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Assessing the progress of river restoration in the UK: has biophysical condition improved over two decades of intervention?

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Abstract:

Biophysical condition is one indicator of the immediate success of efforts to restore degraded rivers as well as longer-term progress towards improving water quality. In the context of the Water Framework Directive (WFD), the biophysical condition of river systems in the UK also reflects how well international environmental policy translates into improved river management domestically. We assess whether the condition of river systems in the UK has improved or declined over the past two decades, whether regions identified by the first WFD assessment have improved or declined, and thus, how effectively international policy has been implemented nationally. Methods include: statistical and spatial analysis of more than 25,000 habitat condition records collated in the River Habitat Survey over the 1990s and 2000s; computing of an Index of Change for Local Authorities; and comparison of Indices of Change with a sub-sample of 1,727 WFD assessments conducted in 258 Local Authorities. Findings include that three of four measures indicate that biophysical quality has declined, although only decline in one measure (habitat quality) was statistically significant. Riparian quality has improved, although measures do not consider invasive compared to native coverage. In total, 27 regions were identified with the worst declining quality. Comparative analysis of regions suggest that condition has declined most substantially in regions that were previously in 'good' condition. Priorities for future investment include improving degraded sites, protecting high quality sites, and increasing monitoring of 'data poor' regions. Our methodology offers an approach for utilising 'messy' routinely collated data like the RHS. However, guidelines are needed to support the use of similar datasets for the international river restoration community.

1. Introduction

Many of the biggest environmental challenges facing societies involve managing resources in river basins, and mitigating the negative impacts of development and emerging threats, such as water over-extraction (Kingsford, 2000; Palmer et al., 2008), declining water quality (Dawson et al., 2015; Lutz et al., 2016), contaminants (Coulthard & Macklin, 2003; Macklin et al., 2006) and habitat loss (Reid et al., 2019). Over the past three decades, the central purpose of river management has shifted from more utilitarian services, such as flood management involving significant morphological changes (Tompkins & Kondolf, 2007), towards ecological protection, enhancement, and restoration (Bernhardt et al., 2007). Records of river restoration projects collated in the UK National River Restoration Inventory (NRRI) (River Restoration Centre, 2020) demonstrate that the number of river restoration projects established increased dramatically during the 1990s and has continued to rise: 38 projects were established prior to 1990, 510 projects were established between 1990 and 2000, and 2,080 projects were established between 2000 and 2010. This trend is consistent with international agendas, such as the introduction of the European Union Directives, including the Water Framework Directive (WFD) and Habitats Directive (Ormerod, 2004).

River restoration projects involve designing and implementing infrastructure and practices to address degradation, such as revegetation to improve the biophysical condition of river systems, including ecological and hydromorphological condition (Wohl et al., 2015). Other common river restoration projects include building fish ladders on dams to promote fish migration and breeding (O'Brien et al., 2010), constructing fences on riverbanks to prevent cattle access to improve water quality and reduce bank erosion from trampling (Brooks & Lake, 2007; Kondolf et al., 2007), and reintroducing woody debris to river channels to improve riverbed morphology (Erskine & Webb, 2003). After three decades of investment in such projects, river researchers recognize the need to monitor and assess the biophysical condition of riverine environments in order to advance the field of river restoration (Bernhardt et al., 2007; Kondolf et al., 2007; Morandi et al., 2014).

Monitoring, assessment and record-keeping post-restoration is not straightforward; some elements of biophysical improvement are more difficult to measure than others. For example, water quality improvement can take years or even decades to occur in response to restoration projects (Hamilton, 2012; Meals et al., 2010). This is because instream recovery trajectories are influenced by land use in wider catchments as well as individual projects; the impact of restoration is cumulative. Other approaches to monitoring and assessment involve measuring biophysical components of restoration with more immediate recovery trajectories, such as vegetation condition. Compared to instream conditions which may require decades for measurable recovery, vegetation condition can improve substantially within ordinary project monitoring timeframes of between 5-10 years (Moore & Rutherfurd, 2017).

Common challenges for monitoring and assessing the progress of river restoration are related to data quality, including recording errors (taxonomic and transcription), and inconsistent data collection between multiple surveyors over time (Vaughan & Ormerod, 2010). These issues transcend individual river basins or countries. National assessments of the progress of river restoration have been conducted in regions including North America (Bernhardt et al., 2005, 2007; Palmer et al., 2010) and Australia (Brooks & Lake, 2007; Moore et al., 2018; Moore & Rutherfurd, 2017) using databases of projects established over the past 30-50 years. For example, in 2005 a project was undertaken in the United States of America to summarize and assess the progress of river restoration. The result was a database, the National River Restoration Science Synthesis (NRRSS), including records of more than 37,000 projects compiled from more than 60 national and regional sources and agencies. Of these records, only 10% included any mention of monitoring (Bernhardt et al., 2005), and little information was found related to the ecological effectiveness of restoration (Palmer et al., 2007). Similarly, of more than 5,000 river restoration projects recorded in the UK National River Restoration Inventory (NRRI), only 21% of records indicated that follow-up monitoring and assessment of existing projects has been undertaken (England et al., 2019), and where monitoring had been undertaken, results were often inconsistent (Smith et al., 2014).

Despite these limitations, Vaughan & Ormerod (2010) suggest there is considerable value in analysing large regional or national datasets as the size, geographic and temporal spread of the data, are likely to overcome many of the weaknesses associated with data quality. Here we report our analysis of a comprehensive national dataset collated between 1994 and 2008 by multiple organisations, although primarily the UK Environment Agency (EA) including more than 25,000 assessments of habitat condition in river basins, known as the River Habitat Survey (RHS). This dataset was collated over two periods; the first was 1994 and 1996 and the second period was between 2007 and 2008. The RHS was undertaken to build a national inventory of habitat features, and to assess the condition of river habitats after two decades of investment in river restoration projects (RHS, 2018). The RHS was not intended to monitor or assess the effectiveness of individual river restoration projects. Rather, the purpose was to examine the overall outcomes of coordinated efforts to improve the morphological and biophysical condition of degraded river systems. Several noteworthy studies have drawn on the NRRI database including records of river restoration projects in the UK to consider trends in river restoration techniques (e.g. Cashman et al., 2019), and the RHS database of habitat condition assessments to examine the relationship between river restoration projects and channel morphology (Smith et al., 2014). These studies have demonstrated that reduction methods, such as collapsing or averaging data across multiple sites within a region, can be used to make meaningful use of ecological measures which are inconsistent or incomplete across the entire dataset (e.g. Moore & Rutherfurd, 2019; Smith et al., 2014).

Assessing whether the biophysical condition of river basins has improved over two decades of restoration is necessary to identify successful strategies and potential challenges, thus advancing the field of river restoration (Kondolf et al., 2007). However, the need to evaluate progress in the UK is also apparent in the context of international environmental policy, including the European Union Water Framework Directive (WFD). The WFD was introduced in 2000, including the first assessment of UK river systems that involved scoring habitat condition as 'high', 'good', 'moderate', 'poor' or 'bad'. Assessment scores are recorded in the NRRI database. Of 1,727 habitat quality assessments conducted, 36% of sites were in 'poor' or 'bad' condition, 49% were in 'moderate' condition, 32% were in 'good' condition, and only one site was considered to be of 'high' quality. Two decades later, policymakers are considering whether international efforts to guide restoration in river basins has been successful. Restoring habitat for wildlife, improving the ecological condition, and achieving clean and plentiful water are also important national priorities and form the cornerstones of the UK Government '25 Year Environmental Plan' (DEFRA, 2018). Given the substantial increase in the number of river restoration projects established during the 1990s compared to prior decades, and again following the introduction of the WFD in 2000, it is reasonable for funding agencies to expect that the biophysical condition of river basins has improved.

