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Recovering lost hay meadows: An overview of floodplain-meadow restoration projects in England and Wales

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ABSTRACT

Restoration of natural habitats plays an important role in nature conservation. After 30 years of efforts to restore species-rich floodplain meadows, most of which had been lost to alternative land uses during the preceding half century, the extent and level of restoration success in the UK remained unknown. **Athree-yearsurvey of floodplain meadow-restoration projects across England and Waleswas completed from 2016to2018. Itallowed evaluation of restoration progress on 163 sites nationwide.**

Restoration success was measured by floristic composition, species richness and balance of functional types in plant communities. To identify factors affecting restoration success, their state prior to restoration, restoration technique, site ownership and quality of ongoing management were analysed. The survey revealed that 25 % of restoration sites demonstrated expected success, achieved mainly by private landowners. Restoration failed or showed very poor progress on another 15 % of sites, managed predominantly by public or charitable organisations. The remaining sixty percent of the sites showed some signs of improvement. The degree of restoration success showed no significant correlation to the state of the site prior to restoration, or to the restoration method applied. Ownership of the site and site management both influenced restoration success. The degree of success appeared to depend on the consistency and sufficiency of the restoration management.

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1. Introduction

Many northern European floodplains have been occupied by semi-natural meadows for most of the last millennium. These diverse communities established under long-term consistent management for hay balancing the nutrient input from floods. These meadows developed as sustainable ecosystems, highly valued for animal feed over many centuries (McGinlay, Gowing, & Budds, 2016; Schaich, Karier, & Konold, 2011). More than 97 % of these habitats were lost from the floodplains of Europe during the period 1930–1990 (e.g. Fuller, 1987; Krause, Culmsee, Wesche, Bergmeier, & Leuschner, 2011), and to a lesser extent in the following years (Jefferson, Smith, & MacKintosh, 2014, Chp 3). Moist or wet, mesotrophic to eutrophic hay meadows (Eunis habitat type E2.14 and E3.4a, EEA 2019) are classed as Endangered in the European Red List of habitats (Janssen et al., 2016) and the importance of floodplain meadow restoration has been recently acknowledged globally by the European Environment Agency (2016) and United Nations Environment Programme (2019). Floodplain meadows are increasingly recognised for the range of ecosystem services they offer (Lawson et al., 2018), and their loss has prompted the initiation of many projects aiming to re-create and restore them (e.g., Vinther & Hald, 2001; Hölzel & Otte, 2003).

Globally, habitat restoration processes have become so widespread that ecosystem restoration targets were set by the United Nation Environment Programme (2019). The increasing number of restoration projects creates a need for critical evaluation of the processes affecting them (Jones, Barber, & Gibson, 2019). In the UK, some positive outcomes have been reported for particular floodplain meadow sites in England (e.g., Woodcock, McDonald, & Pywell, 2011; Hosie, Jones, Rothero, & Wallace, 2019) and Wales (Shellswell & Squire, 2019). However, estimation of restoration extent and progress on floodplain meadows at a national scale has never been previously attempted. A three-year nationwide survey was initiated in the UK by the Floodplain Meadows Partnership (FMP; www.floodplainmeadows.org) in 2016 (Rothero & Tatarenko, 2018). Over three years, 177 restoration sites

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were visited in 20 counties across England and Wales, representing 844 ha of floodplain. Seventeen sites where restoration projects were about to start were also visited. Sixty seven percent of the surveyed sites were entered into an agri-environment scheme. This UK government funded scheme (known as Countryside Stewardship) provides financial incentives for farmers, land owners or managers to maintain and improve the environment (Rural Payments Agency, 2020).

Restoration methods have varied over the past 30 years of floodplain-meadow restoration in England and Wales. The most common method in the last ten years has been the application of freshly cut herbage (Kiehl, Kirmer, Donath, Rasran, & Hölzel, 2010), colloquially referred to as "green hay," taken from an existing species-rich meadow. "Green hay" refers to species-rich herbage from a donor site that is transferred to the restoration site on the same day it was cut (Edwards et al., 2007; Kirkham, Bhogal, Chambers., Dunn, & Tallowin, 2012). However, other methods are also used including sowing commercial seed mixtures, reverting permanent pastures to a regime of hay cutting, application of seed mixtures collected from existing species-rich meadows by hand, often with the help of volunteers, along with planting plug plants. In this survey, botanical data were collected on each site, together with information about historical and current management and restoration techniques, in order to explore the degree of success of restoration projects. Measuring success or even monitoring progress of restoration projects is a challenge, because there is no definitive approach (Kimball et al., 2015). Vegetation structure, species diversity, species abundance, presence of target species and functioning of ecological processes are commonly used (Ruiz-Jaen & Aide, 2005). In the UK, the success of restoration sites involved in agri-environment schemes is measured by both species' richness (as number of species per 1 m^2), and by frequency of particular indicator species selected from targeted plant communities (Natural England, 2012, 2016). Assessing the similarity of a restored community to a target community has rarely been undertaken. In the UK, targets for floodplain-meadow restoration have focussed on the rare, species-rich *Sanguisorba officinalis-Alopecurus pratensis* (MG4) grassland and the *Cynosurus cristatus-Caltha palustris* grassland (MG8) as defined by the British National Vegetation Classification (NVC) (Rodwell, 1992). The match between the vegetation on a restored site and a target community can be measured by calculating a similarity coefficient (Czekanowski, 1913; Malloch, 1996.) This degree of similarity was applied here as the first criterion of restoration success. Apart from the similarity in floristic composition, a restored community is expected to mirror the functionality of the target community. The C-S-R system of describing plant functional types (Grime, 1974) has been successfully used to compare vegetation samples which differed in management regime (Hunt et al., 2004). The C-S-R signature (Hunt et al., 2004), was used as the second criterion in our calculation of restoration success. The combination of these two criteria together with species richness, as a general indicator of biodiversity, were adopted to produce a robust scale of restoration success.

As the success of a project is defined by its results, so assessments of project management are usually based on the achievements of pre-set goals and objectives (Hockings, Stolton, Leverington, Dudley, & Courrau, 2006). For example, the management of restoration sites in agri-environment schemes is assessed by the presence of indicator species in the sward (Natural England, 2012). The spectrum of methods that have been used to assess the management of protected areas is broad in scale and the degree to which the criteria are formalised is broad too (Stoll-Kleemann, 2010.) However, the role of management in restoration projects has rarely been discussed (e.g. Guerrin, 2015). The socio-economic component of management is even more rarely considered because of the variability of management approaches, especially in the private sector, the lack of records of management activities, and the poor structure and ambiguity of questionnaires collecting management data (McGinlay et al., 2016). Restoration projects are expected to be managed in accordance with restoration guidelines and advice (e.g., Natural England, 2012). However, the dynamic nature of floodplain environments, e.g. variation in soil nutrients (Klaus, Sintermann, Kleinebecker, & Holzel, 2011) and flooding regime, brings additional challenges for restoration managers. Our approach seeks to explore whether management traits, such as consistency, sufficiency and adaptability help to explain the trajectory of restored vegetation.

