



- CHAPTER 1 -

GENERAL INTRODUCTION AND SUBJECT REVIEW

Nor is there much satisfaction in contemplating the world with nothing left to the spontaneous activity of nature; with every foot of land brought into cultivation, which is capable of growing food for human beings; every flowery waste or natural pasture ploughed up, all quadrupeds or birds which are not domesticated for man's use exterminated as his rivals for food, every hedgerow or superfluous tree rooted out, and scarcely a place left where a wild shrub or flower could grow without being eradicated as a weed in the name of improved agriculture.

Mill J. S. (1848) *Principles of Political Economy IV*: 6.2.

When we alter the biosphere in any direction, we move the environment away from the delicate dance of biology. When we destroy ecosystems and extinguish species, we degrade the greatest heritage this planet has to offer and thereby threaten our own existence.

Wilson E. O. (2002) *The Future of Life*. Little Brown, London.

SUMMARY

1. The processes of industrialization and homogenisation of agriculture in the twentieth century, and most particularly of the last 50 years, have led to wide-scale destruction of species-rich, semi-natural habitats. Traditional meadows and pastures have taken the brunt of these changes and it has been recently estimated that only 1-2% of grasslands have escaped agricultural improvement. Such statistics strongly support the need to reverse these trends through applied restoration ecology. Although ancient species-rich communities cannot be replaced, restoration science can attempt to establish and accelerate development of new grasslands, and restore diversity and other functional attributes to damaged systems.

2. In symbolic and practicable terms, attempting to reverse the loss of species-rich grassland through restoration represents a high-order commitment to environmental amelioration. The conversion of semi-natural mesotrophic (or neutral) grasslands such as MG5 *Cynosurus cristatus* - *Centaurea nigra* communities to intensive production has been particularly thorough and widespread. In response to these losses, the restoration of neutral grasslands is of a high priority in Biodiversity Action Planning. In addition, when restoration schemes are rigorously designed and monitored, they can provide useful ecological data, valuable both for examining practical and theoretical considerations.

3. However definitions of what "ecological restoration" entails in both theoretical and practical terms, abound. In North America, *naturalness* is the watchword. However in Britain a very small proportion of the landscape can be described as ostensibly *natural* in formation. Necessary pragmatism allows multiple definitions of restoration including *complete*, *functional* and *experiential*. Much controversy surrounds the basic dichotomy between *natural* and *artificial* (human) values in restoration. Even within the specified scope of human-directed restoration, debate is still provoked over the degree of intervention required. Overall though, the general consensus is that ecological restoration should always be secondary to the conservation of extant diverse ecosystems.

4. Much evidence suggests that even agriculturally depauperated grasslands can be more valuable in overall biodiversity terms than recently created ones. The fundamental management adjustment in restoring such grasslands is the cessation of fertiliser inputs. The depletion of artificially bulked reserves of phosphorus and potassium in the topsoil is also crucial, but complex in practice. Many studies demonstrated that efforts to reduce overall soil fertility and grassland productivity through cropping are often remarkably slow, and predicted to take decades or even centuries.

5. Another crucial limiting factor in restoration is natural recruitment of depleted species. In order to naturally re-assemble grasslands after agricultural perturbation it is very important to have unhindered sources of propagule inputs from unimproved species-rich habitats. However, because of the fragmentation of semi-natural habitats in contemporary landscapes, natural recolonisation may be so slow that the deliberate inoculation of grasslands with *missing* components through seeding and transplanting is the only practicable option. Introductions have the advantage in that they bypass the problems of natural dispersal and have the potential to produce rapid results, including the establishment of scarce and/or aesthetically attractive species.

6. The research projects detailed in this thesis have been undertaken in order to explore a range of methods for diversifying agriculturally improved mesotrophic grassland. The techniques studied include traditional cropping management; inoculation with transplants; introduction of seed; and the creation of artificial regeneration gaps. The results from this research are intended to provide a quantitative appraisal of practical techniques for grassland restoration.