In this paper we assess the progress of river restoration in the UK using two datasets: the RHS database of habitat condition scores, and condition assessment scores from the first national WFD assessment in the UK. To date there has been no comprehensive analysis of the progress of river restoration in the UK with regards to observable changes in biophysical condition. Our approach is two-fold. The first purpose of the research was to compare the scores from River Habitat Surveys conducted in the 1990s to those assessments conducted in the 2000s to determine whether change has occurred, and if change reflects improved or worsening biophysical condition.

The RHS database includes six measures of habitat condition, four of which are included in our research: Habitat Quality Assessment (HQA) including measures of flow type, channel substrates, and vegetation structure; River Habitat Quality (RHQ)including the conservation value of river habitat; Riparian Quality Index (RQI) including complexity, continuity and naturalness of the riparian vegetation, and; Hydromorphological Impact Ratio (HIR) including channel substrate, channel vegetation and geomorphic activity characteristics (see Table 1 for a detailed description of each measure). In the absence of widespread monitoring and assessment of individual river restoration projects, this unique dataset offers the opportunity to explore the effectiveness of river restoration on a national scale. We computed an 'Index of Change' to examine whether the average scores recorded for four of these measures within UK Local Authority (LA) regions have changed between the rounds of assessment conducted in the 1990s and those conducted in the 2000s. This analysis involved employing data reduction methods (Moore & Rutherfurd, 2019) to overcome limitations, such as the fact that the number and location of sites assessed in each Local Authority (LA) vary between datasets collated in the 1990s and those collated in the 2000s.

The second purpose of the research was to explore whether changes in the biophysical condition of riverine environments over the past decade represent an improvement since the first WFD assessment of habitat and water quality. The time between the WFD assessment and the second round of RHS assessments is sufficient for some visible improvements in biophysical condition to occur, such as vegetation establishment, while other forms of condition improvement may take substantially longer (Moore & Rutherfurd, 2017). Our analysis involved comparing measures of biophysical condition from two different datasets; we compared WFD scores from the first national WFD assessment with habitat condition scores from the second round of RHS condition assessment. This approach allowed us to identify whether regions with 'poor' or 'bad' habitat quality have improved or declined, and to reflect on how well the river restoration sector is supporting ambitious international policy. Following this analysis, we offer some suggestions for optimizing the outcomes of river restoration and achieving the objectives of international policy, including improving habitat quality.

2. Methods

The research involved an assessment of habitat condition data collated in the RHS database, and WFD condition scores. Three main research methods were utilized to address our research questions; statistical computation of an Index of Change, spatial visualization of the Index, and ground-truthing of RHS assessments. Ground truthing surveys were carried out in the summer of 2019 (28/8/19) to verify our understanding and interpretation of RHS data and measures. The methods and results for ground truthing are reported in supplementary material (S-1).

2.1 Research Aims and Questions

The first aim of the research was to assess the records collated in the RHS database and determine whether change has occurred between the 1990s and 2000s across four of six habitat quality measures recorded in the RHS undertaken by the EA. This involved computing and mapping an Index of Change to identify which LA regions could be a high priority for future restoration efforts. The second aim was to compare the assessment of habitat condition undertaken in accord with the WFD with measures recorded in the RHS throughout the 2000s, specifically to determine whether regions with sites in 'moderate', 'poor' or 'bad' condition have improved, and whether regions with sites in 'good' or 'high' condition remain in these conditions.

2.2 Data handling and cleaning

To determine whether biophysical condition has improved over two decades of river restoration in the UK, we examined four of six measures of habitat condition collated in the RHS database; Habitat Quality Assessment Index (HQA), River Habitat Quality (RHQ) Index and Riparian Quality Index (RQI).

To examine whether biophysical condition has improved since the first WFD assessment, we computed an average WFD score for all site condition assessments conducted for LA regions and compared our Index of Change, computed from RHS scores, with WFD scores. For some LAs, scores were only recorded in the RHS database and not the WFD database. Thus, we reduced the combined dataset to include only LA regions with scores in both databases; in total, 258 LA regions (of a total 404 LA regions across the UK) were included in the final analysis, comprising 1,727 WFD assessments.

2.3 Measures

River Habitat Surveys

The River Habitat Survey (RHS) follows a context analysis approach based on Principal Component Analysis plots (Jeffers, 1998). The RHS database contains more than 25,000 records of assessments undertaken between 1997 and 2011. Data were collected under the long-term monitoring project managed by the Centre for Ecology and Hydrology, Lancaster, UK. Each assessment was conducted by surveyors accredited by the EA, including EA staff, local authorities, and members of private agencies. The original survey was designed and run by the National Rivers Authority, then EA. The EA trained and accredited several hundred RHS surveyors. From 1994 to 1996 and from 2007 to 2008, 9,000 RHS sites in England and Wales were selected using a stratified random sample design. Sites in Scotland and Northern Ireland were included in surveys conducted in the 1990s but were discontinued in the 2000s. Sampling of both the 1990s and 2000s assessments were based on the 250k scale river network. Sites were selected using the Ordnance Survey (OS) 10km grid. For the 1990s assessment round three 2km^2 grids were selected randomly within each 10km square resulting in a total of 4523 sites. In 2007-8, the same process was repeated including two rather than three sites within the same 250k network, as well as one site outside the 250k network to represent headwater streams which were under-represented in the previous sample. The remaining sample of more than 1,500 sites were selected following a near-random process for the purpose of targeting priority rivers and catchments across the UK. Thus, while assessments were conducted at different specific locations, most assessments across both time periods were conducted along 500m of river network at sites within the same grids (Furse et al., 2016).

Conducting the RHS involved recording morphological and ecological features, including bank and channel structure, artificial modification, surrounding land use, and vegetation structure, along a 500m reach of a priority river in the UK (Environment Agency, 2003). Measures of these features were collated into four scores and indices represented by five discrete five-point Likert-type scales. The characteristics, methodology and calculation of the individual indices for habitat quality and hydromophological indices are summarised in Table 1. For the Habitat Quality Assessment (HQA) and Riparian Quality Index (RQI), the scale of 1-5 reflects a progression from poor condition to good condition. For the River Habitat Quality (RHQ) index and Hydromorphological Impact Ratio (HIR), the scale of 1-5 is inverse, with 1 representing a good condition and 5 representing a bad condition (River Restoration Centre, 2020).

Our analysis included 4 of 6 measures included in the RHS. Two measures, Habitat Modification Score (HMS) and Channel Re-sectioning Index (CRI) were excluded from our analysis for two reasons. Firstly, in most cases, modification infrastructure, such as dams, and modification processes, such as channelization, are unlikely to have been removed or reversed over the period of data collection considered in our research. In the UK, barrier removal, including dams and weirs, and channel remeandering projects, are much less common than projects that involve revegetation for ecological restoration. Of nearly 5,000 restoration projects undertaken in the UK over the past three decades, approximately 1,100 projects have involved barrier removal and less than 100 have involved re-meandering (NRRI dataset, River Restoration Centre (2018)), while approximately 40% involve ecological restoration and revegetation.

Secondly, ideally, a Before-After research design involves comparing two scores from the same site. The RHS assessments conducted in the 2000s were undertaken at different sites compared to those undertaken in the 1990s. However, sites were chosen from within the same grid (see above) for both rounds of assessment. Thus, we used a data reduction method to compute an average score for each measure at the Local Authority scale. While imperfect, data reduction of this nature is a common approach for analysing some large-scale physical data in river basins, such as vegetation condition and habitat quality (e.g. Moore & Rutherfurd, 2019; VCMC, 2017). In the case of habitat and riparian condition measures, multiple vegetation measures were taken along 500m reaches at different sites within the same grid. Vegetation condition at one site may reasonably be assumed to reflect vegetation condition at nearby sites. Thus, data reduction can offer meaningful insight (Smith et al., 2014). However, in the case of physical modification, it is impossible to compute an average score when one site within a grid may contain a dam wall while other nearby sites may not.