Our survey combined information from a diversity of landowners and restoration approaches, with other factors, such as the condition of the site prior to restoration to evaluate variation in the effectiveness of restoration.

Within this paper, we aim to address two questions:

How close are we to restoring lost hay meadows on British floodplains?

Has a particular habitat restoration approach proven successful?

Our second question gave rise to four separate hypotheses:

- Restoration success is a function of site ownership
- Restoration success depends on the restoration technique used
- Restoration success depends on site condition prior to restoration
- Restoration success correlates with the consistency, sufficiency or adaptiveness of management

2. Materials and methods

2.1. Identifying restoration locations

The diversity of organisations, landowners and other bodies involved in floodplain-meadow restoration projects in the UK is extensive, but their identification was made feasible by using the network already developed by the Floodplain Meadows Partnership (FMP) A layered approach was used to identify them:

- Data supplied under licence from the Government adviser for the natural environment in England, Natural England (Natural England, n.d.), was entered into a Geographic Information System (QGIS association, Switzerland) and used to find sites that were registered in the Countryside Stewardship Scheme. We focussed on land entered under option GS6 [Restoration of species-rich, semi-natural grassland] or GS7 [Creation of species-rich, semi-natural grassland] and located within floodzone 2 of the floodplain (Environment Agency, 2020) The sites identified were then followed up through local Natural England staff, who were able to contact landowners, and in some cases help with access.
- proactively approaching local contacts (e.g. The Natural England Grassland Network, Local Wildlife Trusts, Local Biodiversity Record Centres) to request information on floodplain-meadow restoration activity in their areas
- advertising the study through the FMP newsletter and social media.

2.2. Collection of physical and management information from sites

The following physical data were collected:

- On 127 sites, five 1 m × 1 m quadrats were surveyed per site, listing all plant species present and their percentage cover. Quadrats were placed randomly across each field. Positions of the quadrats were recorded with Mobile Topographer GPS app (Google, 2020) with an accuracy to 0.5 m. Quadrat locations were shown on maps provided to the landowners together with survey results.
- Thirty-six further fields were surveyed on a walk-through basis due to time constraints, where species lists were recorded rather than quadrat data collected. All species seen along a walk across the field were recorded with estimates of their abundance and frequency.
- The landowner or manager was questioned about site management and restoration methods (Appendix 1 — Site Assessment Form). In some cases, follow-up emails and telephone calls were required to fill data gaps.

- Of the 177 sites visited, information from fourteen sites (111 ha) remained incomplete, so they were excluded from the data analysis.

2.3. Statistical tests

The Kruskal Wallis H test was applied to address the following hypotheses:

- Restoration success is a function of site ownership
- Restoration success depends on the restoration technique used
- Restoration success depends on site condition prior to restoration

The Kruskal Wallis test was chosen because restoration success was assessed on an ordinal scale, whilst the multiple potential explanatory variables were categorical. Where significant effects were indicated, a Mann–Whitney *U* test was used as a *post hoc* test.

The Spearman rank correlation test was used to address the following hypotheses:

- Restoration success correlates with the consistency of management
- Restoration success correlates with the sufficiency of management
- Restoration success correlates with the adaptiveness of management

The Spearman rank test was chosen because management regimes were scored subjectively on an ordinal scale, the success of restoration and the management regime were paired at site level and visualisation of the data suggested a monotonic relationship.

The number of sites in each success category entered into an agri-environment scheme was analysed using a chi-square contingency table. This approach was taken because both variables were categorical.

3. Theory and calculations

In order to estimate restoration success, we summed measures of species richness, similarity to target community and functional diversity.

To evaluate characteristics of restoration management (management factors), questionnaire responses were scored against criteria set out below.

3.1. Definition and measure of restoration success

In this study, several measures in combination are proposed as a robust approach to assessing restoration success:

1 Species richness.

Species richness is a frequently used measure of habitat quality (e.g. Ruiz-Jaen & Aide, 2005). On restoration sites, it has been widely used as a criterion of success (e.g. Natural England, 2012). The targeted vegetation types in this context (MG4, MG8 and MG5), tend to be species rich with typically more than 20 plant species per 1 m^2 (Wallace & Prosser, 2016). However, if the number of species is boosted by the presence of ruderal species, as is often the case during the early phases of a restoration scheme, this measure alone can be unreliable.

2 Similarity to National Vegetation Classification communities.

For many of the restoration projects, a specific restoration target was set at the outset; namely to achieve a sward composition as described by the British National Vegetation Classification (Rodwell, 1992). The Modular Analysis of Vegetation Information System (MAVIS; CEH, 2016) was used to measure the similarity coefficient between observed and target communities. Smaller samples were taken than recommended for NVC survey, to be consistent with existing data held for these grassland types (Wallace & Prosser, 2016). MAVIS uses the same form of the Czekanowski coefficient as an earlier software application, MATCH (Malloch, 1996). In this study, a similarity coefficient of over 60 % was assumed to represent a good fit to the particular NVC type. Here we followed a methodological study by Semkin (2009), which demonstrated that exceeding a threshold coefficient of 59 % was indicative of high similarity between communities. Scores below 50 % were assumed not to conform to the target plant community (Dodd, Silvertown, McConway, Potts, & Crawley, 1994). Scores between 50 and 60 % suggest community re-assembly is partially achieved (Tatarenko, Rothero, & Wallace, 2018). Similarity to target communities alone was not considered sufficiently sensitive to evaluate restoration progress fully and therefore additional measures were included.

3 C–S–R functional types.

The high diversity of floodplain meadows can be explained by hydrological niche segregation in space and time (Silvertown, Dodd, Gowing, & Mountford, 1999). This heterogeneity can promote both taxonomic and functional diversity. The latter has been proposed as a finely tuned characteristic of restoration success, although it is more difficult to measure (England & Wilkes, 2018; Jones et al., 2019). Based on C—S—R functional types, as defined by Grime (1974), a C—S—R signature was suggested as a tool for comparison of herbaceous vegetation (Hunt et al., 2004). Species with competitive (C) or ruderal (R) life-strategies tend to occupy newly cleared areas, such as restored arable fields, much faster than species with a stress-tolerant (S) strategy. The latter group tend to perform poorly in the early stages of vegetation succession (Pywell et al., 2003). Meadow communities restored in tundra, after 15 years, had low S-value in functional evenness compared to C and R-values: e.g. C:S:R 0.38:0.24:0.40 (Novakovskiy & Panyukov, 2018). Established species-rich meadow communities are characterised by an even spread of CSR functional types. For example, in alpine hay meadow C:S:R was found as 0.36: 0.30: 0.34 (Onipchenko et al., 2020). Based on the arguments above, we suggest using evenness of C:S:R scores in measuring restoration success. C—S—R signatures as defined by Hunt et al. (2004), were calculated in MAVIS for each quadrat, and averaged per site as C:S and S:R ratios.

