The cost and practicality of techniques for the reversion of arable land to lowland wet grassland—an experimental study and review

S. J. Manchester*, S. McNally, J. R. Treweek, T. H. Sparks and J. O. Mountford

Agricultural intensification within Britain has been responsible for the destruction of semi-natural habitats and the subsequent loss of species. Opportunities have become available to reinstate such communities through agri-environmental initiatives e.g. the Environmentally Sensitive Areas (ESA) scheme. Lowland wet grasslands represent a severely declining habitat which are nonetheless a major element in eight English ESAs, where they have been targeted for protection, enhancement and re-creation. However, the continued agricultural usage of the land places constraints, both ecological and financial, upon the conservation of such habitats. This paper outlines the effects of intensive agriculture upon wet grasslands, the justification for their protection, and how targets for their conservation might be derived. Techniques and costs involved in the restoration of grassland are discussed. Finally the cost and effectiveness of re-creating lowland wet grassland are considered using the example of an ex-arable site within the upper Thames tributaries ESA.

Keywords: cost effectiveness, wet grassland, habitat restoration, Environmentally Sensitive Area, arable reversion.

Introduction

The intensification of agricultural practices has had severe impacts on those semi-natural habitats which developed under traditional agricultural management. Lowland wet grasslands have been particularly affected. Not only have many lowland wet grassland plant communities been damaged or lost, but those that survive relatively intact tend to be generally small and isolated from one another. At the same time, the dramatic changes in soil properties and hydrological regime, the time elapsed under intensive management, together with ever-increasing distances from sources of propagules, make it unlikely that areas abandoned from/for agriculture will revert to ‘semi-natural’ species-rich wet grassland vegetation without intervention.

Agri-environment schemes, such as the Environmentally Sensitive Areas (ESA) scheme and Countryside Stewardship (CS), offer unprecedented opportunity for the rehabilitation, restoration or re-creation of threatened habitats. This paper discusses reasons for the decline of wet grasslands, why these habitats should be protected and how targets for their conservation might be derived in terms of vegetation composition. Techniques and costs involved in the restoration of grassland are introduced, together with the factors which need to be taken into account when evaluating the cost, practicality and effectiveness of selected restoration techniques. Finally the cost and effectiveness of re-creating lowland wet grassland is considered for an ex-arable site on clay soil within the context of the upper Thames tributaries ESA.
Reasons for decline of semi-natural communities

The basic purpose of agricultural intensification has been to increase the productivity of a limited range of fast-growing crop species. The very nature of farming changed as mixed-farming systems in the lowlands were displaced by single-species arable-cropping systems (Nature Conservancy Council, 1990). Grant aid and mechanization have encouraged intensive forms of farming which have destroyed extensive areas of semi-natural habitats and their associated species (Smith, 1969), particularly those that developed under traditional agricultural management. Where low intensity farming continued, it provided refuges for many previously ubiquitous species.

Conservation importance of lowland wet grassland

Lowland wet grasslands of conservation interest comprise ‘old, moist mesotrophic meadows and pastures’ on soils which are neither markedly acidic or alkaline. They are neither excessively drained nor permanently waterlogged (Trewear and Sheail, 1991). For the most part they have developed under low-intensity livestock systems.

Historically, the area of lowland wet grassland in England and Wales has been estimated at 1 200 000 ha (Thomas et al., 1995). It is probable that only 220 000 ha now remain (Dargie, 1993), with possibly less than 20 000 ha being agriculturally unimproved wet grassland of high conservation value (Thomas et al., 1995). Williams and Bowers (1987) estimate that, since 1930, 40% of the total area of wet grassland in Britain has been lost.

As an ecologically valuable, semi-natural, species-rich habitat, lowland wet grassland supports 16 of the nationally rare and scarce vascular plant species in Britain. Approximately 130 of Britain’s 170 species of non-marine aquatic higher plants have been found in ditches associated with lowland wet grassland (Thomas et al., 1995), together with invertebrates such as dragonflies, water beetles and snails. Wet grasslands support breeding, overwintering and migratory birds including 32 Red Data Book species (or candidate species), and are particularly important for breeding waders including lapwing, redshank and snipe (Thomas et al., 1995).

More generally, the floodplains that sustain wet meadows provide a wider range of benefits over and above species conservation, including flood protection, nutrient cycling, reduced water erosion, groundwater recharge and recreational opportunities (Hey and Phillip, 1995; Kadlec and Hey, 1994; Petts, 1998). Wet grasslands may act as buffer zones for agricultural runoff, improving water quality (Muscutt et al., 1993).

Opportunities

Overproduction in the European Agricultural Community has led to the introduction of policies to reduce output through such devices as set-aside. There has also been growing recognition of the adverse impacts of agricultural intensification on the natural environment. Consequently, opportunities to reinstate farmland habitats became available, and, more importantly, funds were also made available to encourage more sympathetic land management for that purpose.

In 1985, through Article 19 of EC Regulation 797, the UK Agricultural Departments introduced ESAs as one of a range of environmental land management schemes designed to protect and enhance the farmed landscape. The regulation requires Member States to adopt ‘agricultural production methods compatible with the requirements of the protection of the environment and the maintenance of the countryside’. Under the ESA scheme, farmers receive positive incentives to manage land in an environmentally sensitive manner. Management agreements are designed to prevent further intensification and damage to landscape and wildlife, by restricting agricultural inputs and outputs to levels which maximize environmental benefits. The use of environmental management payments and the reduced emphasis on price support enables integration of agricultural and environmental policy. True integration should result in reduced agricultural output, maintenance
of farm incomes and farming populations, and environmental benefits e.g. conservation and enhancement of wildlife habitats and landscapes, and reduced pollution (Jenkins, 1990). Potential benefits from restoring lowland wet grassland on a floodplain include reduced inorganic additions to watercourses, stabilization of the soil by perennial vegetative cover, and increased habitat for wildlife.