Table 1. RHS habitat quality and hydromorphological indices (River Restoration Centre, 2020). Note for ranges, green signifies positive end of the range, red signifies negative end of the range.

RHS index	Range	Description	Measures	Calculation of index
Habitat Quality Assessment score class (HQA)	1 (very low) to 5 (very high)	The presence, diversity and naturalness of habitat features that are known to benefit local wildlife compared to similar sites.	Flow types, natural channel substrates, natural channel features (e.g. mature islands), natural bank features (e.g. earth cliffs), bank vegetation structure (simple or complex), point bars, in-stream channel vegetation, land-use within 50m, trees and associated features, special features (e.g. debris dams).	Sub scores are given to features observed in each of the categories based on the presence of features with higher scores given to features that are considered more 'natural'. Sub scores are collated to produce a final score.
River Habitat Quality (RHQ) index	1 (excellent) to 5 (very poor)	The overall habitat quality and conservation value.	Management prioritisation resulting from this index range from 1(protect) to 5 (restore).	HQA and an additional Habitat Modification Score (HMS) are amalgamated into one index and compared against benchmark (high quality) sites in terms of distance of the HQA score to the nearest benchmark site using context analysis.
Riparian Quality Index (RQI)	1 (very low) to 5 (very high)	The complexity, continuity and naturalness of the riparian vegetation (area stretching from the riverbank face to 5m away from the bank top).	Complexity: vegetation structure (e.g. uniform/bare to complex). Continuity: how contiguous the vegetation is. Naturalness: Evidence of modification.	Sub scores are given to each of the categories for complexity, naturalness and continuity (max 60, 40 and 20 points respectively). Scores are collapsed to a final score between 1 and 5. Higher scores correspond to better riparian quality.
Hydromorphological Impact Ratio (HIR)	1 (low impact) to 5 (very high impact)	The extent of departure from natural hydromorphological conditions.	Hydromorphological characteristics considered include channel substrate, flow regime, channel vegetation and geomorphic activity characteristics.	The index is measured as a ratio and translated into a 5-point scale.

Water Framework Directive assessments

The WFD habitat quality assessment follows the same methodology as the RHS, including measuring habitat modification and habitat quality, with a visual assessment of hydromorphological features. We used the WFD habitat quality measures to assess whether biophysical condition has improved in regions identified through the WFD assessment as 'very poor', 'poor' and 'moderate', and whether those regions considered to be in 'good' or 'high' quality have remained so over the decade following the WFD assessment. Thus, research question one considers change in four measures of habitat condition over two decades of river restoration, while research question two considers whether a single measure, habitat quality, has improved since the introduction of the WFD.

2.4 Data analysis

Statistical analysis

Four t-tests were computed to address our first research question about whether biophysical condition has improved between the 1990s and the 2000s, for the measures HQA, RHQ, RQI and HIR. Four One-Way ANOVAs were computed to address our second research question about whether habitat condition has improved since the first WFD condition assessment. Of 1,727 sites included in the WFD assessment only one was classed 'high' quality and 66 were classed as 'bad' quality. Therefore, we re-classified these data into three categories; 'good', 'medium' and 'poor', whereby 'good' was inclusive of the 'high' quality site and 'poor' was inclusive of the 'bad' quality sites. ANOVA was used to explore whether LAs with on average 'poor' or 'medium' condition at the time of the WFD assessment have improved, and whether LAs with on average 'good' condition continued to be in good condition. This was achieved by comparing our Index of Change scores for HQA, RHQ, RQI and HIR between LAs with sites in 'good', 'medium' and 'poor' condition.

The Index of Change and spatial representation

To identify high-priority regions for future restoration, we computed an Index of Change for each of four RHS habitat quality measures that indicates whether change for each measure was positive, negative, or no change. These indices were used to represent change spatially at the Local Authority scale. This involved five steps. The RHS database contains records of all habitat assessments conducted in the 1990s and 2000s. Records include spatial point data, specifically the Eastings and Northings coordinates for each site where the habitat condition assessment was undertaken. Thus, the first step involved converting these Easting and Northing coordinates to latitude and longitude values (using a standard batch conversion website https://gridreferencefinder.com/batchConvert/batchConvert.php). The second step was to overlay the Easting and Northing on a Local Authority map in ArcGIS, join point data to Local Authority labels, and extract the joined data to produce an excel spreadsheet. For the third step, assessment records were divided by decade for the purpose of computing the Index of Change. The fourth step was data reduction. Average values for each measure were computed at the Local Authority scale. There was some variability for number of assessments conducted in each LA, as demonstrated in S-2. In some cases, comparative analysis was not possible at the LA scale as assessments were not conducted in both the 1990s and the 2000s. Therefore, 4 LA regions were removed from the RHQ index analysis, 8 LA regions were removed from the HIR index analysis, 74 LAs were removed from the RQI analysis. In total, 348 of a total 404 principle LAs in the UK were included in the final analysis. The fifth step was to compute the change index for each measure. For measures including HQA and RQI, this involved subtracting the average LA scores obtained during assessments undertaken in the 2000s from the average score for each LA obtained from assessments undertaken in the 1990s. The outcome was a standardized score for each LA whereby negative values represent a decline in habitat condition, positive scores represent an improvement, and a score of 0 reflects 'no change'. However, the Likert-scale scores for the measure RHQ and HIR were on an inverse scale. Thus, we inverted negative and positive scores to produce a consistent Index of Change, allowing for comparison between each measure, and for visual identification of regions which could be a priority for future investment in habitat condition improvement.

In addition, Mann Whitney U analyses[2] were computed for each LA across each of four RHS measures to determine whether the changes captured by the Index of Change are statistically significant. We did not anticipate that many results would be significant at the LA scale. In most cases, the number of assessments conducted per LA, and the number of assessments conducted for a single LA between the 1990s and 2000s varied considerably. The Index of Change is intended as an indicator of the direction of change across RHS measures. Statistical significance may point to LAs that require particular attention for restoration. However, we do not dismiss non-significant results which may reflect trends ($p<.1$) in the direction of change.

The habitat quality indices HQA, RHQ, RQI and HIR were mapped to display spatial variations. Spatial patterns for each year and the differences between the years were also mapped. In order to compare the habitat indices with one another, the indices were normalized and projected onto one scale. The spatial data pertaining to the habitat quality indices were divided into positive, negative, zero and no data maps and then converted to raster data in order to assign a continuous colour palette within ArcGIS.

3. Results

3.1 Descriptive results

River Habitat Surveys and WFD assessments

In total, the RHS database contained 25,227 assessments, including 13,967 conducted in the 1990s and 11,280 conducted in the 2000s. A total of 1,727 WFD assessments were conducted in 2000. The Means (M) and Standard Deviations (SDs) for HQA, RHQ, RQI, HIR and WFD scores are reported in Table 2.

Table 2. Means (M) and Standard Deviations (SD) for River Habitat Survey measures, including scores (whereby a score of 1 reflects poor condition and a score of 5 reflects good condition) from assessments conducted in the 1990s and 2000s for Habitat Quality Assessment (HQA), River Habitat Quality (RHQ), River Quality Index (RQI), Hydromorphoogical Index Ratio (HIR), as well as scores for Water Framework Directive (WFD) assessments conducted in the 2000s.