Therefore, a combination of four measures: species richness, similarity to target community, C:S ratio and S:R ratio, were used to develop a quantitative scale for evaluating restoration success. The scale ranges from 1 (failure), to 5 (success), with 2, 3, and 4 marking different levels of progress in between (Table 1).

The scale was developed in discussion with several grassland

Table 1
Measures of success for restoration of floodplain meadows.

Measure	Measure of success 1 Failure	2	3	4	5 Success
Average scores from five botanical quadrats per field as calculated in MAVIS					
Species richness	<8	8–12	13–15	16–20	>20
NVC similarity score	<50 %	50–55 %	55–60 %	>60 %	>60 %
C:S ratio (average)	>1.39	1.27–1.39	1.18–1.27	1.10–1.18	<1.10
S:R ratio (average)	<0.79	0.79–0.81	0.81–0.84	0.84–0.89	>0.89
Scores based on walk-through survey using Countryside Stewardship manual					
Number and frequency of species deemed to be -indicators of success	0	1–2 occasional	4–5 occasional	1–4 frequent	>4 frequent
Number of species common to lowland meadows	0–2	3–5	6–7	>7	>7

Table 2
Management factors affecting restoration projects for floodplain meadows.

Categories	1	2	3
A – Consistency	**Inconsistent:** Timing of hay cuts delayed beyond when hay was ready. Hay cut missed in some years. Cut material not collected promptly when dry. Lack of grazing in autumn. Overgrazing causing soil compaction	**Partially consistent:** Occasional cases of inconsistency as listed in column 1	**Consistent:** A timely annual hay cut Timely hay removal Regular grazing with its pressure determined by the availability of grass.
B – Sufficiency	**Insufficient** Hay making too late or too incomplete to balance nutrient inputs. Drainage infrastructure insufficient to avoid periodic soil anoxia Cover of litter allowed to accumulate. Too few propagules introduced and/or seed introduction methods failed to optimise germination	**Partially sufficient** Some aspects of the factors mentioned in column 1.	**Sufficient:** Nutrient input and outputs are in balance over a flood cycle. Flood waters leave site quickly enough to avoid anoxia. Well managed grazing or occasional harrowing to avoid litter accumulation Seed material of good quality, sown at an appropriate density and onto adequately prepared ground. Propagules introduced in more than one year.
C – Adaptiveness	**Inflexible:** Following published protocol (e.g. Countryside Stewardship Manual) to the letter without consideration of local conditions. For example, no additional hay cut in years when nutrient availability peaks after a major flood. No re-application of propagules if initial recruitment is poor.	**Partially adaptive**: Making some limited adjustments to the restoration plan to reflect conditions on the ground.	**Fully adaptive:** Taking management decisions based upon monitoring data, prevailing site conditions and weather.

ecologists experienced in the classification of plant communities in English and Welsh floodplain meadows.

For fields surveyed by a walk-through, the assessment of restoration progress was in accordance with guidelines in the Countryside Stewardship manual (Natural England, 2016) which includes floodplain meadow plant communities defined within the lowland meadows broad habitat type. The combination of presence and frequency of common and indicator species was used to calculate restoration success scores, as shown in Table 1. The thresholds were set to create an even spread of sites across the range of scores.

3.2. Role of management in restoration success in dynamic floodplain-meadow ecosystems

How management is delivered differs. We define three characteristics of management, which we use to assess the management regime for each site (Appendix 2). Firstly, consistency of management defined as an annual midsummer hay cut with prompt removal of hay and followed by a period of aftermath grazing. These practices have been proposed as important for the development and maintenance of a species-rich floodplain meadow (Gerard et al., 2008; Poptcheva, Schwartze, Vogel, Kleinebecker, & Hölzel, 2009) particularly with respect to balancing the soil–nutrient budget (Rothero, Lake, & Gowing, 2016). Secondly, sufficiency of management captures whether the degree of restoration effort is planned and tailored to the specific site to ensure the target can be achieved. On floodplains, lack of management may result in flood waters failing to drain (Leyer, 2004), nutrients accumulating (Fry et al., 2017; Timmermann, Damgaard, Strandberg, & Svenning, 2015), propagules being too sparse (Carter & Blair, 2012) or germination being sub-optimal (Abbandonato, Pedrini, Pritchard, De Vitis, & Bonomi, 2018). All these problems would be noticeable from the early stages of restoration projects as would others such as weed infestation, poaching of the soil and ingress of scrub along boundaries. A third characteristic – adaptiveness of management – reflects the dynamic nature of floodplain habitats (e.g. unpredictable spring and summer floods,) which require adaptive management in response to the condition of the habitat from month to month (Lemke et al., 2017).

To identify the management factors involved in the success or otherwise of a restoration project, we determined for each site whether the management was: A – consistent, B – sufficient, and C – adaptive. Information gathered about management during the site visit was compiled and structured along a three-point scale, using the criteria set out in Table 2. A degree of subjectivity was required, but sites for which there was too little information to make an informed judgement about the consistency, sufficiency and adaptiveness of the management were omitted from the analysis.

Table 3
Number of floodplain-meadow restoration sites surveyed in the counties in England and Wales in 2016-2018. A more complete summary of the data is presented in Appendix 2. Categories of restoration success range from 1 (failure) to 5 (success) as explained in Table 1.

County	Number of restoration sites surveyed in the county	Categories of restoration success				
		1	2	3	4	5
Berkshire	1	0	0	0	0	1
Buckinghamshire	17	1	3	10	2	1
Cambridgeshire	3	1	2	0	0	0
Clywd	2	0	0	1	1	0
Cumbria	16	0	3	6	7	0
Gloucestershire	10	3	2	3	2	0
Gwynedd	3	0	2	1	0	0
Hampshire	2	0	0	1	0	1
Herefordshire	2	0	2	0	0	0
Lancashire	3	1	1	0	1	0
Lincolnshire	26	4	7	6	7	2
Montgomeryshire	1	0	1	0	0	0
Northamptonshire	10	1	1	4	3	1
Oxfordshire	39	5	10	18	5	1
Shropshire	4	1	1	2	0	0
South Yorkshire	2	0	2	0	0	0
Staffordshire	5	2	2	1	0	0
Surrey	2	2	0	0	0	0
Wiltshire	5	0	3	1	0	1
Yorkshire	10	3	1	2	4	0
Total:	**163**	**24**	**43**	**56**	**32**	**8**