There are also areas eligible for support within ESAs which have been intensi®ed: grasslands that have been drained, fertilized or reseeded, and areas previously used for intensive arable production. These areas are the focus of habitat restoration effort, since the scheme seeks not only to conserve existing ‘valued countryside areas, features and resources’, but also to enhance and restore them where possible. Farmers are most likely to participate in an ESA scheme where the opportunity costs are lowest. Potentially, the entry of the more marginal, low-lying areas will bring both a greater saving of inputs and more substantial benefits from compensatory payments.

The Upper Thames Tributaries ESA

The Upper Thames Tributaries (UTT) ESA was designated by the Ministry of Agriculture, Fisheries and Food (MAFF) in 1994 primarily to protect the landscape and wildlife value of extensively managed, unimproved wet meadows and pastures. There are three tiers of entry. Tier 1 requires the maintenance of permanent grassland to preserve wildlife and landscape interest. Where speci®ed water levels can be maintained, permanent grassland is eligible for Tier 2 payments, designed to conserve and enhance ecological interest, especially its suitability for overwintering and breeding birds. Tier 3 is intended to facilitate the reversion of arable land to permanent grassland: Tier 3A toward permanent pasture in general and Tier 3B speci®cally toward wet grassland. The level of compensation payment rises with increasing constraints upon farming practices, from £30 ha$^{-1}$ for the maintenance of permanent grassland to £330 ha$^{-1}$ for the reversion of arable land to wet grassland.

As of 1993, further grants were available to cover a proportion of the costs of specified farm operations. Such eligible items include restoration of ditches (30%), provision of water penning structures and other works to control water levels (80%), and the provision of water supplies and fencing associated with the reintroduction of grazing (40%).

This paper focuses upon those reversion tiers designed to bring about the restoration of wet grasslands on former arable land. Currently the prescription for Tier 3B requires the establishment of a permanent grass sward using at least ®ve suitable species chosen from an approved list of indigenous grass species (MAFF, 1994). Species of wild or reseeded, and areas previously used for intensive arable production. These areas are ®ower may be included in the seed mixture, if desired. According to the MAFF, this Tier is expected to encourage a gradual re-colonization of wildlife species characteristic of river valley grassland, thus enhancing the landscape.

Habitat restoration

On the majority of sites ‘released’ from arable farming, agricultural practices have altered both site-physical factors (through cultivation, drainage and inorganic additions such as fertilizer) and biotic characteristics (through the increase in competitive weed species and corresponding decrease in desirable propagules). Such modi®cations, together with isolation from relict semi-natural grasslands, mean deliberate introduction of species will be necessary to ensure successful restoration.

For habitat restoration to be widely implemented, techniques must be relatively straightforward and cost effective. The precise techniques adopted will depend on the physical characteristics of a site, e.g. its location relative to potential sources of colonizing species, and on the time and financial resources available. There are a variety of methods available for the reinstatement of grassland vegetation, ranging from the wait-and-see approach of natural regeneration, to the use of commercially- or locally-produced seed and plant plugs, or turf translocation.

The utility of these techniques may be assessed according to their cost and technical feasibility, their relative ecological effectiveness and reliability, and the time taken, to achieve the desired ecological aims.
Techniques

Natural regeneration/colonization

In the absence of deliberate introduction of propagules, revegetation of any site will depend upon naturally occurring sources of propagules, which may either be present within the soil at a site (the seed bank) or may disperse from adjacent vegetation (the seed rain). The seed bank contains seeds of the above-ground vegetation, seeds of species of communities that previously occupied the site, and seed that has rained in from further afield. Replacement of semi-natural vegetation with agricultural crops results in altered soil seed bank composition, with decreasing numbers of seeds of ‘desirable’ species and increasing numbers of arable, annual weed seeds (Graham and Hutchings, 1988a, b; Leck et al., 1989).

If appropriate propagules are available at or adjacent to the site, this technique may be the cheapest method for restoring vegetation. Natural regeneration does not involve the acquisition of seeds and may merely require light soil disturbance to encourage germination of species from the soil. It also ensures that seed is of local provenance and of the correct ecotype for the region.

However, on sites used for arable cropping for a number of years, seed banks are likely to be degraded, and thus seed dispersal from nearby areas of semi-natural vegetation will be vital to the natural establishment of the desired vegetation. Fragmentation of remaining wetlands means that natural colonization is a slow and uncertain process.

Deliberate introduction of propagules

In many areas, artificial introduction of species may be the only way to ensure their arrival at a site. Propagules may be acquired from commercial sources or from extant habitats as seed or vegetative parts.

(1) Seed present in hay bales

Where propagules are acquired from a local species-rich meadow, seed will be of local provenance and of the correct ecotype. Seed present in hay baled from a ‘good’ meadow may introduce species that would not be available commercially, and ensure that all species introduced are ‘desirable’. However, the precise seed content of hay bales is difficult to predict, and will depend upon which species have ripe seed at the time of the hay cut, the length of time the hay lies on the ground and the prevailing weather conditions. There has been relatively little research on their use as a seed source, but Smith et al. (1996) suggest that the majority of seed in hay bales will be overwhelmingly of grass species.

(2) Topsoil

Topsoil taken from species-rich sites may be used to introduce seed and vegetative fragments. Since this technique damages donor sites, and may introduce undesirable weed seeds, it is probably most appropriate when the donor sites themselves are otherwise likely to be destroyed.

(3) Turf transplantation

The use of whole turfs from existing species-rich habitats should accelerate re-establishment of the entire community, but again damages the donor site. Differences in hydrology, aspect, substrate type, etc. between donor and receptor sites makes the success of transfer of wet turfs unpredictable, and these differences between sites may be responsible for changes in species composition after transplant. Although a useful technique, turf transplantation is most likely to be employed in relocating habitats, and its cost in restoring whole habitats may be prohibitive.