	HQA		RHQ		RQI		HIR		WFD
	1990s	2000s	1990s	2000s	1990s	2000s	1990s	2000s	2000s
N	12,301	11,279	12,300	10,563	4,499	4,862	11,840	9,822	1,727
M	3.1	2.88	3.97	4.05	2.6	3.09	3.56	3.63	1.79
SD	.48	.82	.3	.36	.5	.6	.19	.22	.45

The Index of Change

After aggregating RHS records, the Index of Change was computed for 348 LAs. Table 2 reports the means and standard deviations of HQA, RHQ, RQI, and HIR scores for surveys conducted in each of the two time periods (1990s and 2000s). By comparison, Table 3 reports the means and standard deviations of the index we computed to represent the *difference between* scores for surveys conducted in the 2000s compared to those scores computed in the 1990s. The Means (M) and Standard Deviations (SDs) of Index of Change scores for Habitat Quality Assessment (HQA), River Habitat Quality (RHQ), River Quality Index (RQI), and Hydromorphological Index Ratio (HIR), are reported in Table 3. Negative scores indicate a decline in biophysical condition. Positive scores indicate an improvement in biophysical condition.

[2] Non-parametric analyses were selected on the basis that for most LAs the number of assessments conducted in the 1990s compared to the 2000s, and the number of total assessments conducted per LA both vary considerably. In some cases, the number of assessments is less than the minimum required for reasonable statistical power (N=50 for ~70% accuracy).

Table 3. Means (M) and standard deviations (SD) of Index of Change scores for River Habitat Survey measures, including Habitat Quality Assessment (HQA), River Habitat Quality (RHQ), River Quality Index (RQI), and Hydromorphoogical Index Ratio (HIR). Negative values reflect condition decline while positive values reflect condition improvement.

	HQA	RHQ	RQI	HIR
M	-.22	-.07	.5	-.06
SD	.56	.31	1.05	.29

3.2 Has biophysical condition improved between the 1990s and 2000s?

Four t-tests were computed to determine whether biophysical condition has improved by comparing scores from habitat assessments undertaken in the 1990s with scores from those assessments undertaken in the 2000s.

The results for the t-test computed to compare index values for the measure 'Habitat Quality Assessment' (HQA) indicate that on average, index values from assessments conducted in the 2000s (M = 2.88, SD = 0.82) are lower than scores from assessments conducted in the 1990s (M = 3.10, SD = 0.48), t(710) = 1.96, p = 0.00. Low scores reflect poor habitat quality while high scores reflect good habitat quality. Thus, HQA measures suggest that habitat quality has declined.

The results for the t-test computed to compare scores for the measure 'River Habitat Quality' (RHQ) indicate that there is no significant difference between scores from assessments conducted in the 2000s (M = 4.04, SD = 0.36) and those conducted in the 1990s (M = 3.97, SD = 0.3), t(702) = 1.96, p = 0.08.

The results for the t-test computed to compare scores for the measure 'Riparian Quality Index' (RQI) indicate that scores from assessments conducted in the 2000s (M = 3.09, SD = 0.58) are higher than scores for those assessments conducted in the 1990s (M = 2.59, SD = 0.49), t(282) = 1.96, p = 0.00. This suggests that condition has improved in relation to RQI measures.

The results for the t-test computed to compare scores for the measure 'Hydromorphological Impact Ratio' (HIR) indicate that there is no difference between scores from assessments conducted in the 2000s (M = 3.63, SD = 0.22) and those assessments conducted in the 1990s (M = 3.6, SD = 0.18), t(694) = 0.06.

3.3 Which Local Authority regions are a high priority for future restoration efforts?

Indices of Change were computed for four of the RHS quality measures to demonstrate if there was a positive, neutral or negative change for each measure between the surveys conducted in the 1990s and 2000s. In addition, the statistical significance of these changes for each LA across all four RHS measures was determined using non-parametric analyses of medians. A total of 369 Mann Whitney U tests were computed for each of the four RHS measures to investigate whether the differences observed between scores from assessments conducted in the 1990s and scores from assessments conducted in the 2000s were statistically significant. Individual Mann Whitney U tests results are reported in Supplementary Material (S-3) and summarised in Figure 1 which displays the percentage of scores falling within each change category for the RHS measures. The solid colour component of the bar chart shows the proportion of all records of LAs where habitat condition has worsened (red), improved (green), or where no change has been observed (orange). The dotted component of the bar chart shows the proportion of all LAs where a statistical result was computed for the Mann Whitney U Test. The diamond pattern component of the bar chart shows the proportion of Mann Whitney U Test computations for which it was not possible to compute a statistical result due to small sample size.

The results of the t-tests conducted to determine whether habitat condition has improved are further reflected in the Index of Change scores. The results indicate that RQI has the largest percentage of positive changes across local authority regions (52.13%) and smallest negative changes (16.31%).

Conversely, percentages across the HQA measures indicate the largest frequency of negative changes across Local Authority regions (64.89%) and smallest positive changes (21.35%).

-- Figure 1 about here --

Figure 1. Percentage of negative, neutral or positive change scores for RHS quality measures at the Local Authority Scale. Solid coloured bar sections represent change scores with non-significant p-values. Line patterned bar sections represent change scores for which p-values could not be computed. Dot patterned bar sections represent change scores with significant p-values.

The computed Index of Change scores for each RHS quality index were also spatially mapped according to Local Authority regions to identify those regions that are a high priority for future restoration efforts (Figure 2). These results are also reported in Table 4, including the best and worst performing Local Authorities with respect to how much river habitat condition has improved or deteriorated over time. A more detailed breakdown, including those Local Authorities with a ‘neutral’ Index of Change score (‘0’) (supplementary material S-3), and Mann Whitney U tests exploring the statistical significance of differences between scores obtained from assessments conducted in the 1990s compared to scores from assessments conducted in the 2000s are reported in the supplementary material (S-4).

--Figure 2 about here--

Figure 2. Spatial representation of Index of Change for, a) Habitat Quality Assessment (HQA), b) River Habitat Quality (RHQ), c) Riparian Quality Index (RQI) and d) Hydromorphological Impact Ratio (HIR). Green areas represent positive changes, red areas represent negative changes, orange represents no change and white represents areas where there is data missing; no surveys were undertaken in Scotland and Northern Ireland in the 2000s. Darker colours reflect larger changes.

Table 4. Lowest (greatest decline in condition) and Highest (greatest increase in condition) performing local authorities (LAs) according to Habitat Quality Assessment (HQA), River Habitat Quality (RHQ), Riparian Quality Index (RQI) and Hydromorphological Impact Ratio (HIR).

	HQA		RHQ		RQI		HIR	
		Score		**Score**		**Score**		**Score**
Lowest performing LAs	Rushmoor	-2.5*	Na h-Eileanan Siar	-1.4***	Gateshead	-3.0	Bury	-1.3~
	Fife	-2.4~	Mole Valley	-1.1***	East Riding of Yorkshire	-2.0*	Stockton-on-Tees	-0.9~
	South Ayrshire	-2.3~	Hounslow	-1.0~	Lewisham	-2.0*	Liverpool	-0.9~
	Clackmannanshire	-2.3~	Wyre	-0.9***	North Lincolnshire	-2.0~	Hertsmere	-0.8~
	South Lanarkshire	-2.1~	Falkirk	-0.9~	Reading	-2.0~	Copeland	-0.8~
	Derby	-2.1~			Southampton	-2.0~	Luton	-0.8*
	Corby	-2.1~			Thanet	-2.0~		
					Warrington	-2.0*		
					Welwyn Hatfield	-2.0*		
Highest performing LAs	Falkirk	2.1~	Dartford	1.4~	Carlisle	3.0***	North Tyneside	1.3~
	Slough	1.5~	Merthyr Tydfil	1.2**	Craven	3.0***	Hastings	1.0~
	Brentwood	1.3~	Erewash	0.9~	Redbridge	3.0*	Elmbridge	0.9~
	Gloucester	1.2~	Dudley	0.7*	Stockport	3.0*	Havant	0.9~
	Kingston upon Thames	1.0~	Kingston upon Hull, City of	0.7~			Brent	0.8~
	Lincoln	1.0~						
	Oadby and Wigston	1.0~						

*non-significant change
**change significant at p<.05
***change significant at p<.01
~not enough data to compute

3.4 Does change reflect progress following the first WFD assessment?

Four one-way ANOVAs were computed to compare change indices for habitat quality scores between sites categorized in the WFD assessment as ‘poor’, ‘moderate’, and ‘good’ to investigate whether degraded sites have improved, and also whether sites in ‘moderate’ or ‘good’ condition have been maintained to these standards.