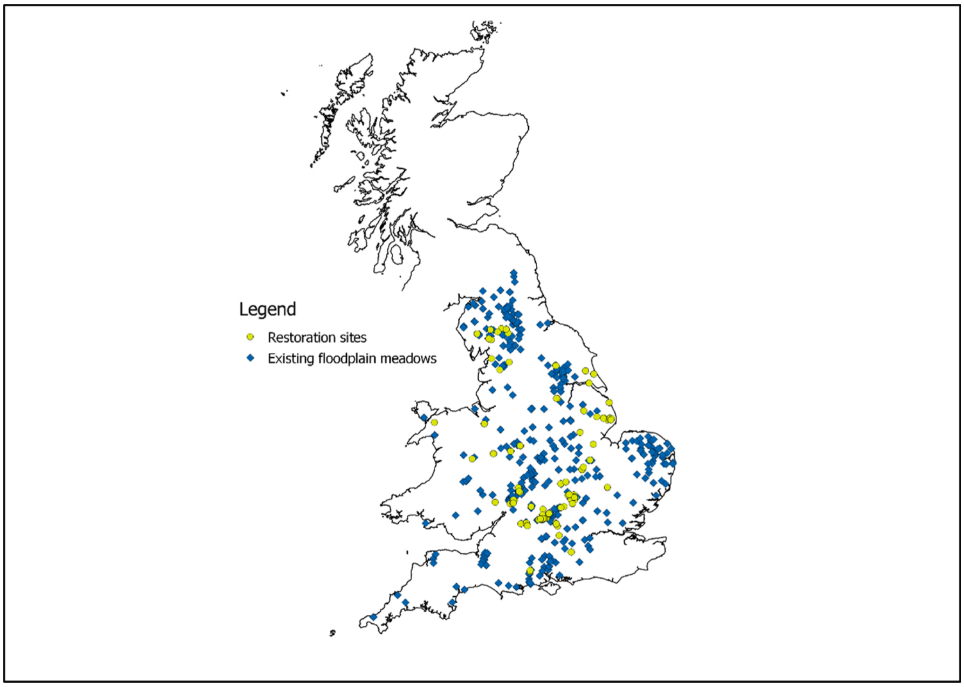

Fig. 1. Map of restoration sites and existing species-rich meadows in England and Wales.

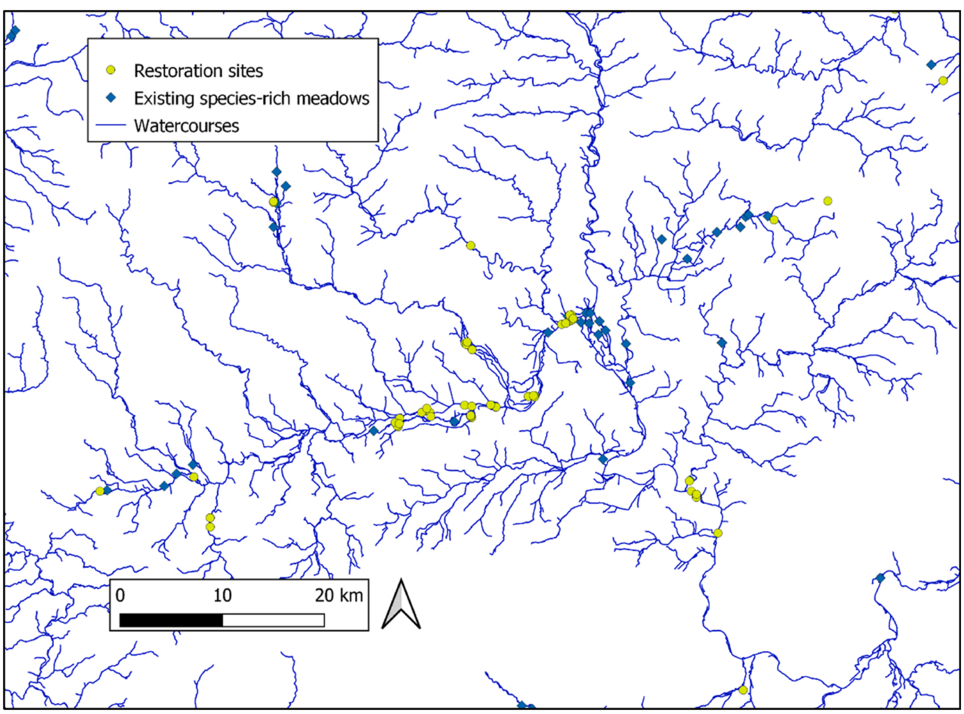

Fig. 2. Distribution of restoration sites and existing species-rich meadows along the Thames valley around Oxford, England.

4. Results

4.1. Extent of floodplain-meadow restoration across the UK

Data collected from 163 restoration sites in 20 counties across England and Wales (Table 3) representing 733 ha of floodplain grassland, were included in the data analysis. 70 % of restoration projects started between 2006 and 2015, 12 % occurred during 1990s, and 6 % in the period 2000–2005. Some decline in the number of new restoration projects was observed in recent years. Restoration projects were found in most of the major river floodplains in England, most notably the Thames, Severn, Ouse, Wye, Kent, and Ribble (Fig. 1). A number of sites were found along lakesides or along the coast. The highest density of restoration sites was found in the Thames catchment, in proximity to some of the oldest and best-preserved floodplain meadows, such as North Meadow and Clattinger Farm (Wiltshire), and Oxford Meadows, Ducklington Mead and Chimney Meadows (Oxfordshire). Restoration sites along the river Thames have started to fill the gaps in between existing species-rich meadows, in some areas starting the forming of a 'flower-rich corridor' along the river valley (Fig. 2). In the North of England, restoration sites were found in connection with existing floodplain-meadow systems in North Yorkshire, such as Clifton Ings and Rawcliffe Meadows along the river Ouse, and the flat landscapes of Lincolnshire, which historically supported vast areas of former fen used for agricultural purposes, including hay production. There are very few remaining species-rich floodplain meadows in the area, but the 38 restoration sites from that one county cover 53 ha, or 8% of the total area, and comprise 23 % of the total number of sites visited. The hilly landscapes of the Lake District with its smaller, flashier river valleys, where remaining traditional hay meadows are again very limited in extent, revealed 16 sites covering 31 ha. Wales has few floodplains considered suitable to support classic floodplain meadows, with only a very small handful of existing sites recorded in the country. A number of future restoration fields are located next to two of the three known MG4 Sites of Special Scientific Interest (SSSI) (Natural Resources Wales, 2020) in Wales — Old Pulford Brook Meadow, and Crabtree Green. Dolydd Hafren meadow restoration project (Montgomeryshire) is located in a very active river floodplain on very thin, young alluvial soils, and C'aer Ddol in Gwynedd is on the margins of Lake Padarn.

Five percent of restoration sites surveyed in England and Wales were classified as fully 'successful' (category 5, see Table 1). Progress was substantial on 20 % of sites marked as category 4 (Table 1). These two categories add up to 25 % of the restoration sites which can be considered as meeting the expected "restored" status (Table 3 and Appendix 2). The target plant communities of MG4 and MG8 (Rodwell, 1992), as well as MG15, which is closely aligned to MG4 (Wallace & Prosser, 2016), were recorded. These restoration sites tended to be either more than 20-years old, or had received large and repeated applications of propagules.