(4) Container-grown plants

Seedlings or established plants may be used either densely planted or acting as ‘nuclei’ from which further colonization may occur. Their use results in instant revegetation of a site, but is most often used for the diversification of existing vegetation through re-establishing desirable species. This technique may be very labour and cost intensive in terms of transport, planting and aftercare.
(5) Seed mixtures

The most common technique for the restoration of habitats on degraded land (and within CS and ESA schemes) is that of reseeding with suitable species to accelerate the establishment of ‘desirable’ vegetation (Countryside Commission, 1993). The use of seed is considerably cheaper than the introduction of species as transplants (Byrne, 1990), and can be carried out using standard agricultural techniques. However, species may have specific requirements for germination that are not met in the field, may be unavailable commercially or very expensive, and may be of the wrong ecotype or even from non-native sources.

Costs associated with habitat restoration

Re-creation of lowland wet grassland on farmland is constrained by the need to maintain an income from land in continued agricultural usage (Armstrong et al., 1995). The ESA tier payments are designed to encourage farmers to adopt such practices as are necessary to attain the ecological aims, while compensating for any reduction in income resulting from a more sympathetic form of land management. Switching from intensive to a more extensive form of husbandry does not simply mean, however, cessation of inorganic inputs and collection of a compensation payment. The successful reinstatement of species-rich communities may involve considerable effort and expense.

The cost of managing semi-natural vegetation is generally reckoned to be lower than that of commercial cropping (Cobham, 1983). There may nevertheless be high expenditure on one-off operations often required to reestablish vegetation. Close account has to be taken of four critical aspects, namely soil nutrient levels, site hydrology, availability of propagules and choice of site.

Soil nutrients

Residual soil fertility may influence the success of propagule introduction. Many arable sites are characterized by high nutrient availability, giving rural and agricultural species a competitive advantage over slower growing herbaceous perennials which often characterize semi-natural vegetation (Hodgson, 1989). A reduction in the soil nutrient status may therefore be necessary if the restored vegetation is to persist (Marrs et al., 1991), and a variety of methods have been suggested, ranging from repeated cropping to topsoil stripping or deep ploughing. Costs vary widely, with removal of topsoil being expensive (>£2000 ha\(^{-1}\)), whilst deep ploughing may only cost somewhere of the order of £50 ha\(^{-1}\) (Nix, 1995).

Propagules

Choice of technique will have implications for the overall cost, for example, seed from commercial sources may be available in both native and non-native strains. In conservation terms, it is desirable to use seed as local to the restoration site as possible, and native seed would always be preferred over non-native seed. However, acquiring native seed of certain species (if available) may involve a considerable increase in price over non-native seed, e.g. in 1993 (when the seed was procured) ‘British’ Yorkshire fog cost £54 kg\(^{-1}\), whilst the European strain cost only £4.50 kg\(^{-1}\).

Hydrology

Wet grasslands are sustained by particular hydrological regimes, with different communities requiring differing regimes. An understanding of the hydrology, and the ability to manipulate water levels may be vital to the success of wet grassland restoration, and one of the main considerations, since without the correct water-regime the wetland components of the vegetation may not persist (Willis et al., 1996). Different soil types will not be similarly affected by hydrological alteration. The drainage of peat soils, particularly, may result in irreversible physical and chemical alteration of the peat. Following increased aeration of the topsoil, mineralization of organic matter will result in the release of nutrients, particularly nitrogen (de Mars et al., 1996; van Duren et al., 1997), the water holding capacity of the peat will be
reduced, and the soil will shrink and decompose (Fojt, 1994). Whilst rewetting of peat should result in an increase in anaerobic conditions, reduced mineralization and lowered nitrogen availability, successful restoration cannot be ensured (van Duren et al., 1997).

The degree of intervention necessary to adequately control water levels will have a major influence on costs (Trewick and Sheail, 1991). Whilst systems that rely on natural flooding are likely to be reasonably inexpensive, involving construction of ditches, sluices and dams, pumped systems will be more expensive.

**Choice of sites**

There will often be little choice as to which site to restore. However, agri-environment schemes may offer multiple sites for the same use, and the choice of sites will have a bearing on the expense of the scheme. It is therefore important to establish which sites have the greatest potential to be successfully restored and which have the lowest associated costs in terms of soil fertility, seed sources and water management.

**Ecological evaluation and assessment of cost-effectiveness**

Environmentally Sensitive Areas were created to protect landscape and wildlife designated as ‘valuable’, e.g. extensive, permanent grasslands within the UTT ESA. Therefore, these habitats do not have to compare economically with more intensive cropping systems to justify their retention within the landscape. However, there is a need to determine the most cost-effective methods for achieving the desired goals. The evaluation of the available options, in terms of their cost-effectiveness, depends upon identifying the most appropriate ecological measures of success.

There are several procedures available for appraising alternative approaches to conservation. One established economic technique is Cost Effectiveness Analysis (CEA), which compares the costs of different options and assesses their relative effectiveness in meeting the objectives, identifying the option which provides the required benefits at least cost (Willis et al., 1996). In practice, CEA depends upon how the objectives are defined, and their achievement measured (Cobham, 1983). Cost Effective Analysis may therefore be ambiguous where objectives are imprecisely specified and where outputs cannot be easily measured. Restoration and agri-environment schemes frequently lack measurable objectives to assess their success. For example, there is an obvious difficulty in assessing how far the objective of ‘gradual re-colonization of characteristic wildlife species’ within the UTT ESA has been attained.

In assessing cost effectiveness the costs of carrying out restoration work, and of maintaining the site, need to be considered together with the benefits arising from the restored land. Whilst the costs can be identified relatively easily, the value of restored sites is much harder to measure. It is nevertheless important that the various benefits should be identified and measured, where possible. If nature conservation is the aim, there is usually no direct financial benefit, and assessment of benefits may need to be based on subjective criteria. However, in the context of continued agricultural usage of sites (albeit extensively) there will be measurable financial benefits, i.e. a hay crop and/or livestock yield, which should be accounted for in assessment if appropriate. In general, many of the benefits of restoration are not easy to quantify financially, e.g. the extra benefit in terms of reduced pollution of reducing or eliminating inputs on one site may be difficult to quantify for an area other than a whole catchment.