Table 4 demonstrates that there was a significant difference in change indices between ‘poor’, ‘moderate’, and ‘good’ sites for the HIR index. There was no difference between change indices in these categories for all other measures.

Table 4. ANOVAs comparing change indices for habitat quality scores between sites categorized in the WFD assessment as ‘poor’, ‘moderate’ and ‘good’ (P<.01)

		df	*F*	Sig. (*p*)
HQA Change	Between Groups	2	.565	.569
	Within Groups	1244		
	Total	1246		
RHQ Change	Between Groups	2	.576	.562
	Within Groups	1240		
	Total	1242		
RQI Change	Between Groups	2	1.572	.208
	Within Groups	950		
	Total	952		
HIR Change	Between Groups	2	5.622	.004
	Within Groups	1238		
	Total	1240		

Table 5 displays the mean change between 1990s and 2000s scores for each measure. Change values for the measures HQA, RHQ and HIR indicate that on average, sites in all categories have declined. For HQA and HIR sites in ‘good’ condition show a larger decline than sites in either the ‘moderate’ or ‘poor’ classes. In contrast, average change values for the measure RQI indicate that all sites in all categories have improved. However, except for HIR, these changes were not found to be statistically significant (Table 5).

Table 5. Mean change between 1990s and 2000s scores for ‘poor’, ‘moderate’ and ‘good’ assessments in the WFD. Positive values reflect improvement and negative values reflect deterioration. Grey shading highlights the changes for Hydromorphological Impact Ratio (HIR) which are statistically significant (P<.01).

		N	Mean	SD
HQA Change	Poor	458	-.24	.52
	Moderate	606	-.1	3.37
	Good	183	-.25	2.37
RHQ Change	Poor	456	-.09	.28
	Moderate	604	-.1	.24
	Good	183	-.07	.29
RQI Change	Poor	329	.29	1.11
	Moderate	482	.43	1.11
	Good	142	.37	1.12
HIR Change	Poor	454	-.0486	.25
	Moderate	604	-.0865	.25
	Good	183	-.1143	.22

4. Discussion

4.1 Has biophysical condition improved?

The River Habitat Surveys conducted in the 1990s were intended to provide a baseline for future habitat quality assessment, and a basis for monitoring future biophysical changes (Raven et al., 2000). Given efforts to restore degraded systems over the past two decades, including increasing investment in river restoration, the agencies involved might reasonably expect that some elements of habitat condition have improved. Our analyses of surveys undertaken in the 1990s and in the 2000s suggest that overall, habitat quality has significantly declined (HQA) while riparian quality has significantly improved (RQI). No change was observed for measures of River Habitat Quality (RHQ) and Hydromorphological Impact Ratio (HIR). On average, RHQ scores across both periods of assessment were high, indicating poor conservation value and suggesting the need to restore degraded sites for the purpose of providing habitat for native species. Average HIR scores were also high, indicating significant departure from natural conditions related to hydromorphology, such as channel substrate, flow regime, and geomorphic activity.

Our finding about the decline of habitat quality reflects wider trends observed across the UK. For example, Carey et al. (2008) observed a decline in the biological condition of freshwater environments between 1996 and 2007. Similar trends have been reported elsewhere in Europe, including river habitat loss in France Austria and the Netherlands (Aarts et al., 2004), and the severe decline of floodplain vegetation in Germany (Krause et al., 2011).

Figure 2 demonstrates that HQA scores vary less than other measures; habitat quality has declined in most LAs. In contrast to habitat quality, our results about riparian quality are inconsistent with wider research about the declining quality of riverine vegetation (Carey et al., 2008); our findings suggest that riparian quality has significantly *improved* across the UK. One explanation for this is that riparian vegetation responds more rapidly to restoration efforts compared to other measures of habitat quality, such as in stream condition (Moore & Rutherfurd, 2017). However, how riparian quality is measured using the RHS should also be taken into consideration. During our ground-truthing exercise we observed that sites with high scores for riparian condition were often characterised by a high proportion of invasive species cover. Our observations are supported by Cary et al. (2008) who found that the abundance of invasive species, compared to native species, has increased across UK countryside's between 1998 and 2007.The RQI index scores the naturalness, continuity and complexity of riparian zones (River Restoration Centre, 2020). Importantly, this approach distinguishes between denuded and vegetated riverbanks but does not account for whether species occurring in the riparian zone are native or invasive. For example, a stretch of riverbank may be scored highly for complexity and continuity based on the presence of multiple invasive species, such as *Impatiens glandulifera* (Himalayan balsam) despite the absence of native species that comprise healthy habitat. This oversight reflects a more general challenge within the river basin management industry. Measures of riparian improvement tend to focus on the function of vegetation for morphological condition, such as bank stabilization. Where biophysical and ecological condition is taken into account measures are often limited to single processes or features, such as vegetation structure and continuity (de Sosa et al., 2018). As such, the full complexity of ecosystems are rarely assessed (England et al., 2019).

River restoration in the UK is guided by best practices (River Restoration Centre, 2014), including methods for riparian management which are well documented (de Sosa et al., 2018; Mercer et al., 2014; Vidon et al., 2019). Monitoring and assessment feeds back into the design and implementation of future projects, and the evolution of best practices in response to the changing dynamics of river systems. Using measures that do not reflect key elements of biophysical or ecological condition, such as the proportion of exotic compared to native vegetation (Hulme & Bremner, 2006), constrains the usefulness of the RHS as an assessment tool, and presents a challenge for determining the true condition of riparian areas in the UK.

In summary, our results suggest that no significant change has occurred to overall habitat quality and hydromorphological conditions over the two decades examined. These findings may reflect the historic legacy of earlier river management and more recent land use change. It is likely that major morphological changes occurred prior to the period of examination, and, in many locations conservation value has been permanently degraded by land use change, such as urbanisation (see Section 4.2 below). However, morphological recovery typically occurs over longer timeframes than ecological recovery (Moore & Rutherfurd, 2017). In addition, our observations about assessing riparian condition are indicative of shifting priorities in river management, rather than a reflection of poor methodological design. In the early days of the river restoration movement, a central goal in the UK (Harper et al., 1999), America (Bernhardt et al., 2007) and elsewhere (Hubble et al., 2010) was revegetating denuded and degraded riverbanks. In this context, measuring vegetation cover without distinguishing between exotic and native species has been an effective way of assessing morphological recovery, such as bank stabilization and erosion control. After two decades of practice and policy, the goals of restoration have diversified and include enhancing biodiversity. Invasive species in riparian zones out-compete native species in riverine ecosystems, transform nutrient cycling and alter interspecific interactions related to the habitat function of vegetation (Robertson & Coll, 2019). Thus, there is a need to revisit the measures and criteria for riparian quality included in the RHS. Future assessments could distinguish between genuine improvements in riparian condition and increased vegetation cover related to the spread of invasive species.

One further observation is that while the RHS was designed to measure overall habitat condition, our findings indicate that there is little relationship between measures; habitat and vegetation condition has declined while hydromorphological and geomorphological condition does not appear to have changed substantially. These trends reinforce the notion that different pressures drive ecological, compared to morphological, changes (Leigh & Sheldon, 2008; Stecca et al., 2019).