More than half of all the sites were classified as being in a transitional state, demonstrating some progress towards formation of species-rich meadows (categories 2 and 3 with 27 % and 34 % of sites respectively). They showed a tendency to develop grass-dominated communities, such as MG6, MG7C, MG7D, MG9 and MG10 (Rodwell, 1992). The remaining 15 % of sites were evaluated as category 1 ('failure').

The number of restoration sites and their success outcome varied between counties in England and Wales (Table 3). The large variability in restoration success observed on the surveyed sites was analysed against a range of factors involved in restoration projects.

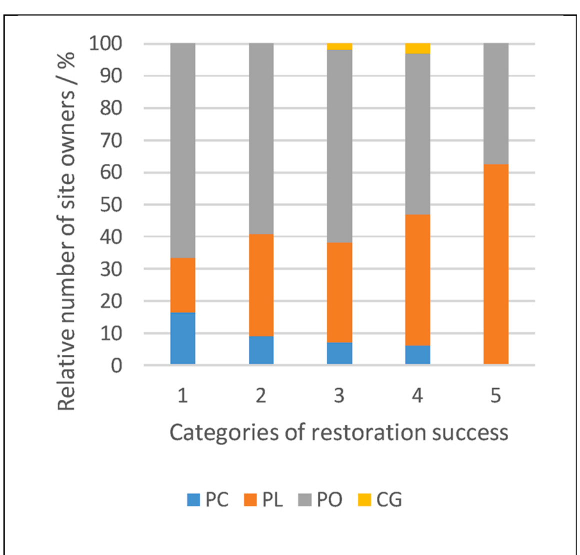

Fig. 3. Proportion of site owners in each of the five categories of restoration success as defined in Table 1. PC – private companies, PL – private landowners, PO – public and charitable organisations, CG – community groups.

4.2. Factors affecting restoration success on the sites

a) *Site ownership*

Restoration projects in the UK were categorised by the type of landowner or manager responsible for them. Individual farmers and private landowners of mainly small fields attached to a house were grouped as "private landowners" (PL); they comprised 42 % of all owners, managing 255 ha of restoration sites. Wildlife charities, local councils, and local and national organisations were grouped in the category of "Public & Charitable ownership" (PO) and managed 43 % of restoration sites covering an area of 386 ha. Private companies (PC) included represented 14 % of owners, managing more than 90 ha. Community groups play a minimal role in the restoration of floodplain meadows at a national scale, representing only 1% of owners.

Success of restoration was found to be associated with ownership category; two thirds of sites within category 5 (success) belonged to private landowners (PL). Differences between PL and PO as the two major categories of land manager, were clear in category 1 (failure,) where the number of public and charitable organisations (PO) and the associated area managed were 3 times higher than that from private landowners (PL) (Fig. 3). Schemes managed by private companies (PC) were almost equally represented in categories 2-4, with higher number in category 1. Community groups (CG) were only represented in categories 3 and–4 (Fig. 3).

The success scores were found to differ significantly between three main types of landowners (Kruskal Wallis H test; $n = 14, 51, 89$; for PC, PL and PO categories respectively; $H = 6.83$; $d.f = 2$; $p = 0.03$). *Post hoc* Mann–Whitney tests comparing median values between PC ($n = 14$) and PL ($n = 51$) and between PO ($n = 89$) and PL ($n = 51$) both showed the PL value to be significantly higher.

b) *Site condition prior to restoration and method of restoration used*

The condition of sites prior to restoration showed a wide range of starting points (Fig. 4). Seven types of land use were changed to restore floodplain meadows. The majority of the sites (57 %) were restored from some form of species-poor permanent grassland, such as pastures, old degraded meadows and agriculturally improved meadows. More than 200 ha (27 %) were restored from arable land. Land uses such as allotments and amenity grasslands were rare (0.3 %) and not included in the analysis for this reason. The success of restoration was not strongly determined by land-use prior to the restoration attempt (Kruskal Wallis H-test, $n = 163$, $H = 3.23$, $d.f. = 3$, $p = 0.36$).

Green hay application was used on 29 % of sites, the majority of which were permanent grassland prior to restoration (Fig. 4). Some sites receiving green hay were first scarified, but this level of detail of restoration technique was not considered in the data analysis. Most sites restored by green hay fell into success categories 2 and 3.

Sowing commercial seed mixtures and reverting permanent pastures to a regime of hay cutting were applied on 23 % of sites. The application of commercial seed mixtures was successful on half of the arable fields where it was applied, however the number of sites with insignificant progress and failure (categories 1 and 2) was also high (Fig. 5). A simple change of management was applied to pastures, where it resulted in success (category 5) on two fields (Fig. 5). Application of seed mixtures collected from existing species-rich meadows, along with planting plug plants, has been used occasionally, and was recorded on 13 % of the sites in our survey. The success of these methods and their combination was variable across the different pre-restoration conditions of the sites (Fig. 5). Most sites that listed commercial seed and seed/plug planting as their restoration method, also had a change of management as part of the process, typically from year-round grazing to an annual hay cut and aftermath grazing. This restoration approach was called 'multiple' because several methods were used on the same site. Five main restoration techniques: ChM – changed management, CSM – commercial seed

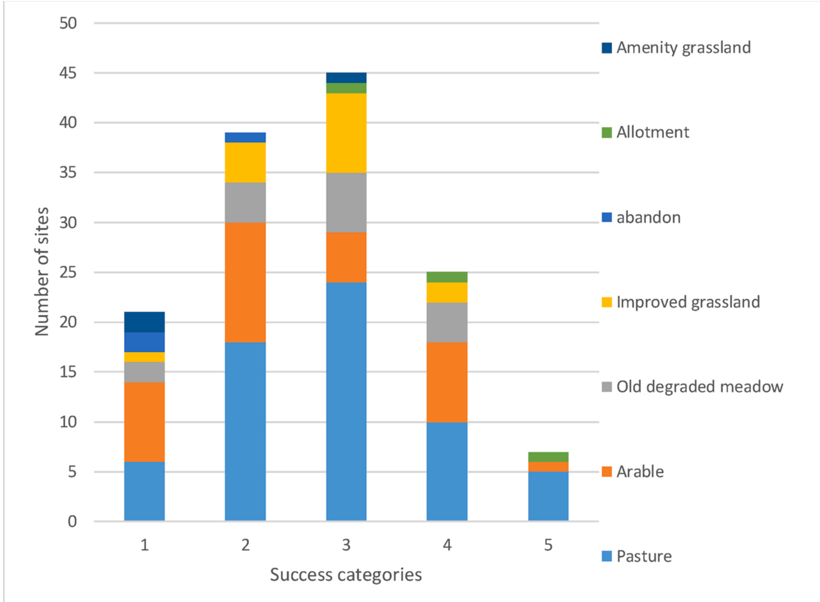

Fig. 4. Restoration success measured by categories 1–5 (as described in Table 1) on different pre-restoration land use types.

