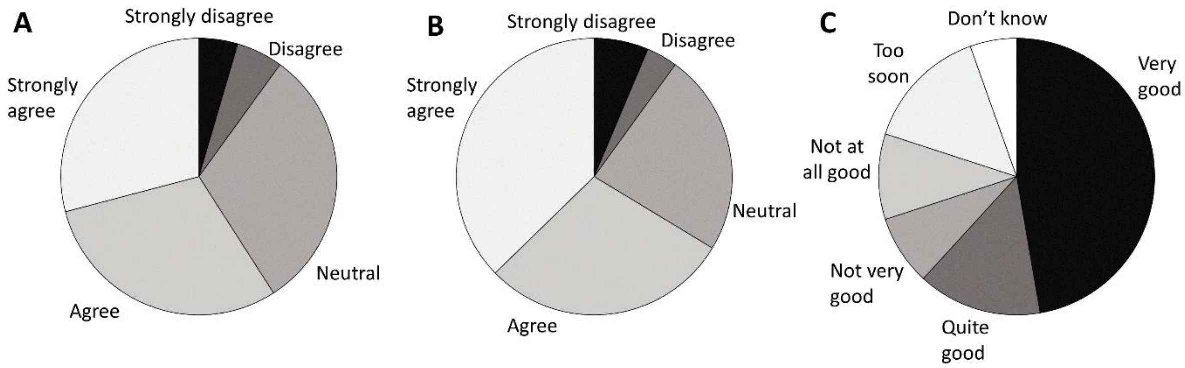

Figure 6. Results of the public perception survey: A - The river and its floodplain have become a better habitat for wildlife since restoration work took place: B – Overall, I feel the new state of the river is an improvement over the state before; and C - Do you think the scheme was value for money?

DISCUSSION

Bringing Back the Bulbourne

The *Bringing Back the Bulbourne* restoration scheme restored natural riverine processes by utilizing living and dead wood and local bank sediments to form a narrower channel with shallow river banks and marginal berms which increased habitat diversity. Analysis of five MoRPh integrative indicators show changes, albeit rather weak ones, in riparian vegetation complexity, aquatic vegetation complexity, and riparian physical habitat complexity in the restored reaches relative to the Control reach following the implementation of restoration measures. Inspection of MoRPh variables that track channel dimensions and contribute to the five integrative indices reveal how the restoration activity changed the channel dimensions encouraging the growth of vegetation on the berms and shallower bank faces. This change within the riparian zone was accompanied by an increase in the in-channel aquatic macrophyte coverage, morphodynamic richness, and a slight change in substrate composition to coarser sediments. Focusing on sites of large wood emplacement, the more detailed habitat assessments clearly confirm the progressive increase in habitat diversity within the restored reaches of the channel close to restoration measures, and only seasonal changes observed within the Control reach. Overall, the repeat MoRPh surveys and accompanying patch scale habitat assessments have captured positive changes in: river morphology (extension of side bars); bed sediments (increase in cobble and gravel exposure as overlying silt reduces); riparian, aquatic marginal, and aquatic bed vegetation; and habitat diversity. These improvements were documented in the first eight months following restoration and are expected to continue as the riparian vegetation matures and the living wood grows. The findings are very encouraging because lowland river systems, including chalk streams like the Bulbourne, are low energy systems (Mainstone, 1999) which often require more extensive changes to the channel morphology to activate river processes (RRC, 2013).

In lowland river systems the presence of large wood and the interaction between sediment and in-stream vegetation is important in defining habitat quality and composition (Gurnell *et al.,* 2002, 2016). This was observed within the River Bulbourne where the restored channel was colonised by submerged vegetation which trapped some fine sediment and altered flow patterns, possibly contributing to allowing emergent broad leaf vegetation to colonise. Once established, the marginal emergent broad leaf vegetation became extensive, further constricting the flow which helped to maintain higher flow velocities within the centre of the channel and thus a riverbed clear of silt. These processes are characteristic of lowland chalk streams and emphasise the importance of vegetation in driving geomorphological changes (Gurnell and Grabowski, 2016) and facilitating habitat diversity (Cornacchia et al., 2018).

It is also anticipated that the vegetation and morphological complexity along the restored River Bulbourne will continue to adjust as vegetation, sediment, flow, and morphological interactions continue. Responses to river restoration take much longer than one year (Gilvear *et al*., 2013) and so continuing habitat adjustments and improvements can be anticipated over at least the next decade. In particular, riparian zone adjustment requires the development of riparian vegetation to interact with river processes (Gurnell, 2014). Thus, the longer-term development of the riparian zone is important and needs to be considered within the remit of process-based restoration (Boudell *et al.,* 2015).

The public reaction to the restoration scheme was mostly favourable, with the majority of people agreeing that it was beneficial to wildlife and was value for money although 22.5% of respondents had yet to form an opinion. This highlights the importance of awareness raising when schemes are being planned and implemented and the need for appraisals to continue for many years after the completion of restoration projects to document recovery and peoples' reaction. The pre project and immediate post project surveys presented here provide the baseline against which future assessments of habitat and public perception can be compared. Fulfilling both social and environmental objectives is increasingly recognised as important for effective and successful river restoration (e.g. Palmer *et al.,* 2005) and the importance of green and blue spaces to human well-being and ecosystem services is recognised (Gascon *et al.,* 2017; Sandifer *et al.,* 2015). However, there were still a proportion of the people surveyed who were critical of the scheme and how the restoration activities had disturbed the system. In order to improve public perception and increase support for future restoration work, it is necessary to communicate more clearly what a naturally functioning and ecological healthy river should look like and the value this brings.