4.2 Regional priorities for future restoration and investment

Based on our analysis of aggregate RHS scores within local authorities, we have identified 27 local authorities in which condition has declined between initial assessments conducted in the 1990s and the most recent round of assessments conducted in the 2000s. However, in most cases change was not statistically significant. We conducted analyses to determine whether change was statistically significant for each LA across all four measures of habitat condition. For each measure, a proportion of analyses could not be computed due to small sample size below the threshold for statistical power (N=50 per LA). These proportions were: 17% for HQA, 21% for RHQ, 19% for RQI and 35% for HIR. Thus, on average less than 23% of all Index of Change scores were unable to be analysed statistically. Further, of Index of Change scores that were computed, less than 20% of changes proved to be statistically significant. Those changes that were significant were exclusively cases where change was either 'positive' or 'negative'; no cases of 'no change' were significant. Thus, while the changes reported here reflect trends and can serve as interim measures of progress towards longer-term restoration goals, our findings should be interpreted cautiously.

The most notable changes are a decline in measures of HQA, related to habitat diversity and naturalness (see Table 1 for further details), and RQI, related to riparian vegetation quality and complexity, with an Index of Change range of between -2 and -3. Thus, while riparian quality has improved overall, the degree of decline in some regions has been substantial. By comparison, changes to measures of HIR, related to hydromorphological conditions, and RHQ, related to the extent of modification (e.g., channelization and instream infrastructure), were more moderate with an Index of Change range of between -0.8 and -1.4. These findings are consistent with our observations above, that the morphological characteristics of rivers and streams, such as channel form, have undergone less significant transformations over the past two decades compared to the ecological characteristics, such as vegetation diversity. These trends reflect the historic legacy of channel modification in the UK; most major morphological and infrastructural changes to river systems took place in the early 19th century. Compared to past eras, channelization, impoundment and diversion is rarely undertaken in contemporary times. In contrast, ongoing development continues to degrade native vegetation and reduce habitat quality in rural (Ridding et al., 2020) and urban (McKinney, 2008) landscapes. Thus, improving habitat and vegetation quality, complexity, and naturalness should be key criteria for prioritising regional investment in future river restoration projects. Giving precedence to biophysical and ecological condition would also support efforts to improve water quality and achieve the objectives of the WFD.

Importantly, the nature of declining habitat condition, and the probable causes of decline, are highly place-specific, as demonstrated by the four maps presented in Figure 2. For example, differences in Index of Change scores between regions along the east coast may reflect the characteristics of economic activity. A case in point is the Humber Estuary on the north east coast. The estuary borders the East Riding of Yorkshire and Lincolnshire and is the site of a Ramsar wetland as well as three large trade ports. Our Index of Change scores indicate that these regions have experienced some of the most severe declines in habitat condition between the 1990s and 2000s. The northern border, Yorkshire, has experienced habitat diversity decline (HQA) and increased modification (RHQ). By comparison, the southern border of North Lincolnshire has experienced an improvement in habitat diversity and naturalness and no change to modification. In both cases, riparian vegetation quality has declined markedly. However, habitat loss and modification in the Yorkshire region compared to habitat improvement and no change to modification in North Lincolnshire reflects the degree of economic activity around ports; the port of Hull in Yorkshire services a significantly larger urban area than the ports of Grimsby and Immingham in North Lincolnshire. Thus, the wider economic landscape and urban dynamics, among other factors, are likely to influence the progress of river restoration and habitat condition (McKinney, 2008). These trends may also reflect development in urban landscapes over the past two decades that impact habitat quality.

Exploring the complexity of local factors that explain declining habitat quality across the UK is beyond the scope of the current paper. Further research, including case studies of high-value regions, is needed to elucidate the relationship between habitat quality and factors including economic activity, urbanisation and rurality, as well as institutional arrangements such as the financial capacity of responsible agencies to invest in the establishment and ongoing maintenance of restoration projects (Moore & Rutherfurd, 2017). However, we have some suggestions for prioritising future investment into restoration efforts. Others have presented guidelines and recommendations for selecting sites and projects for establishing river restoration projects to optimise ecological benefits (Jansson et al., 2007), minimise immediate and long-term costs (Moore & Rutherfurd, 2017), as well as balancing social, economic and environmental values (Beechie et al., 2008). We emphasise the importance of a catchment-wide approach to identify the 'upstream', or underlying causes of declining habitat quality. In some cases, such as regions with rising population, habitat loss may be the irreversible consequence of urban development. In other regions where population and infrastructure remain relatively stable, there may be more realistic opportunities for habitat improvement.

We suggest that there are three equally important priorities for future investment to improve habitat condition and meet the requirements of the WFD regarding water quality. The first priority is to protect the condition of regions with high-quality sites. The second priority is to improve the condition of regions with degraded sites that a) optimise biophysical benefits and, b) where the causes of degradation can realistically be mitigated by river restoration strategies and projects. Smith et al. (2014) suggest that interventions that target ecological compared to morphological characteristics of river systems are more suited to higher energy compared to lower energy conditions respectively. Further, projects are more likely to succeed on less heavily modified reaches. These principles should guide future investment in improvement. The third priority is to focus monitoring and assessment efforts in regions that are relatively 'data poor' such as where too few assessments have been conducted for statistical analysis of change between the 1990s and 2000s to be computed reliably. A particular focus on improving the reliability of HQA and HIR measures would increase our understanding of national habitat quality trends.

Prioritising river restoration is a balance between identifying opportunities to protect and improve biophysical condition and ecosystem functions and services, and pragmatism. Of those 27 Local Authorities identified where habitat condition has substantially declined over the past two decades (Figure 2), some may be more appropriate sites for future investment in restoration, while others may benefit from increased monitoring and assessment to determine the direction of change. Figure 3 presents a decision-making framework to inform investment with regards to sites where habitat quality has substantially declined.

---Figure 3 about here--

Figure 3. Schematic decision-making framework for prioritising investment in local authority regions where habitat quality has declined between RHS assessments conducted in the 2000s compared to RHS assessments conducted in the 1990s.

The habitat condition dataset examined in this research offers an important opportunity to gain insight into the progress of river restoration efforts over the past two decades towards improving habitat condition, including the quality of riparian vegetation and the morphological characteristics of river channels. However, landscapes and land use, particularly in urban areas, are changing rapidly. To accurately interpret our findings there is a need to consider the wider economic and social landscape of regions where habitat condition has improved compared to regions where condition has worsened or remained in a poor condition. It is likely that some negative Index of Change scores point to genuine opportunities to improve habitat quality, and over the longer term improve water quality. In other cases, scores may be indicative of major land use changes that are difficult to address through traditional river restoration strategies, and rather fall into the jurisdiction of urban planning. Similarly, it is likely that some improvements indicated by positive Index of Change scores reflect genuine successes of the river restoration sector, while others may more accurately signify areas where urban development is less viable and passive recovery, particularly of riparian vegetation, has occurred. Further, in some cases the changes observed in the dataset are the result of 'data poverty'. Unpacking these dynamics should be a priority for future research, as well as a means of allocating resources to improve habitat quality and achieve the objectives of the WFD in the UK.