**The experiment**

An experiment began in 1993 to investigate the re-establishment of lowland wet grassland plant communities on land released from arable agriculture within the upper Thames tributaries ESA. Since re-seeding is the most frequently recommended method for restoration of grassland communities, the experiment focused on techniques based upon the re-introduction of species as seed. Both ESA and Countryside Stewardship schemes recommend the sowing of a limited range of grass species, together with wild flowers if
desired. If the sowing of a simple grass species seed mixture achieves the stated aims, then inclusion of wild flower seed may be unnecessary, but if such a mixture does not result in a species-rich wet grassland, additional species will need introducing at proportionately increased cost. The experiment addresses the question of how many species will need to be introduced to ensure successful habitat restoration, and at what cost.

The experiment consisted of a randomized block design with three replicate blocks, each consisting of ten $18 \times 38$ m plots, to which the $2 \times 5$ factorial combination of treatments were allocated at random. Five basic treatments were used, and each was repeated with and without a 'nurse' crop of *Lolium multiflorum*, giving 10 experimental treatments in total:

- **NR** (Natural regeneration)
  - No seed added;
- **HB** (Hay Bales)
  - Seed derived from hay harvested from the SSSI;
- **SM1** (Seed Mixture 1)
  - ‘Basic’ mixture of four species of grass;
- **SM2** (Seed Mixture 2)
  - ‘Intermediate’ mixture of six grass and five forb species;
- **SM3** (Seed Mixture 3)
  - ‘Comprehensive’ mixture of eight grass and fifteen forb species.

The composition of the seed mixtures (SM1–3) is given in Appendix 2.

### The study area

The study site occupied approximately 4 ha of the floodplain of the river Ray within the UTT ESA. The area is subject to seasonal inundation and is largely underlain by impermeable soils of the Denchworth and Fladbury series, which are unusually difficult to drain and cultivate resulting in the persistence of extensive wet meadows and pastures. Farmers thus take advantage of set-aside, Countryside Stewardship and ESA schemes to release such marginal sites from intensive arable use. The study site was in arable use for at least 15 years before being set-aside in 1993.

The experimental site was chosen for restoration to lowland wet grassland due to a number of factors:

- despite hydrological ‘improvements’, the river Ray (bordering the site to the south) still floods, resulting in seasonal inundation of the experimental area;
- such a frequently inundated site on heavy clay soil is probably marginal for agriculture;
- an existing drainage channel to the north offered the potential to manipulate water levels;
- immediately adjacent to the site was an unimproved, species-rich wet meadow, Long Herdon SSSI. It was hoped that this meadow might act as a source of propagules;
- locating the restored habitat adjacent to the SSSI adds to the ‘existing’ block of semi-natural and rehabilitating grasslands, buffering the nature reserve to some extent.

Although not within the ESA scheme, the study site was felt to meet the conditions of entry into Tier 3B, being an arable field on the floodplain adjoining an existing area of wet grassland suitable for entry into Tier 2.

### National targets for conservation of lowland wet grassland

The ability to evaluate effectiveness depends on clearly defined objectives. The aims of both ESA reversion to wet grassland and Countryside Stewardship restoration of waterside landscapes are too broad for use in evaluation of individual restoration schemes. In particular, those community types in need of restoration need to be defined. The National Vegetation Classification (NVC) (Rodwell, 1992) has made it possible to identify targets in terms of species composition and abundance within specific plant community types. Table 1 lists NVC community types characteristic of mesotrophic, lowland wet grasslands.

Particular concern and conservation effort are focused upon the unimproved, species-rich community types (i.e. MG4, MG5, MG8), notably the MG4 flood-meadows which are listed under Annex 1 of the Council Directive on the Conservation of Natural Habitats and Wild Fauna and Flora (The Habitats Directive, 92/43/EEC).
Table 1. National Vegetation Classification (NVC) plant communities present within lowland wet grassland habitats, together with mean species m$^{-2}$

<table>
<thead>
<tr>
<th>Community</th>
<th>Description</th>
<th>Species m$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG4</td>
<td><em>Alopecurus pratensis</em>—<em>Sanguisorba officinalis</em> grassland. Alluvial meadows on seasonally flooded land.</td>
<td>25-3</td>
</tr>
<tr>
<td>MG5</td>
<td><em>Cynosurus cristatus</em>—<em>Centaurea nigra</em> grassland. Typical ‘old’ hay meadows, typically on drier areas within wet swards.</td>
<td>23-5–24-9</td>
</tr>
<tr>
<td>MG6</td>
<td><em>Lolium perenne</em>—<em>Cynosurus cristatus</em> grassland. Improved dairying and fattening pasture on moist, freely-draining land.</td>
<td>15-0–19-7</td>
</tr>
<tr>
<td>MG7</td>
<td><em>Lolium perenne</em> ley and related swards. Improved swards, often sown, in lowland river valleys.</td>
<td>7-4–13-3</td>
</tr>
<tr>
<td>MG8</td>
<td><em>Cynosurus cristatus</em>—<em>Caltha palustris</em> grassland. Water meadow vegetation on periodically inundated land.</td>
<td>19-3</td>
</tr>
<tr>
<td>MG9</td>
<td><em>Holcus lanatus</em>—<em>Deschampsia cespitosa</em> grassland. Floristically dull of low agricultural value.</td>
<td>13-4–14-2</td>
</tr>
<tr>
<td>MG10</td>
<td><em>Holcus lanatus</em>—<em>Juncus effusus</em> rush-pasture. Unproductive swards on permanently moist sites.</td>
<td>8-3–13-9</td>
</tr>
<tr>
<td>MG11</td>
<td><em>Festuca rubra</em>—<em>Agrostis stolonifera</em>—<em>Potentilla anserina</em> grassland. On moist, free-draining, possibly frequently-inundated soils.</td>
<td>11-6</td>
</tr>
<tr>
<td>MG12</td>
<td><em>Festuca arundinacea</em> grassland. Coastal moist, free-draining soils.</td>
<td>9-8</td>
</tr>
<tr>
<td>MG13</td>
<td><em>Agrostis stolonifera</em>—<em>Alopecurus geniculatus</em> grassland. Moist, sometimes waterlogged swards.</td>
<td></td>
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</tbody>
</table>

In addition to floristic targets, there may be other ecological targets depending upon the biota to be promoted. For example, many invertebrates characteristic of wet grasslands are adapted to specific plant species, e.g. the main food plant of the Orange-tip *Anthocaris cardamines* is the Cuckooflower *Cardamine pratensis*. Sowing of specific species may thus promote particular species of fauna. Moreover, bird species characteristic of lowland wet grasslands do not necessarily utilize the most species-rich fields, with factors such as soil penetrability and vegetation structure of greater importance than the individual plant species present. Since the present study was designed to investigate the re-establishment of species-rich grassland, all targets were defined solely in terms of vegetation composition.