Modular River Physical (MoRPh) survey

MoRPh provides a quick and easy method for surveying river habitats that can be applied to extensive lengths of channel and can be undertaken by non-specialists as long as they have undertaken the minimum one-day training course (Shuker *et al*., 2017). Within this study all MoRPh surveys were undertaken by one person to minimise operator variance. The method has been trialled successfully within Hertfordshire (Shuker *et al*., 2017, England *et al.,* 2017) where it has been implemented by many surveyors and has been used to distinguish between river reaches of differing hydromorphological quality, but this is the first time it has been applied to assess river restoration activities. The survey technique was found to be sufficiently sensitive to detect modest but statistically-significant changes at the reach scale in some integrative indices that summarise channel form, vegetation complexity, and habitat diversity. This outcome is particularly interesting considering the short study period that gave less than a year for any impacts of restoration to become apparent, and also because each of the indices investigated represents an amalgamation of a wide range of physical and vegetation properties which may or may not respond in such a short period of time. It is likely that greater discrimination would have been achieved if a full set of 10 MoRPh surveys had been feasible in the Control reach and also if the study had incorporated a longer post-restoration time period during which a larger number of the properties contributing to each indicator could have shown measurable responses. Drilling down into the properties that are incorporated into the indices helped to identify *which* had shown some response to changes arising from the restoration and *where* those responses were occurring (bank top, bank face, channel bed). By combining analysis of MoRPh reach-scale survey data with a patch-scale habitat assessment technique, which was deliberately directed at sites where wood had been emplaced, it was possible to demonstrate the success of the restoration scheme and measures even over the short time period since its implementation.

Citizen science techniques have enormous potential in that they are open to all to gather extensive data sets which can capture both spatial and temporal changes and their contributions are increasingly recognised in research (Silverton, 2009; Lukyanenko *et al*., 2016). They have an added advantage of reconnecting people with their river environments (Huddart *et al.,* 2016), an important consideration for effective river restoration schemes (Addy *et al*., 2017) especially within heavily populated areas such as in the vicinity of the River Bulbourne scheme. The data collected on the Bulbourne will contribute to an improved understanding of the physical and biological river processes underpinning effective river restoration (Shuker *et al*., 2017; Smith *et al.,* 2014). Projects such as this also give the people involved a sense of pride and ownership over their stretch of river (Pocock *et al*., 2014), providing a strong basis for future management and widening public perception of the value of river restoration.

CONCLUSIONS

1. This study has illustrated the effectiveness of the *Bringing Back the Bulbourne* restoration scheme. River processes and in-channel habitat diversity have shown improvement within only eight months of the completion of the works and further improvements are anticipated.

2. The incorporation of local wood and sediments within the restoration scheme and the interactions between these, the forms that were created, and subsequent river flow, sediment transport, vegetation colonisation and growth were important elements in the early positive outcomes of the restoration scheme.
3. The public reaction to the scheme was largely favourable.
4. The citizen science MoRPh survey technique was successful in detecting changes within the river following restoration and it is recommended that its wider application will improve our understanding of how the approach can be applied, issues such as inter-surveyor variation, and which restoration techniques work best where.

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Table 2: Multiple regression models relating four indicators (dependent variables) to a set of dummy independent variables representing survey reach (control, upstrm, middle, downstrm) survey occasion (2016Spt, 2017Apr, 2017Jly, 2017Spt) and interactions between reach and survey occasion. The statistical significance of each contributing independent variable is indicated by a probability in brackets.

Riparian Vegetation Complexity = 3.637 + 1.499 control – 0.856 downstrm – 0.416 2016Spt – 0.762 2017Apr*upstrm – 0.605 2017Apr*downstrm R^2(adj) = 0.315

(0.000)   (0.000)   (0.027)   (0.013)   (0.067)

Riparian Vegetation Complexity = 3.670 + 1.594 control – 0.912 downstrm – 0.437 2016Spt – 0.492 2017Apr R^2(adj) = 0.309

(0.000)   (0.000)   (0.024)   (0.012)

Aquatic Vegetation Complexity = 3.375 – 0.942 upstrm - 1.600 middle -1.342 downstrm -1.433 2016Spt16 – 0.933 2016Spt*downstrm R^2(adj) = 0.311

(0.001)   (0.000)   (0.000)   (0.000)   (0.001)

Riparian Physical Habitat Complexity = 1.126 – 0.256 2016Spt*upstrm – 0.233 2016Spt*middle – 0.328 2016Spt*downstrm R^2(adj) = 0.152

(0.003)   (0.008)   (0.000)

Channel Physical Habitat Complexity = 1.705 – 0.309 2016Spt R^2(adj) = 0.023

(0.010)