4.3 Achieving the objectives of the WFD

Overall, our findings suggest that habitat quality has declined in the UK since the first WFD assessment. However, except for HIR, no other statistically significant changes were observed between the first WFD assessment and aggregate measures of habitat condition from assessments undertaken in the 2000s. For measures of HIR, the average condition of sites in regions scored in the WFD assessment as 'good', 'moderate' and 'poor' condition has declined, with the largest decline occurring in regions with sites previously scored as 'in good condition'. Thus, the challenge for future river management is two-pronged; improving degraded sites as well as preserving high-quality sites. These findings are consistent with parallel measures of river quality. For example, a recent assessment undertaken by the Environment Agency, including pollutants, water quality and the number of small animals found in rivers found that only 14% of rivers meet the Good Ecological Status outlined in the Water Framework Directive (Bevan, 2020). The HQA index analysed in our research refers to overall habitat diversity in stream considering natural channel features that are conducive to supporting habitat diversity. Thus, our observations reflect the results of the EA assessment about the structure and functioning of riverine ecosystems (European Environment Agency, 2018). Our observations about how well restoration efforts are achieving the objectives of the WFD in relation to habitat condition in the UK are not unique. Many regions in Europe are struggling to effectively implement the WFD, with key challenges including economic viability and the difficulties associated with multi-level governance (Berbel & Expósito, 2018; Bouleau, 2008; Maia, 2017). Further research is required to elucidate the institutional factors that may explain the decline of habitat quality in the UK compared to condition at the time of the WFD assessment in 2000.

4.4 Strengths and limitations

The UK river restoration sector is incredibly data rich. However, there are inherent challenges with retrospectively analysing 'messy' routinely collected observational data, such as the habitat condition database presented here. There is a need to develop consistent guidelines for the use of observational data in the river restoration sector. This study does not represent a controlled trial or an experimental 'before/after' study design in the truest sense. Few changes at the LA scale are statistically significant. Further, our study does not consider other factors that influence biophysical condition, such as the wider characteristics of river basins, including land use and degree of urbanisation or rurality. Thus, interpreting our results requires a balance of caution and optimism; our findings reflect wider trends in water quality and resource condition documented elsewhere (e.g., Aarts et al., 2004; Carey et al., 2008; Krause et al., 2011) . However, our findings regarding 'worst' and 'best' condition LAs should be considered cautiously. The need for caution does not diminish the value of analysing observation datasets (Vaughan & Ormerod, 2010), but, rather, points to future avenues for improving data collection.

In most cases, the sites assessed within an LA during the 1990s assessment period were different to the sites assessed within the same LA in the 2000s, although the majority of assessments across both periods were conducted within the same grids. Therefore, we aggregated the Index of Change scores within LAs for comparative analysis. While aggregation reduces the complexity and richness of the dataset, this approach is not unprecedented (e.g. Moore & Rutherfurd, 2019; VCMC, 2017). Monitoring and assessment are rarely conducted empirically or consistently within or between regions (Bernhardt et al., 2007; Kondolf et al., 2007). Some degree of aggregation or collapsing is usually required to make regional comparisons. In the case of vegetation condition, aggregate measures from nearby sites are likely to be meaningful (Smith et al., 2014). Aggregate measures of hydromorphological condition may be less indicative of change, which may explain the non-significant results reported above. However, the observed trends are consistent with wider landscape change and the history of channel morphology in the UK.

A further challenge of using the RHS data to explore the progress of river restoration in the UK is the characteristics of measures. In particular, the RQI related to riparian vegetation does not distinguish between native versus invasive species. Thus, while an indicator of morphological recovery (e.g., bank stabilisation) it is difficult to determine the ecological value of riparian vegetation.

To counteract the limitations of aggregation, we integrated spatial and statistical analysis, facilitating a more in-depth interpretation of the Index of Change. Visually displaying the RHS data allowed us to examine spatial trends that are not immediately apparently from statistical analysis alone. Spatial analysis illuminated important geographic differences between regions with negative Index of Change scores across different measures of habitat condition.

5. Conclusions

A critique of the early decades of river restoration in Europe is a lack of strategy and coordinated investment to improve the condition of degraded environmental assets (Szałkiewicz et al., 2018). After more than three decades of implementation there is a need to assess progress in order to facilitate more targeted investment in high-valued ecological services and features of natural landscapes. Domestic efforts to restore degraded ecosystems encompass the dual challenge of implementing projects that satisfy national priorities at the same time as achieving the goals of international initiatives, such as the WFD (Wharton & Gilvear, 2007). In the wake of BREXIT, the endeavours and commitments set in motion by the European Union remain a cornerstone of best practice that should be honoured and upheld. We evaluated trends in habitat condition over two decades in the UK to determine whether restoration projects are having the desired effect on riverine ecosystems. We make four observations from this analysis: firstly, habitat quality has declined while abundance of riparian cover has increased; secondly, while the legacy of river modification has severely impacted both the biophysical and geomorphological characteristics of habitats, biophysical conditions may have declined to a greater degree in recent years. However, ecological changes can occur over shorter periods than morphological changes. Repeating our analysis in the future will be necessary to detect positive or negative changes that are likely to require much longer timeframes to emerge; thirdly, change in condition has not progressed in the desired direction since the initial assessment conducted under the WFD; and fourthly, these trends are not homogenous – some regions have declined more substantially than others.

Finally, we offer some guidance to optimise the benefits of future investment to improve habitat and water quality. As a preliminary step, further local and regional scale research is needed to address the current data deficit in many LAs, and to elucidate the underlying causes of condition decline. Where possible, efforts should be targeted to further investigate why condition has declined in some regions compared to others, and to establishing best management catchment practices to address declining condition. However, in some cases degradation may be related to wider land use changes. Thus, there is a need to coordinate efforts alongside urban planning and landscape design, particularly in rapidly expanding urban areas. In a post-BREXIT world, the purpose of the WFD remains relevant, safeguarding water and ecosystems for a sustainable future. The challenges associated with analysing 'messy' routinely collected data are common in the river restoration field. Our methodology offers an approach for utilising difficult data to progress the field. The next step is developing guidelines to optimise the value of datasets like the RHS.

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Data availability statement

The data was utilised under formal agreement with the River Restoration Centre. While we are unable to make the data available for public use, our supplementary materials contain detailed statistical analysis and output.

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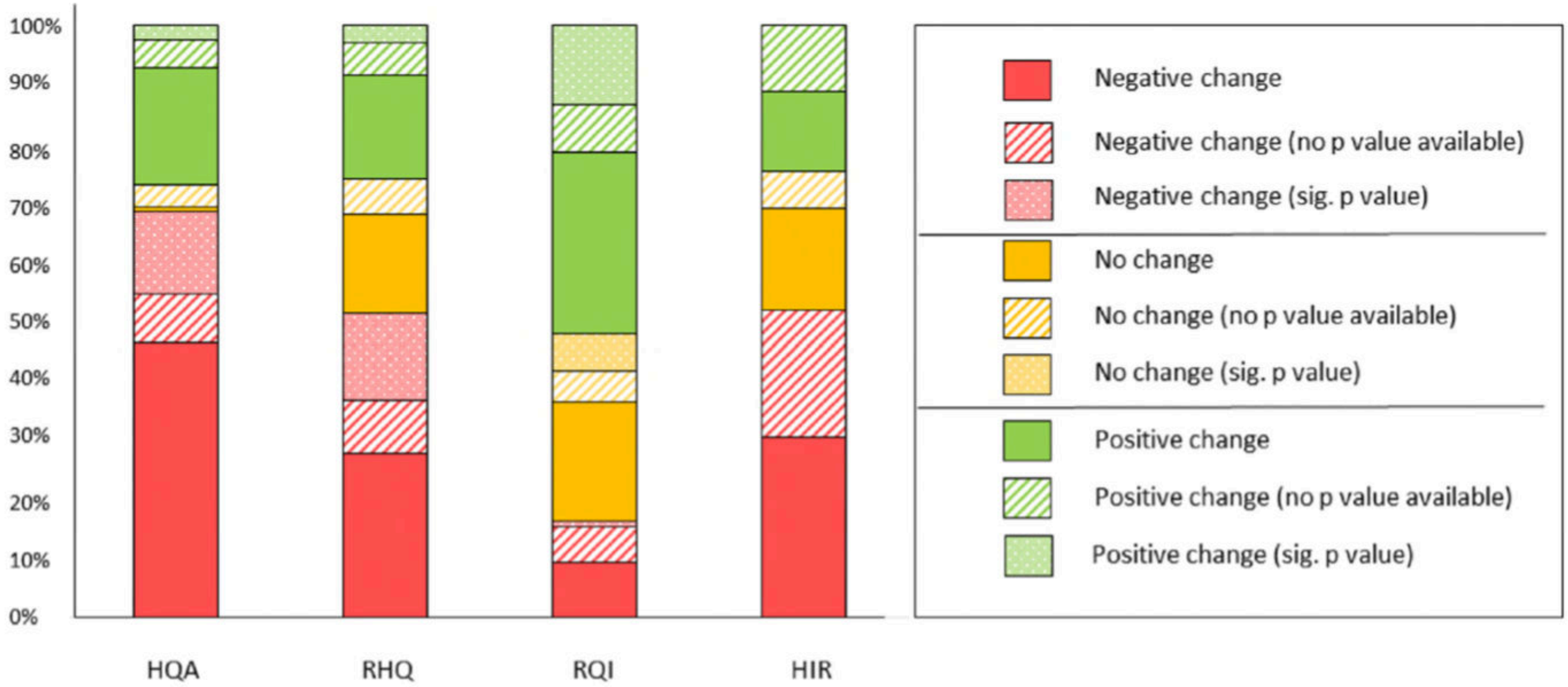