**Lowland wet grassland targets for the river Ray catchment**

**Vegetation communities**

It is essential when restoring habitats to ensure that the chosen area, currently supports, or has in the past supported, the communities proposed for restoration. A botanical survey of river valley grasslands within the study area (Treweek et al., 1993) revealed the older swards to be a mosaic of MG4, MG8, MG9 with MG5 limited to the more elevated/freely-draining areas. Those fields ‘improved’ by past nitrogen application and under-drainage tended towards MG6 and MG7. In addition, all community types listed in Table 1 do occur within the catchment with the exception of MG12.

Whilst MG4 is the only community to be explicitly mentioned in relevant biodiversity plans, any of the less ‘improved’ communities could be considered of importance and in need of promotion, and all are important in the context of the UTT ESA (Lambrick and Robinson, 1988). Habitat restoration on the floodplain should therefore focus principally upon the reinstatement of species-rich grasslands, although maintenance of the existing full range of communities may ensure that species groups other than plants also benefit.

**Site-specific targets for the restoration experiment**

Once broad targets have been identified at the national scale, and modified regionally, site-specific targets are necessary. For the purposes of this study, a local ‘reference habitat’ or ‘target’ community was used to define the botanical targets for the restoration experiment, thereby ensuring consistency with
both the local environment and national species distributions. The adjacent SSSI was chosen to act as a ‘template’ for the restoration.

**Target NVC community types**

As variation within-fields was widespread (with reasonably small changes in topography/hydrology/soils responsible for transitions between community types), it was felt inappropriate to isolate any one community type as an absolute target, particularly since the target vegetation comprised components of various communities characteristic of old grasslands within the region, i.e. MG4, MG5, MG8 and MG9.

**Target species**

Intensive survey of the SSSI prior to the experiment led to the formulation of specific floristic targets. Such officially scheduled sites may be defined as ‘valuable’ and hence all grassland species found within the SSSI were considered suitable, and subsequently designated as Class II target species. The appearance of any of these species within the restored vegetation would thus be considered desirable, since old, unimproved wet grassland in the area already supports these species. However, it was recognized that the introduction of all species from the SSSI target habitat would not be feasible. Not only were many of the species unavailable commercially, and perhaps difficult to hand-collect in sufficient quantity, but the inclusion of such a diverse range of species would likely make any seed mixture prohibitively expensive. The proximity of a species-rich source of suitable propagules should also ensure that at least some of the species might colonize the restoration site naturally, thus negating the need to introduce them. Accordingly, a subset of the Class II species (Class I target species) were defined on the basis of species’ requirements for available soil moisture and nitrogen (Ellenberg, 1988). Class I target species were considered the ‘core’ of desirable species for inclusion in wet grassland, from which experimental Seed Mixtures were derived.

**Species richness**

The main grasslands of conservation interest have been described as species-rich, varied swards of grasses and herbaceous dicotyledons (Rodwell, 1992). Therefore total numbers of species and small-scale species-richness were also considered important in the experiment. The mean number of species per m² in adjacent grasslands of differing management histories ranged from set-aside fields (mean of 6·2 species m⁻²; SE 0·54) to the unimproved grasslands (19·9 species m⁻²; SE 0·46). A species-richness approaching that of unimproved grassland was thus adopted as a desirable target.

**Evaluation of experimental results**

The use of the SSSI as a template set unusually high standards for the restoration experiment. Most land in the countryside is not subject to statutory nature conservation designation, and within the UTT ESA itself there is a great variation in ecological quality. Maintenance of the full range of successional stages and, to some degree, of the differing levels of intensification represented may well be important for sustaining the full range of ‘characteristic’ wildlife, e.g. species-poor swards may be of importance to certain over-wintering and feeding birds.

It is not feasible to expect all land to be of SSSI quality. Considering the length of time taken for semi-natural, unimproved communities to develop, the setting of such rigorous short-term goals may apparently doom restoration projects to failure. In practice, evaluation of the restored vegetation was performed using a variety of measurable, predefined criteria:

1. Similarity to valued NVC community types (i.e. MG4, 5a, 8):
   (a) As assigned by TABLEFIT (Hill, 1996);
   (b) Numbers of target community constituent species present.
2. Numbers of sown species established.
3. Species-richness:
   (a) Total numbers of species;
   (b) Numbers of Class II species present;
   (c) Numbers of Class I species present;
Table 2(a). Summary of experimental results by 1996 (third year)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of species</th>
<th>Number of unique species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Class I</td>
</tr>
<tr>
<td>Natural Regeneration</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>Hay Bales</td>
<td>36</td>
<td>9</td>
</tr>
<tr>
<td>Seed Mix 1</td>
<td>28</td>
<td>8</td>
</tr>
<tr>
<td>Seed Mix 2</td>
<td>37</td>
<td>12</td>
</tr>
<tr>
<td>Seed Mix 3</td>
<td>45</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 2(b). Similarity to target communities (results of TABLEFIT analysis)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Best Fit</th>
<th>MG4</th>
<th>MG5a</th>
<th>MG8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Regeneration</td>
<td>MG9a (36)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hay Bales</td>
<td>MG7b (29)</td>
<td></td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Seed Mix 1</td>
<td>MG6a (34)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Mix 2</td>
<td>MG6a (44)</td>
<td></td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>Seed Mix 3</td>
<td>MG4, MG8</td>
<td>33</td>
<td>31</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 2(c). Numbers of constituent species present, as identified from the NVC constancy tables (Rodwell, 1992)