Keywords: agricultural improvement, semi-natural, mesotrophic, restoration, naturalness, artificial, traditional, biodiversity, soil fertility, landscape, fragmentation, natural recruitment, propagules, introductions, cropping, inoculation, regeneration

INTRODUCTION

In his book of 1700 entitled *Campania Foelix*, the gentleman farmer Timothy Nourse implored those that managed the English landscape to redouble their efforts in the ‘Restauration of Nature’ (Thomas 1983). Initial impressions may indicate that this was an early clarion call to redress the damage humans had, even by then, already meted out on Britain’s biodiversity (Rackham 1986; Gordon & Duncan 1994; Ingrouille 1995). However, it was instead a petition to *modern* agriculturists to cultivate as much open and wild land as possible, so that both human and *biblical* order could be restored to wastelands such as ‘barren’ heaths and ‘filthy’ grasslands (Marshall 1789; Marshall 1992). Such strident attitudes towards farming, and its relationship with nature and the wider countryside, became far less biblical and far more scientific as the so-called *Agricultural Revolution* progressed from the 1700s onwards. For the first time, farmers began to have the economic and technological means with which they could significantly determine vegetation structure (Lane 1980). For grasslands, this meant that the majority of *naturally* occurring species, often deemed as ‘pernicious weeds’, could be subjugated and eradicated to make space for the selected few *desirable* species, consisting mainly of grasses (Buckman 1863; Davies & Davies 1997). However, as the majority of farmers were too poor, and/or uneducated to make the most of these opportunities, throughout most of this period, only gentlemen improver-farmers were able to develop agricultural impoverishment of grassland biodiversity (Davies & Davies 1997). Because of this, it was only until the socio-economic changes of the twentieth-century that dramatic transformations in grassland vegetation could be brought about by modern agricultural *improvement* (Ratcliffe 1984; Fuller 1987; Green & Burnham 1989; Stoate 1995; White 1996; Blackstock *et al* 1999).

The processes of industrialization and homogenisation of agriculture in the twentieth century, and most particularly of the last 50 years have changed the rural landscape as never before (Fuller 1987; Moore 1987; Green 1990; Hodgson & Grime 1990; Stoate 1996; Blackstock *et al* 1999; CIS 2000; Thirsk 2000). With rapid technological developments and wholesale subsidisation of agriculture, the pace of landscape and ecological change began to increase beyond even the wildest dreams of such early agricultural ‘reformers’ as Timothy Nourse and Arthur Young. In the UK, despite the designation of National Parks, National Nature Reserves, Areas of Outstanding Natural

Beauty and Sites of Special Scientific Interest, there has still been massive destruction of large tracts of natural and semi-natural habitats, and the continuing biological degradation of much of what is left (CIS 2000; FOE 2000; Haines-Young *et al* (2000). In fact, so much has been destroyed in the post-war period in Britain that there is now a growing movement among nature conservationists to not only conserve what is left, but also to redress the balance proactively by expanding the wildlife resource (Wells *et al* 1989; Green 1990; Wells 1990; Anderson 1995; Dryden 1997; Pywell *et al* 1997; Gilbert & Anderson 1998; Flora Locale 2000; Lyster 2000). In order to achieve this aim, there is an evident need to attempt to recreate and restore lost and damaged ecosystems (Baldwin *et al* 1994; Dryden 1997). Sheail (1995) cogently describes the common interface between modern agriculture and ecological restoration:

“The challenge, as taken up in the nineteenth century in respect of farming, may now provide a perspective for present-day efforts to sustain, rehabilitate and, in some cases, re-create wild plant and animal communities. The establishment and management of species of, say, the wetlands, heathlands and herb-rich grasslands require the same kind of scientific rigour that agricultural scientists strove to apply from the time of the first Rothamstead experiments.”