FIGURE 1 Percentage of negative, neutral or positive change scores for RHS quality measures at the Local Authority Scale. Solid coloured bar sections represent change scores with non-significant p-values. Line patterned bar sections represent change scores for which p-values could not be computed. Dot patterned bar sections represent change scores with significant p-values [Color figure can be viewed at wileyonlinelibrary.com]

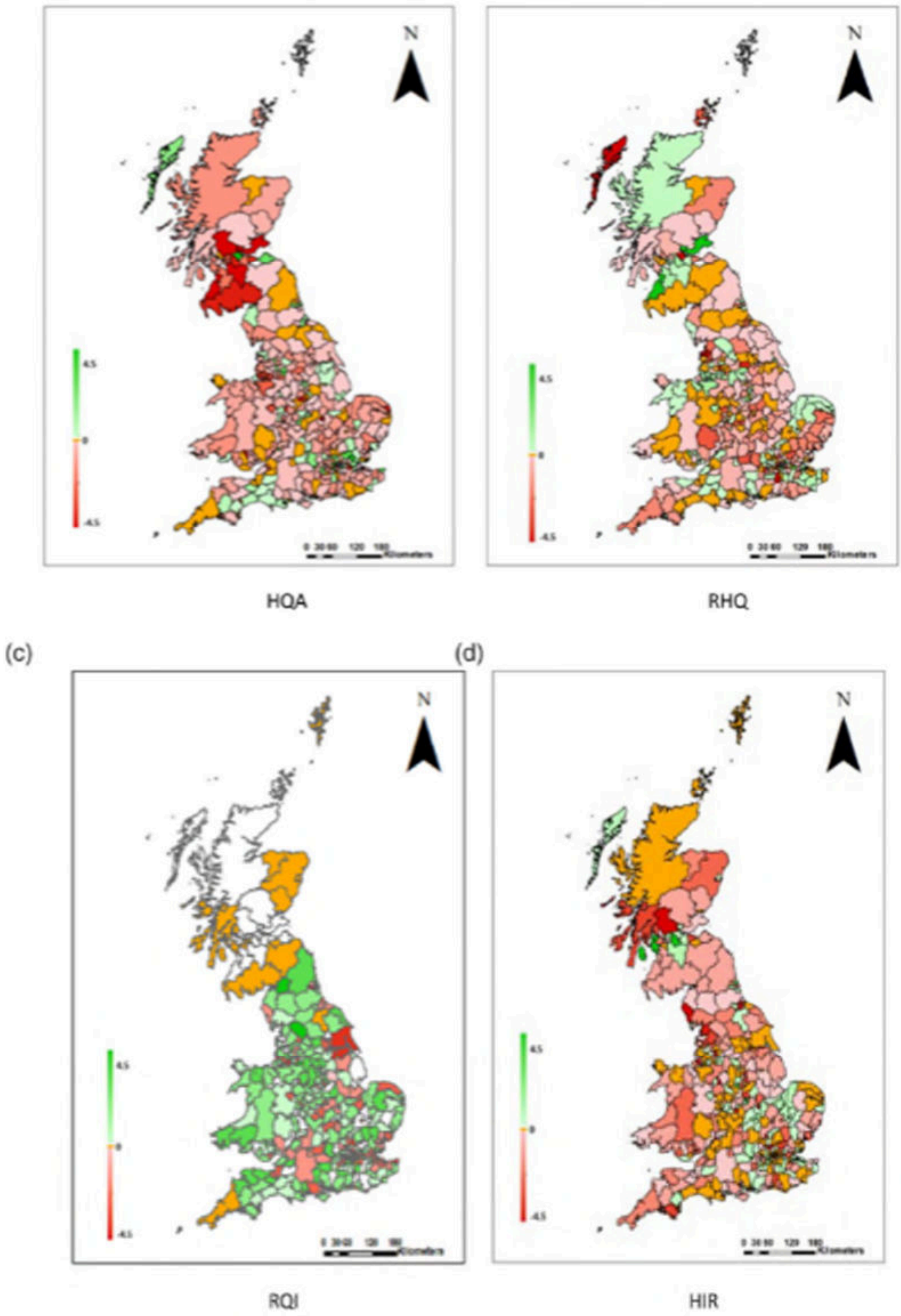
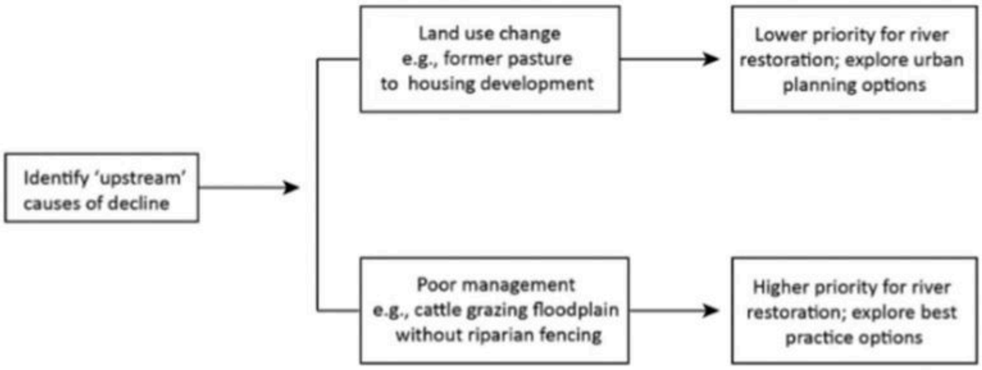


FIGURE 2 Spatial representation of Index of Change for, (a) Habitat Quality Assessment (HQA), (b) River Habitat Quality (RHQ), (c) Riparian Quality Index (RQI) and (d) Hydromorphological Impact Ratio (HIR). Green areas represent positive changes, red areas represent negative changes, orange represents no change and white represents areas where there is data missing; no surveys were undertaken in Scotland and Northern Ireland in the 2000s. Darker colours reflect larger changes [Color figure can be viewed at wileyonlinelibrary.com]

FIGURE 3 Schematic decision-making framework for prioritising investment in local authority regions where habitat quality has declined between RHS assessments conducted in the 2000s compared to RHS assessments conducted in the 1990s



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