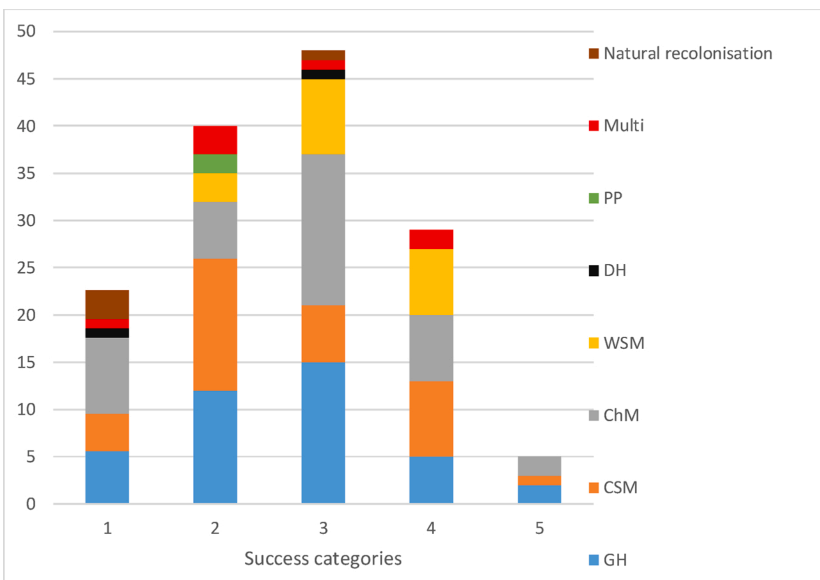

Fig. 5. Restoration success measured by categories 1–5 (as described in Table 1) with different restoration techniques applied. Restoration techniques: ChM – changed management, CSM – commercial seed mixture, GH – green hay, WSM – wild seed mixture, PP – plug plants, DH – dry hay, Multi – multiple methods, Natural regeneration (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

mixture, GH – green hay, WSM – wild seed mixture, and Multi – multiple methods, have been tested against categories of restoration success as defined in Table 1. The Kruskal Wallis test ($n = 163$, $H = 3.48$, d.f. $= 4$, $p = 0.48$) showed no significant difference in the effect of restoration method on the success of a restoration project.

Older methods not apparently used since the 1990's include dry hay application (3 sites) and natural regeneration (4 sites). The latter approach relied on propagules of meadow species arriving naturally from neighbouring species-rich fields, but their swards remained species-poor 30 years later. Dry hay on its own resulted in failure or weak progress on two sites, however in combination with other restoration methods (plug plants, turf transfer and wild seed sowing) it led to a very good outcome at Copse Meadow along the river Ouse (York). Two sites were successfully restored from pasture by changes in management regime. A few sites successfully practised a mixture of techniques, e.g. green hay, commercial seed and plug planting, or dry hay, wild seeds and plug planting. In those cases, the application of different plant material was spread through several years, while in the majority of sites, plant propagules in one form or another were applied only once. About 6% of sites did not keep records of the restoration methods used (Appendix 2, Table 1).

4.3. *Impact of management on restoration success*

Restoration success was measured using a 5-point scale (Table 1) and analysed against three characteristics of management using a 3-point

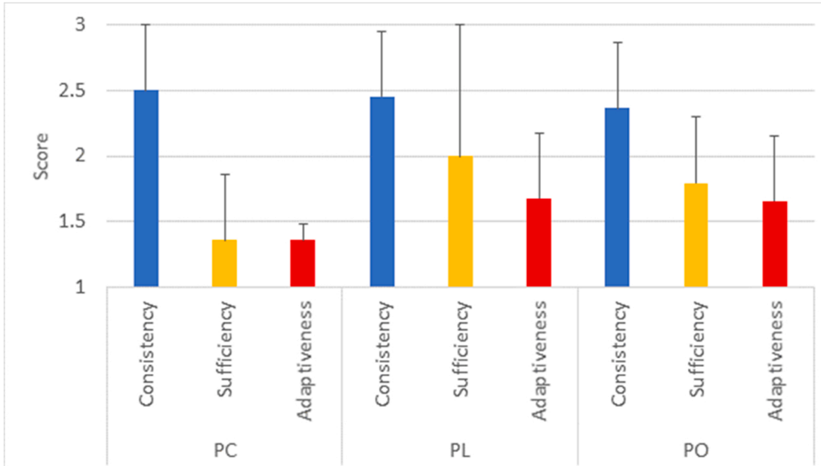

Fig. 6. Median values of the management-regime scores of the three main ownership types: private companies (PC,) private landowners (PL) and Public and charitable organisations (PO.) Bars represent the mean and error bars the interquartile range.

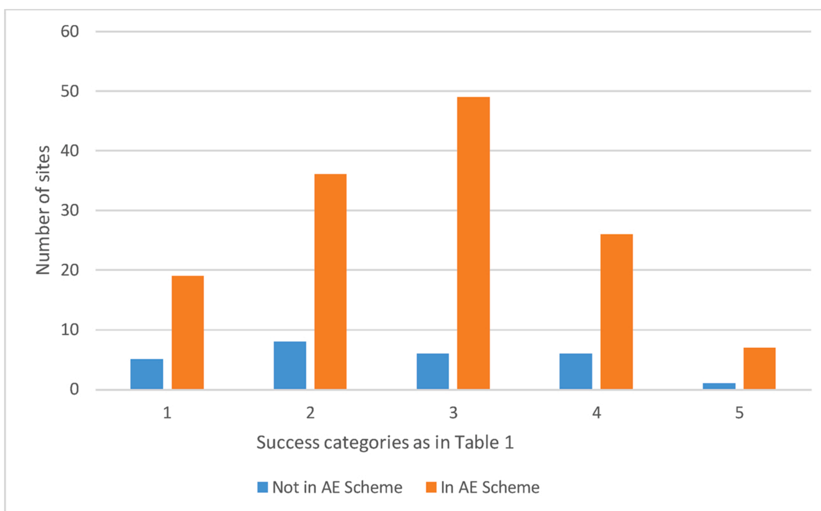

Fig. 7. Split of restoration sites within and outside of an agri-environment scheme.

scale (Table 2). Correlation between quality of management and restoration success was positive in all three categories described in Table 2. The strongest correlation (Spearman rank test, $\rho = 0.77$; $p = <0.001$) was found between sufficiency of management and restoration success. The coefficients from the same test for consistency ($\rho = 0.49$; $p = <0.001$) and adaptability ($\rho = 0.28$; $p = 0.002$) were lower, but nevertheless significant. The restoration success rate of the three main types of ownership using the three management characteristics described in Table 2 was tested using the Kruskal-Wallis H-test. It revealed that public and charitable organisations (PO), private landowners (PL), and private companies (PC), had similar levels of management consistency ($n = 14, 51, 83$; $H = 1.36$, d.f. $= 2$, $p = 0.50$) and adaptiveness ($n = 14, 34, 67$; $H = 3.09$, d.f. $= 2$, $p = 0.21$), while sufficiency differed significantly ($n = 14, 51, 83$; $H = 8.13$, d.f. $= 2$, $p = 0.02$) between the three groups of owners (Fig. 6).