<table>
<thead>
<tr>
<th>Community</th>
<th>NVC</th>
<th>SSSI</th>
<th>NR</th>
<th>HB</th>
<th>SM1</th>
<th>SM2</th>
<th>SM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG4</td>
<td>72</td>
<td>48</td>
<td>15</td>
<td>19</td>
<td>15</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>MG5a</td>
<td>81</td>
<td>47</td>
<td>15</td>
<td>20</td>
<td>16</td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>MG8</td>
<td>70</td>
<td>43</td>
<td>10</td>
<td>16</td>
<td>12</td>
<td>16</td>
<td>19</td>
</tr>
</tbody>
</table>

(d) Proportion of the vegetation accounted for by Class II species;
(e) Small-scale species-richness (species m⁻²).
(4) Numbers of unique species contained within treatments.

Summary results for the third annual survey (1996) are presented in Table 2a–c, indicating the magnitude of the differences between techniques. The information presented in Table 3 shows a simple ranking of the restoration treatments in terms of their effectiveness at meeting the criteria.

Statistical analysis of results

The experimental results were compared using Analysis of Variance (ANOVA) to identify significant differences between treatments in terms of the numbers of species present. Treatment differences were assessed using Tukey’s HSD multiple comparison test. Statistically significant differences between treatments existed for: numbers of target community constituent species present (P<0.05), total species richness (P<0.05), numbers of Class I (P<0.001) and Class II (P<0.005) species, and small-scale species-richness (P<0.05). However, for the purposes of this paper treatment results are considered only in terms of their ‘effectiveness ranking’ (based on the criteria listed).

Results: cost effectiveness of experimental techniques

Where extremely high values are placed on the conservation of habitats, the financial costs involved may be irrelevant. In such cases, analysis may be limited to asking whether the chosen instrument is the most cost effective in achieving the aims, or whether other options may achieve the same results but at lower cost.

In the case of the UTT ESA, the policy objective of conservation, enhancement and re-creation of extensive permanent grassland and lowland wet grassland has been predetermined, and as such the question of ‘is it
Table 3. Ranking of treatments in terms of success at meeting criteria (1 most successful, 5 least successful)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Presence of MG4, 5a, 8</th>
<th>Number of constituent species</th>
<th>Total species</th>
<th>Target species</th>
<th>Proportion of Class II</th>
<th>Unique species</th>
<th>Species per m²</th>
<th>Additive total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Regeneration</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Hay Bales</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Seed Mix 1</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Seed Mix 2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Seed Mix 3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
worth doing?' is of less importance than 'how best can it be achieved?'

In the case of Tier 3B arable reversion the objective is to revert arable land to wet grassland for increased benefits to wildlife (MAFF, 1994), and considering one site, the costs involved are primarily those of the propagules used. All treatments require seed bed preparation, and all but natural regeneration may incur the costs of propagules and sowing. Initial differences in labour costs (i.e. sowing) between treatments may not significantly affect the choice of treatment over relatively small areas in a real farm situation. Aftercare will also be the same for all treatments, i.e. traditional meadow management of cutting for hay and aftermath grazing. Additional costs (i.e. nutrient-stripping or water-control structures) would be of increased importance when considering the relative cost effectiveness of restoring different sites, but the choice of propagule source for use within one site will be unaffected by such costs.

**Similarity to NVC community types**

| TABLEFIT. NR and SM1 did not approximate to target communities (Table 2b). SM3 was clearly the most effective, although the goodness-of-fit values are low compared to those of SM2. The choice of technique would depend on the importance attached to the restoration of the target communities, i.e. if MG4 were not especially valued, SM2 represents greater value for money, approximating more closely to MG5a and MG8, and costing less than SM3. |
| Constituent species present. NR and SM1 produced the lowest numbers recorded (Table 2c). SM3 appears to be most successful, but is not so markedly more effective than SM2 or HB considering the increased numbers of species introduced. SM2 and HB produced very similar results. |
| **Establishment of sown species** |

Costs of the seed mixtures vary considerably, being highest for the mixture that could potentially establish the highest number of species. If money is not to be wasted, successful germination and establishment of all sown species is essential. For an extra £504 ha⁻¹, SM3 increases the number of sown species established by 80% relative to SM2 (Appendices 1 and 2). However, the difference in price per hectare between SM2 and SM3 is also roughly 80%, and thus both mixtures could be deemed effective.

**Species-richness**

| Total numbers of species, Class II and Class I target species. SM3 produced the highest total numbers of species (Table 2a), accounted for by the 'extra' contribution of the sown seed. There is little difference between SM2 and HB, suggesting that these two treatments may have introduced roughly the same numbers of species. NR and SM1 perform similarly poorly. Whilst SM3 maximizes the numbers of species present, it does so at considerably increased cost, and thus in terms of cost-effectiveness, HB is probably the best option, considering the minimal cost of the seed source. |
| Proportion of the species complement accounted for by target species. This criterion should only be considered in the context of total species-richness (Table 2a). SM3 not only maximized the total number of species, but also contained the highest proportion of target species. NR appears to perform nearly as well as SM3, but is a species-poor option (SM3 contains 60% more species). This criterion could alternatively be considered in terms of numbers of non-target species present (total species minus Class II species). NR does contain fewer non-target species, with very little differences between the remaining techniques. |
| Small-scale species-richness. Unsurprisingly, the addition of seed mixtures with varying numbers of species appears to be responsible for differences in number of species m⁻² (Table 2a). The magnitude of the differences are small considering the very different numbers of species sown, i.e. despite the sowing of double the number of species, at nearly double the cost, SM3 provides only two more species m⁻² than SM2. |
Numbers of unique species to treatments

Whilst SM3 contained the highest number of treatment-specific species, many were sown in that treatment (Table 2a), and thus there is an increased cost attached to their presence. The only unsown Class I target species present in SM3 is, however, a nationally scarce species (*Oenanthe silaifolia*).