The post-WW2 loss of semi-natural grassland is an often-quoted icon of countryside depletion (FOE 2000; Pye-Smith 2000). It has been recently estimated that only 1-2% of grassland is agriculturally unimproved (Blackstock *et al* 1999). This is a high-profile representation of the overall depauperisation of the biodiversity of the British countryside (Westbrook 2000a). In symbolic and practicable terms, attempting to reverse the loss of species-rich grassland through restoration and recreation represents a high-order commitment to environmental amelioration (Baldwin *et al* 1993; Packard & Mutel 1997; Mitchley, Burch, & Lawson 1998). The conversion of semi-natural mesotrophic (or *neutral*) grasslands such as *Cynosurus cristatus-Centaurea nigra* (MG5) (Rodwell 1992) to intensive production has been particularly thorough and widespread (Frame *et al* 1994; Fisher *et al* 1996), and its successor grassland community types are now ubiquitous throughout Britain (Rodwell 1992; Haines-Young *et al* 2000). In Somerset, for example, the loss of species-rich, unimproved grassland has been as dramatic as elsewhere in England in the post-war period (White 1996; Whyte 1997; Gibson 1998). Neutral grasslands have been one of the main targets for agricultural improvement (White 1996). In response, to these losses, neutral grassland conservation and

restoration is of a high priority in Biodiversity Action Planning (SSDC 1998; Haines-Young *et al* 2000; Westbrook 2000b). Attempts at restoring diversity to impoverished swards are proliferating (Clark & Baldock 1994; Frame *et al* 1994; Hopkins & Hopkins 1994; MAFF 1998; Pywell *et al* 1997; Dryden 1997; Davies *et al* 1999; Flora Locale 2000a; Smith & Corkhill 2000; Westbury & Dunnett 2000). When these schemes are rigorously designed and monitored, valuable practical and theoretical lessons can be accrued.

In order to evaluate some of these aspects, the work described in this thesis is an experimental approach to understanding the factors involved in increasing the nature conservation value of previously agriculturally improved mesotrophic lowland grassland in Somerset. The primary aim was to assess the efficacy of some key methods of floristically restoring improved swards. Further research objectives included evaluation of the processes, time-scales and practicalities involved in grassland restoration.

The science of restoration: theory and practice

The dialectics of restoration ecology are central to the academic debate surrounding restoration (Clark 1997). Anderson (1995) and Bradshaw (1997) use dictionary definitions to draw the distinctions between ecological restoration and related methodologies. A primary delineation in the European context is often made between restoration and creation (Anderson 1995; Parker 1995). Restoration can suggest a sense of restitution, or reinstating some former state, renewal or replacement, or bringing back to health, whereas *creation* primarily implies the act of bringing something new into existence, the formation of a novel entity. Parker (1995) consolidates habitat creation as the activity of deriving an ecological “something from nothing”, implying that any land worth applying habitat creation to is so far removed from semi-natural biodiversity that restoration is not possible, and artificial enhancement methods are requisite. The Chambers Dictionary (1995) emphasises the process of restoration involving the return of “something lost or stolen”, or “the act of returning to a former and higher status.” Gilbert and Anderson (1998) identify restoration and creation as distinct phenomena, with restoration a defined process of restitution of degraded semi-natural habitat, and creation limited to development of “sites that are bare or support a simple community.” Strictly speaking, restoration can