Only 18 % of all restoration projects were not run under a government-funded Agri- environment scheme As shown in Fig. 7, sites participating in agri-environment schemes were well distributed across all five categories of restoration success, as were sites not in a scheme. A chi-square contingency table ($n = 163$, d.f. $= 4$, $p = 0.76$) showed no significant effect of scheme membership on the distribution of sites between success categories.

5. Discussion

5.1. Spatial extent of floodplain meadow restoration

Restoration of semi-natural habitats, especially those which declined in the 20th century due to agricultural intensification, was thought to be an effective way of bringing them back (e.g., Wells, Pywell, & Welch, 1994). There are 2980 ha of species rich floodplain meadows remaining in England and Wales (Rothero et al., 2016). The 844 ha represented by restoration sites described here would extend these rare plant communities by 28 % if successful, which would be a substantial contribution to their conservation. In some areas, for example the Thames river valley around Oxford, restoration sites have started to fill the gaps between existing species-rich meadows, forming ‘wildflower rich corridors’ (Fig. 2), which are important for the exchange of propagules and gene flow between fragmented habitats (Arponen et al., 2013; Krause et al., 2011). However, the extent of restoration projects does not determine how effective restoration has truly been in practice (Ramstead, Allen, & Springer, 2012). Restoration success varied across the sites in this survey, as well as in most projects carried on wet meadows across Europe (Dicks et al., 2019). The challenges of grassland restoration have been discussed using examples of projects at different scales: from small fields (e.g., Hölzel & Otte, 2003; Smith, Diaz, & Winder, 2017), up to landscape-scale restoration projects across the world (Gerard et al., 2008; Guerrin, 2015; Lemke et al., 2017; Nakamura, Ishiyama, Sueyoshi, Negishi, & Akasaka., 2014). After 20–60 years of restoration, no projects were recognised as fully successful and completed (e.g. Poptcheva et al., 2009; Fagan, Pywell, Bullock, & Marrs, 2010; Smith et al., 2017). In the UK by 2018, only twenty five percent of surveyed sites achieved restoration success (categories 4 & 5.) On half of the sites visited, the vegetation showed limited signs of progress towards desirable species-rich communities (Tatarenko et al., 2018). On fifteen percent of the sites in this survey, restoration has made little discernible progress and the process probably needs to start again. Below we discuss the limitations which may explain the slow progress with restoration of floodplain meadows in England and Wales.

5.2. How long does successful floodplain meadow restoration take?

Restoration projects of semi-natural landscapes and habitats are designed to bring back associations of organisms which used to form communities linked into specific ecosystems. Easily germinating and fast-growing grassland species are considered to be quick and easy to re-assemble into specific plant communities (Stevenson, Bullock, & Ward, 1995, Jongepierová, Mitchley, & Tzanopoulos, 2007). The majority of meadow restoration projects and trials have been carried out in dry grasslands (e.g., Hayes & Tallowin, 2007; Edwards et al., 2007; Jongepierová et al., 2007), where vegetation tends to restore faster than in wet meadows (Galvánek & Lepš, 2009). Agri-environment schemes suggest that meadow restoration can be completed in 5–10 years, while in reality it can take much longer (Poptcheva et al., 2009; Smith et al., 2007; Woodcock et al., 2011) as the species re-assemblage requires time for spatial and temporal niches to develop (Fagan, Pywell, Bullock, & Marrs, 2008).

The presence of positive indicator species on the site (e.g., Shellswell & Squire, 2019), is only the very first step in a long process of plant re-assemblage into a community. After 22 years of good progress on Somerford Mead (Woodcock et al., 2011) and almost 10 years on Clattinger Farm (Hosie et al., 2019), target species are still very patchy. Many meadow species, particularly herbs, demonstrate a low rate of establishment from the existing seed bank, as well as poor natural dispersal (e.g. Bakker & Berendse, 1999; Pywell et al., 2002; Bossuyt & Honnay, 2008). These considerations explain the slow progress on many restoration fields in this survey. Even though some target species were present in the fields, their distribution was very restricted. As a result, such vegetation gives low similarity scores with reference NVC targets (Tatarenko et al., 2018). Furthermore, the small number of sites in our survey that are undergoing restoration through natural regeneration, show little signs of improvement after 30 years, despite the close vicinity of existing species-rich meadows. Natural recovery of such sites can take many decades (Walker et al., 2004). For example, it was predicted that colonization by invertebrate species that characterize the target habitat type could take over 130 years (Woodcock et al., 2011).

5.3. Effectiveness of different restoration techniques

Data from 36 wet meadows in the Netherlands, Germany and the UK showed different success rates of the main restoration methods used on wet meadows (Klimkowska, Van Diggelen, Bakker, & Grootjans, 2007). Our data suggest that on floodplain meadows, no one restoration technique was more successful than others. Responses to different seeding methods in the restoration of English lowland calcareous grasslands were also shown to be unclear (Fagan et al., 2010).

Topsoil removal was recognised as one of the most promising techniques to begin a restoration project on lowland meadows including those on the floodplains (Hölzel & Otte, 2003; Kiehl et al., 2010; Klimkowska, Kotowski, van Diggelen, & Grootjans, 2009). In the UK, this method was used on two fields in York (sites 18 and 19, Appendix 2), which resulted in relatively good restoration success on those sites. Overall in the UK, topsoil removal is rarely used, possibly due to the high costs associated with this exercise.

Amongst the eight restoration methods used on British floodplain meadows, green hay spreading was most common. The green hay method was successful in trials (e.g. Edwards et al., 2007) and recommended for wider use by Natural England (2010). However, no restoration sites ran germination tests to calculate transfer rates of species, which is required to evaluate the effectiveness of this technique (Kiehl et al., 2010). As a result, the application of green hay without control of propagules transferred within it, may not provide sufficient re-assurance of restoration success. Commercial seed mixtures (CSM) used for re-seeding grasslands, are variable in their origin, (Kiehl et al., 2010) and quality of seeds (Abbandonato et al., 2018). In the UK, CSM often originate from local sources, which is thought to be important for restoration success (Jongepierová et al., 2007; Schmidt, Kirmer, Kiehl, & Tischew, 2020). Local origin of CSM can explainthe similarity in success rates (category 4) between CSM and wild seed mixtures used on restoration sites (Fig. 5). However, CSM vary substantially in the number of species included (Török, Vida, Deák, Lengyel, & Tóthmérész, 2011). Poor mixtures may have led to the high proportion of sites with no or poor restoration success (categories 1 and 2) in our survey (Fig. 5).