The differences between HB, SM2 and SM3 can largely be explained by the differing numbers, and types, of propagules introduced. SM3 contained increased numbers of treatment-specific species over both HB and SM2, but this seed mixture did contain a number of ‘rarer’ species that SM2 did not. The species introduced in SM2 were some of the more common species of wet grassland, the majority of which were also introduced in SM3. The higher numbers of treatment-specific species in HB than SM2 is attributable to the contribution made by Class II species from the SSSI (the source of the hay seed).

Discussion

Operations associated with habitat restoration

The overriding motive of farming is to increase yields and maximize output. ESA management agreements are not made in perpetuity, and with the possibility that land may be reclaimed for intensive agriculture at some future point, land managers will be unlikely to undertake operations which will impair the potential of the land for future farming. Thus, only in the most exceptional cases would they contemplate removing topsoil so as to reduce the nutrient status of land to levels more suitable for the persistence of semi-natural communities. Indeed, it has been suggested that farmers within the Suffolk River Valleys ESA may have delayed re-entry into the Scheme in order to carry out practices to increase the productivity of their land (Whitby, 1994).

In addition, as demonstrated by the experimental site, much of the marginal land most suitable for restoration of lowland wet grassland may not have high levels of residual soil fertility. Improvement of marginal floodplain land is in itself less cost effective than the improvement of drier, higher-lying sites, and thus such land may not have been as intensively improved.

Propagule costs

Land managers not actively interested in conservation are likely to select the cheapest available option. As such, it is unlikely that more expensive restoration techniques would be voluntarily chosen over cheaper methods. If it were decided that a more diverse seed mixture (or other expensive method) did indeed provide increased environmental benefits, compensatory payments would need to be increased, or an additional payment within the first year required, to at least meet a reasonable proportion of the cost of the more expensive technique.

Additionally, the guidelines for the reversion of arable land currently state that the grass seed mixture used should, where practicable, be of British origin. As previously mentioned, differences in price between native British seed and seed of foreign stock may be considerable. It is debatable whether, particularly for agricultural grasses, there will be any difference between plants established from foreign or native seed. Indeed, considering the long history of agriculture, it is probable that ‘local provenance’ of certain species no longer exist.

Summary of propagule sources evaluated

Natural Regeneration (NR). Even with an adjacent source of propagules, numbers of target species remained low implying that natural regeneration will not result in a species-rich wet grassland in the short-term. Despite the low cost of this technique, the benefits arising are minimal.

Hay Bales (HB). The use of hay bales successfully introduced greater numbers of species, but many were patchily and unevenly distributed within the sward (accounting for low species-richness per m²). This method of introduction has been moderately effective in
achieving the aims, and if hay is available is relatively inexpensive.

**Seed Mix 1 (SM1).** SM1 approximated to the prescribed mixture for Tier 3B, but the expected colonization of the grass matrix by ‘characteristic’ species was minimal during the three years of the experiment. This mixture achieved little that natural regeneration did not, suggesting that there is little ecological value, certainly in the short-term, in sowing a limited range of fairly ubiquitous grass species.

**Seed Mix 2 (SM2).** This intermediate seed mix resulted in higher numbers of species and higher small-scale diversity than NR or SM1, with greater affinity to the target communities than NR, HB or SM1. This seed mixture provided greater benefits than NR or SM1, but overall appeared to perform similarly to HB.

**Seed Mix 3 (SM3).** Re-seeding with a diverse range of species was reasonably successful at reintroducing species. Despite the failure of some species to establish, this was the option that offered the most potential for reinstatement of MG4, the most characteristic community of the Upper Thames area and the only British wet grassland community type to be considered of international conservation importance. In addition, the sward developed from SM3 contained a nationally scarce species, *Oenanthe silaifolia*, which occurs naturally within the region. Whether the species-rich sward was actually more suitable for the establishment of this species, or whether *O. silaifolia* would be present regardless is questionable.

**Hydrology**

One of the main expenses of the restoring wetland habitats derives from the need to reinstate an appropriate hydrological regime. Tier 3 currently covers both arable reversion to extensive permanent grassland (Tier 3A) and to wet grassland (Tier 3B), with both targeted on arable land on the floodplain. In both cases, the farmer is required to follow Tier 1 (permanent grassland) guidelines, whilst Tier 3B also requires management to be in accordance with Tier 2 (wet grassland) guidelines. Where the site under consideration requires a high degree of engineering to meet the water management prescription, the farmer might take the easier (and equally valid) course of reverting the land to permanent grassland. The difference in payment of £50 ha\(^{-1}\) between the two Tiers may be insignificant when the additional constraints imposed upon Tier 3B are considered, i.e. maintenance of water levels in ditches and watercourses, prohibition on grazing livestock between 1 April and 15 May, and the cessation of organic and inorganic fertilization (including farmyard manure).

Given its obvious nature conservation value, it might be suggested that the SSSI adjacent to the reversion site was suitable for entry into Tier 2 as an existing example
of the type of valued wet grassland habitat characteristic of the Upper Thames Tributaries ESA. The wetness status of the grasslands on the floodplain is naturally maintained by seasonal inundation and relatively impermeable soils, rather than by high water-tables. However, the Tier 2 requirement for artificially maintained, increased water levels was expected to be met following the installation of a sluice on a drain to the north of both the SSSI and the reversion site. Extremely low flow in the main river, and low rainfall within the experimental period (Rose and Armstrong, 1996), has meant that levels have not been maintained. The low hydraulic conductivity of the soils prevents quick lateral movement of water, such that even if water levels were maintained in surrounding watercourses, undrained soils would be unlikely to benefit through increased wetness. Previously drained fields, such as ex-arable sites, could potentially benefit from increased ditch levels as the existing under-drainage could function in reverse to bring water into the field from the surrounding watercourses.