be considered the activity of returning an ecosystem to a former (valued), pre-disturbance state (Throop 2000a), perhaps with the implicit goal of long-term sustainability (T. Kendle *pers. comm.*). Yet in the broader perspective Bradshaw (1997) and Bratton (2000) contend that this definition of restoration relates more to an essentially impractical *idealism*. Restoration, as defined by Bradshaw (1997) aims at returning an ecosystem to a previous *untouched* state. This presents a multitude of philosophical and objective defining problems, such as determining what the pre-disturbance systems were like, which one to use as a goal, the complexities of scale, and also the lack of understanding and resources to attempt restoration even if the parameters of the pristine system are objectively ratified (Bratton 2000; Throop 2000a). In contrast, rehabilitation and re-creation are seemingly applied solutions, allied with practicable outcomes (Clark 1997). Anderson (1995) and Throop (2000a) note that ecological restoration, creation and rehabilitation, in any case, are terms that can be, and are used “rather loosely”, their blurred distinctions a function of interlaced perspectives and the need for feasible results. This, perhaps, can be extended to the whole notion of *restoration*. In practical terms, distinctions can become indefinite, especially in the fluxing, highly managed landscape of Britain. For example, laying arable down to diverse grassland is creation, though very often the arable was claimed from previous grassland cover, thus the process may be broadly deemed restoration as well (Dryden 1997). Parker (1995) admits that with former peatlands, for example, that restoration and creation activities are delineated with difficulty. If tightly held designations are held, many schemes may regularly cross definition boundaries. McDonald (*pers. comm.*) favours the term *re-creation* for her work on Somerford Mead (McDonald 1993) because the continuity with the previous species-rich MG4 grassland cover had been lost through 20 years of intensive sheep grazing, silage harvesting and, finally, ploughing for barley crops. Though pragmatically her 1993 paper uses the term ‘restoration’ to describe the overall research aims. The prescription given by The Society for Ecological Restoration (2000) for informing its growing caucus of members, presents a broad perspective, which seems to derive restoration as an overarching umbrella term for landscape creation, re-creation, rehabilitation, reconstruction, enhancement, translocation, diversification, mitigation, invention and so on:

“Ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices.”

As shown by the SER definition, in broad terms, among United States ecological circles, restoration often seems to be all encompassing despite the burden *naturalness* imposes (Baldwin et al 1994; Howell & Jordan III 1989; SER 2000). Discounting antagonistic philosophical positions, restoration may span polarities such as reinstating natural wilderness areas, creating prairies, to seeding road cuttings with native seed mixes (Cottam & Wilson 1966; Jordan III et al 1987; Howell & Jordan III 1989). Clearly restoration ecology seems to engender a degree of contentiousness, and Urbanska et al (1997) also confess that what is meant by restoration is far from simple. Elliot (1997) and Katz (2000) emote polemically about the philosophical and ethical aspects of restoration ecology, emphasising the perspective that *naturalness* should be restoration’s primary goal, and if this is unattainable, then restoration is coherently flawed. In contrast, Packard & Mutel (1997) embrace the human interventionist approach, that the most distinctive aspect of restoration is the restorationist’s “commitment not just to rehabilitate or *heal* the land in the abstract sense, but actually to re-create a particular kind of ecosystem, returning it to the landscape and setting it in motion again.” Excluding extreme positions, much of the North American ecological restoration *experience* can be viewed as establishing normative rules in the reassembly of community-like groupings of plants and animals, native to an area, on suitable sites. Howell & Jordan III (1989) identify three main restoration trajectories: i. *complete restorations*, whereby the attempt is to establishment species groups “in abundances and proportions similar to those in natural communities such that natural processes occur”; ii. *functional restorations*, entailing the use plants established in community-like groupings “to perform general processes similar to those characteristic of natural communities”; and iii. *experiential restorations* with the aim to establish the “visual or emotional essence of natural communities, often with a simplified array of native species.” Clark (1997) emphasises similar restoration targets: functional equivalency of habitat and organism components, structural equivalency of habitat and organism, and elemental equivalency of habitat and organism. Cairns (1991) further expands the range of possible theoretical

restoration outcomes by defining eight classes of restoration ranging from “resetting the ecological clock” to allowing natural processes repair an ecosystem (Throop 2000a).