A positive effect of a high diversity of seeding material and dense seeding has been shown to enhance establishment of species on sites (Carter & Blair, 2012; Manchester, McNally, Treweek, Sparks, & Mountford, 1999). In our survey, the number of sites that were re-seeded over several consecutive years was very small, so this treatment could not be considered independently in the analysis. Several individual sites (e.g. sites 113, 141, 163, Appendix 2) achieved steady restoration success (categories 4 and 5) via repeated application of propagules. Seed limitation is a well-recognised barrier to the recovery of temperate grasslands (e.g. Walker et al., 2004; Johnson, Catford, Driscoll, & Gibbons, 2018). In semi-natural habitats, seed dispersal is an annual, repetitive process under hay cut management, where the date of the hay cut is critically important (Bischoff, Hoboy, Winter, & Warthemann, 2018). Different meadow species have annual fluctuations in their abundance, sizes, and seed production (Pierce, Bottinelli, Bassani, Ceriani, & Cerabolini, 2014), so the amount of propagule available for germination varies from year to year. This variation can affect the quantity and quality of seeding material transferred to a restoration site (Bischoff et al., 2018; Kiehl et al., 2010) and restoration success in general. Multiple applications of propagules should ensure greater species richness in the restored field. This rarely used technique has good potential, which merits more research. However, multiple applications can be expensive and time-consuming, unsuitable for the goal of restoration of large areas at low cost (Liira, Issak, Jõgar, Mändoja, & Zobel, 2009). The project budget often defines the choice of restoration technique used (Török et al., 2011).

5.4. The role of pre-restoration condition of the field

Pre-restoration condition of the fields is a major factor to consider in restoration projects (Walker et al., 2004); Harvolk-Schoning, Michalska-Hejduk, Harnisch, Otte, and Donath (2020) found that arable fields on floodplains can be restored more successfully than species-poor grassland. In our survey, about half the sites restored from arable use showed no or poor restoration success. The number of restored arable fields in the higher success categories was lower than permanent grasslands including pastures (Fig. 4). Statistically, no significant differences in success were found between the four main types of pre-restoration land use (arable, improved pasture, unimproved pasture and species-poor hay meadow). Pre-restoration soil treatment on the sites (e.g. harrowing) was not analysed in this paper. Soil disturbance has helped to explain differences in restoration success on ex-arable fields with bare soils (Kiehl et al., 2010). Access to the mineral soil surface promotes seed germination (Hellström, Huhta, Rautio, & Juha, 2009; Réka et al., 2020), suggesting soil disturbance can be a more powerful factor than pre-restoration condition of the site, though the benefits may be short-lived (Harvolk-Schoning et al., 2020)

5.5. Three qualitative approaches to management of restoration sites

Whilst physical condition of the site and the restoration technique used showed no significant influence on restoration success, the quality of restoration management (its consistency, sufficiency and adaptiveness) did play a significant role. The type of land ownership/management has been found to have an effect on the progress of restoration projects elsewhere (Stoll-Kleemann, 2010). In our survey, private landowners (PL) had a significantly higher rate of success compared to both public and charitable organisations (PO) and private companies (PC). A potential explanation that private landowners had smaller sites, which were easier to restore, was not supported, as the size of field had no significant effect on restoration success within any group of landowners. Another hypothesis, that private landowners have better funding opportunities, availability of resources for hay cut and aftermath grazing, as well as a better focus on their sites, was given some support because their management was deemed sufficient to a greater degree than other managers. The mean degree of consistency and adaptiveness of management showed no significant differences between the three main groups of land managers in our study, but institutional factors have been suggested as playing a role in the failure of restoration projects elsewhere (Guerrin, 2015).

Sufficiency of management showed a significant correlation with restoration success in general. High sufficiency (category 3, Table 2) specifies that all restoration measures were implemented effectively: enough propagules were introduced, nutrient availability was managed in advance and drainage infrastructure was maintained. Insufficiency of post-restoration management can include reduced livestock grazing (e.g. Timmermann et al., 2015) and poor control of nutrients brought with flood sediments (Lemke et al., 2017). In our survey, consistency of management also showed a significant correlation with restoration success, reflecting the importance of the regular hay cut (Smith, Buckingham, Bullard, Shiel, & Younger, 1996) and timely hay removal (Schaffers, Vesseur, & Sýkora, 1998).

Restoration of floodplain ecosystems and their specific functions can suffer from a lack of knowledge of basic processes and dynamics, such as sedimentation and flood duration (Klaus et al., 2011). On dynamic floodplain landscapes, flexibility in approaching restoration projects appears to be key to success. More than half of the sites surveyed in the first year of our project showed very slow restoration progress because of high nutrient availability in the soil (Rothero & Tatarenko, 2018). Double hay cuts in June and September were found to be beneficial for soil-nutrient management in wet-meadow restoration projects in Germany (Poptcheva et al., 2009). In British meadows, timing of the hay cut is very restrictive for those within an agri-environment scheme, where mowing is often not permitted until after 15th July. An adaptive management (AM) approach (Zedler & Callaway, 2003) should be well suited to the management of such a dynamic ecosystem to allow the variation of environmental conditions across space and time to be considered (Kimball et al., 2015). The flexible, open approach to restoration practice advocated by Higgs et al. (2018), is consistent with our findings here.

Agri-environment schemes are designed in part to reinstate past habitat losses, but their effectiveness has been variable (Arponen et al., 2013). The majority of sites in this survey (137 of 163) were entered into such a scheme, which incentivised the landowner to attempt restoration. However, according to our survey, participation in the scheme did not significantly enhance the likelihood of a successful outcome.

6. Conclusions

From a survey of 163 field sites, neither the restoration method nor the previous land use was found to affect restoration success in floodplain-meadow schemes. However, the category of ownership did influence the outcome, with schemes managed by private landowners being the most successful.

The aspect of a management regime that appeared to have the strongest correlation with success was a set of actions we classified as "sufficiency." This aspect was a measure of the care and diligence taken by the scheme manager. These results suggest that the pathway by which a meadow is restored is of less importance than the care with which that management is applied. The manager needs to assess the efficacy of their own management and adjust their actions accordingly. Our findings suggest that following a pre-determined set of rules (a recipe) for restoration is not ideal. The manager needs to respond to what they can see on the ground. Where a manager lacks experience, the help of an adviser may be key.

The category of ownership and the sufficiency of management appear to be linked in as much as it was the private landowner category that scored most highly in terms of management sufficiency.

The survey has documented the extent of restoration activity in England and Wales and has demonstrated that the current resource of this valuable habitat is being increased by restoration schemes. However, the data were unable to show any effect of affiliation to an agri-environmental scheme on the outcomes.

Declaration of interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jnc.2020.125925.

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