Whilst, the reinstatement of appropriate hydrological regimes has been identified as essential to wetland restoration, the unnatural maintenance of water levels may not actually be appropriate for floodplain areas. The character of existing grasslands, currently sustained by natural flooding, may be damaged by the implementation of a ‘new’ hydrological regime. It may be more appropriate to increase flooding frequency by addressing the problem of low river flow than to artificially raise water levels. The lack of water not only has implications for the creation of new habitat, but also for the maintenance of the existing wet grasslands, i.e. in order to protect and prevent irreversibly damaging the SSSI, the provision of adequate water supplies to maintain this habitat needs to be ensured.

Regardless of precise water control, it is likely that the revegetation of the floodplain site with perennial cover will have benefits to the environment other than specifically to wildlife species or aesthetics. For example, Rose and Harris (1994) found that 5 year non-rotational set-aside (or establishment of unfertilized grass) upon areas of clay land previously cropped rapidly reduced the amount of nitrate-N leachate to surface waters.

**The ESA scheme**

The success of ESAs in delivering ecological benefits and increasing diversity upon farmed land will closely reflect the efficacy of prescriptions (Appleby, 1994). Where prescriptions are inadequate to ensure the conservation of species and habitats central to the value of individual ESAs, benefits will be minimal. One distinct problem is the lack of specified measurable outputs. Although an increase in the number of characteristic species would seem an obvious criterion, it would nevertheless exaggerate the value of natural regeneration, the least effective technique considered in terms of the objectives set for the experiment. Since a ‘set-aside’ sward is likely to have little value for hay-making or grazing, the next cheapest options would be the use of hay seed or the most basic seed mixture. Hence, in the context of the current aims of the UTT ESA (and the expected benefits), the basic seed mixture (approximating to that recommended) would seem the most appropriate. Agronomically, it is more valuable than the NR sward. Although not providing the greater benefits associated with the more comprehensive seed mixtures, or hay bales, it does contain characteristic species, and could thus be perceived as encouraging a gradual recolonization of wildlife and hence considered effective.

**Final summary**

The economic value of many of the potential benefits of conservation is difficult to measure with precision. Regardless of the benefits, farmers are unlikely to participate in long-term agreements if the level of payment does not adequately compensate for loss of income and the investment required to initiate the scheme. An individual farmer, not specifically interested in conservation, would generally choose the cheapest available option requiring the least effort to implement.

Of the techniques reviewed by this paper, in meeting the criteria set for the experiment, the most comprehensive seed mixture (SM3)
would appear to be the most successful, followed by the intermediate seed mixture (SM2), and then hay bales (HB), the basic seed mixture (SM1) and lastly natural regeneration (NR).

If restoring semi-natural communities and maximizing species-richness is the ultimate aim, with less importance attached to the costs than to the benefits, SM3 is the option most likely to produce the desired results. If the intention, however, is simply to fulfill the more modest goals as set out in the ESA prescriptions, namely the gradual recolonization of characteristic wildlife, each of the treatments has the potential to be successful. However, hay bales or seed mixtures would always be chosen over natural regeneration in the context of continued agricultural usage of the land.

References


Appendix 1

Costs of experimental treatments (1993 prices)

(Sowing rate for seed mixtures: 40 kg ha\(^{-1}\))

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cost per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Regeneration</td>
<td>No cost</td>
</tr>
<tr>
<td>Hay Bales</td>
<td>No cost (if bales available)</td>
</tr>
<tr>
<td>Seed Mix 1</td>
<td>£156.29</td>
</tr>
<tr>
<td>Seed Mix 2</td>
<td>£628.22</td>
</tr>
<tr>
<td>Seed Mix 3</td>
<td>£1132.89</td>
</tr>
</tbody>
</table>
Appendix 2

Seed Mixtures

(Commercially unavailable species are in parentheses)

Seed mixture 1 (Basic)
*Alopecurus pratensis*, *(Anthoxanthum odoratum)*, *Cynosurus cristatus*, *Festuca rubra*, *Phleum bertolonii*

Seed mixture 2 (Intermediate)

Grasses
- *Agrostis capillaris*
- *Alopecurus pratensis* *(Anthoxanthum odoratum)*
- *Cynosurus cristatus*
- *Festuca pratensis*
- *Festuca rubra*
- *Holcus lanatus*

Herbs
- *(Cardamine pratensis)*
- *Filipendula ulmaria*
- *Leucanthemum vulgare*
- *Lotus corniculatus*
- *Ranunculus acris*
- *Trifolium pratense*

Seed mixture 3 (Comprehensive)

Grasses
- *Agrostis capillaris*
- *Alopecurus pratensis* *(Anthoxanthum odoratum)*
- *Briza media*
- *Cynosurus cristatus*
- *Festuca rubra*
- *Holcus lanatus*
- *Hordeum secalinum*
- *Trisetum flavescens*

Herbs
- *Achillea ptarmica*
- *(Cardamine pratensis)*
- *(Carex disticha* or *C. panicea)*
- *(Carex nigra)*
- *Centaurea nigra*
- *(Cirsium dissectum)*
- *Filipendula ulmaria*
- *(Juncus acutiflorus)*
- *Lathyrus pratensis*
- *Leucanthemum vulgare*
- *(Lotus pedunculatus)*
- *Lychnis flos-cuculi*
- *(Lysimachia nummularia)*
- *Oenanthe fistulosa*
- *(Oenanthe silaifolia)*
- *Ranunculus acris*
- *(Ranunculus flammula)*
- *Rhinanthus minor*
- *Rumex acetosa*
- *Sanguisorba officinalis*
- *(Serratula tinctoria)*
- *Silcaum silaus*
- *Thalictrum flavum*
- *Trifolium pratense*
- *Vicia cracca*
Appendix 3

Establishment of sown species

SM1: All 4 species established
SM2: 10/11 species established (price of seed that did not establish = £196.79 ha⁻¹)
SM3: 18/23 species established (£287.14 ha⁻¹ of seed did not establish)