Clearly, complete restorations require the most ecological expertise and resource commitment. Although ethically this primary trajectory seems the most justifiable, it is debatable whether completeness is ever a realistic aim, as even with all the biotic and abiotic factors in place, totality of development cannot usually be considered feasible over normal human times-scales (Buckley & Knight 1989; Gibson & Brown 1992; Bradshaw 1997; Clark 1997; Gibson 1998). Most restorations pragmatically aim at achieving elements of the functional and experiential categories (Anderson 1995; Gilbert & Anderson 1998). Bradshaw (1997) contends that this pragmatism (Light 2000) is not really restoration *per se*, but better described as *rehabilitation*. Cairns (1986) identifies restoration success hinging on whether ecosystem recovery aims to attain reinstatement of *services* (functions beneficial to society, and/or *form* (ecosystem infrastructure such as species diversity and trophic complexity). The Society for Ecological Restoration (2000) considers a restoration to be successful when “*an ecosystem's biodiversity, functions, ability to accommodate normal disturbances, and abiotic services closely compliment these same attributes in the conceptualised reference ecosystem.*” Complete restorations, though, remain little more than an ideal (Bradshaw 1997), and Elliot (1997) is critical of any restoration attempt without naturalness at the pinnacle. However, the process of trying to assemble and recover a damaged ecosystem can be a highly valuable scientific exercise in itself (Bradshaw 1987), and a *heuristic* undertaking (Helliwell 1989; Clark 1997). It provides a means of gaining greater insight into to the functioning of ecosystems (Bradshaw 1993; Ewel 1987; Edwards *et al* 1997), and an opportunity for posing and answering questions about the communities or ecosystems being restored (Howell & Jordan III 1989; Packard & Mutel 1997). However, Urbanska *et al* (1997) consider that restoration is still all too often based on a *trail-and-error* basis.

Though contested definitions and semantics abound concerning the absolutism or particularism of restoration ecology, it is apparent that the Society for Restoration Ecology has attempted to established restoration as an inclusive description, notwithstanding perfectionist overtones (Bradshaw 1997). As with all relatively new

disciplines, there are multiple competing interests to solidify a centralising credo. The term *restoration ecology* can represent the polarities of both a philosophically diverting debating point (Elliot 1997; Katz 2000), or a thoroughly practical broad description for landscape rehabilitation, enhancement, re-creation etc. Whether rightly or wrongly, restoration seems to be becoming fixed as a generic term for proactive (i.e. non-preservationist) conservation activities. Linguistic pedantry aside, there is no reason why restoration (relating to ecology) should not evolve, by common consent, into a term that encapsulates – or perhaps usurps - related activities. *Restoration* is therefore used as the collective term for the research described in this thesis.

Overall, there is a general consensus that ecological restoration is a poor substitute for the conservation of extant diverse ecosystems (Anderson 1995; Marren 1995; Parker 1995; Elliot 1997; SWT 1998; Cairns 1999; Flora Locale 2000a; Katz 2000; Jones 2001). While theorists such as William Jordan and Frederick Turner controversially elevate restoration science as a new environmental paradigm (Baldwin *et al* 1994), traditional conservation biology is still seen as the bedrock of maintaining biodiversity (Martin 1996). This position is underpinned by the code that first priority must always be given to safeguarding the remaining high-quality areas (Newbold 1989; Jones 2001). As Martin (1996) states, “*The basic principle adopted should be that it is more useful to hang on to what habitat we have left, than to try to re-create it from fresh (in second-rate form, at high expense) on land already degraded.*” The Society for Ecological Restoration (2000) states that it “will not sanction the destruction of any ecosystem on the pretext that it may be restored.” Habitat restoration, however, can be used in various ways to reverse the considerable losses of all habitat types, and add to the overall natural resource, rather than be considered as a *second-rate* or *ersatz* answer to the continuing destruction of habitats (Gilbert & Anderson 1998; Jones 2001), or what Elliot (1997) refers to as “faking nature”. Katz (2000) goes further in describing the “restoration thesis” as a “big lie”: “*It is a policy that makes the best of a bad situation; it cleans up our mess. We are putting a piece of furniture over the stain in the carpet, for it provides a better appearance. As a matter of policy, however, it would be much more significant to prevent the causes of the stains.*” Such strident philosophical views, though almost hostile, help to underline the essential pragmatism inherent in restoration, which allows restoration objectives to be refocused on

practical solutions rather than the ‘head-in-the-clouds’ concentration on the centrality of *naturalness* and *wilderness* (Throop 2000b).

Although, with regard to the above noted caveats, restoration ecology, without doubt, has an increasingly important part to play in nature conservation and sustainability (Bradshaw 1983, 1987; Cairns 1993; Baldwin *et al* 1994; Packard & Mutel 1997; Throop 2000b; Young 2000). Because of the huge biodiversity losses over the latter part of the 20th, restoration may have a pivotal function in redressing some of this damage to ecosystems, especially in strategic conservation programmes (Anderson 1995; Gilbert & Anderson 1998; Mitchley *et al* 1998; Cairns 1999). These main roles are outlined below:

- The recovery, rehabilitation, rejuvenation and recreation of degraded and *insulted* land (Packard & Mutel 1997). This may encompass increasing the resource of all grades of ecosystem or targeting specific key habitats and species. The objectives may extend from attempting complete restorations to biodiversity enhancement (Berendse *et al* 1993; McDonald 1993; Bakker & Berendse 1999; Davies *et al* 1999; Hopkins *et al* 1999; SSDC 1999)
- Restoration has a useful role in buffering ecosystems from deleterious edge effects through developing additional protective habitat layers around high-grade patches (*supportive natural capital* around sites of *critical natural capital* e.g. SSSIs; (Newbold 1989; Kendle 1992; Gilbert & Anderson 1998; Crofts 1999; MAFF 1998; SWT 1998; Yeo *et al* 1998).
- Use of restoration to network isolated high-grade habitat patches and fragments, thus forming connective wildlife corridors – wildlife infrastructure (Newbold 1989; Gilbert & Anderson 1998; Mitchley *et al* 1998; Blackstock *et al* 1999; Bright 1999; SSDC 1999; SER 2000).
- Biodiversity gains through restoration often improve landscape amenity, utilitarian facility and educational potential, adding to the *political* landscape (Anderson 1995; Dryden 1997; Gilbert & Anderson 1998; MAFF 1998; Flora Locale 1999; SER 2000).

Ecological restoration as practiced in Europe, has differed significantly from that of North America (Elliot 1997; Gilbert & Anderson 1998), though there is a steady conflation, especially with the recognition that North American ecosystems are probably more *semi-natural* than once perceived (T. Kendle *pers. comm.*). Few, if any European habitats can be termed *natural*, that is, free from major human influence (Newbold 1989; Ingrouille 1995; Thirsk 2000), and even *near-naturalness* is restricted to a very few areas (Usher 1986). Overall, European ecosystems are artefacts of varying degrees of human-nature interactions. This basic fact thus annuls the much of the

‘natural’ versus ‘human’ landscape debate outlined above, and still at the heart of non-European restoration philosophy (Throop 2000a). Within the UK context ecological restoration is mostly concerned with rehabilitating and re-creating wholly semi-natural *nature*, such as recuperating species-richness to traditional socio-economic ecosystems, such as meadows and coppice woodlands (Dryden 1997; Gilbert & Anderson 1998; Crofts 1999). This may be counter to ‘pure’ biodiversity conservation (Hambler & Speight 1995; Jarman 1995), but is more sympathetic to the complexity of human involvement in the natural history of the British Isles, and concurs with the restoration-sustainability faction in US restoration philosophy circles (Throop 2000b). The increasingly acute restoration debate in the UK context, in ironic contrast to the US situation, revolves around the credence given to restored/created habitats in relation to extant *semi-natural*, species rich ecosystems, and the perceived danger of too closely equating parity between mature and restored habitats, even if biological indicators are comparable (Buckley & Knight 1989; Gibson 1998; Flora Locale 2000; Jones 2001). Restoration is viewed by some camps as undermining the protection of extant habitats, and in the mêlée of development planning and governmental resource allocation, restoration can be perceived as a weapon for advancing the concept of the *expendability* of wildlife habitats (Buckley 1989), or what Light (2000) terms *malicious restorations*. As already discussed, restoration is a function of degree – the degree of damage incurred by the ecosystem, and the degree of human intervention to enable effective recovery. Degree of restoration *effort* may be partitioned into three non-exclusive categories based on level of human intervention:

- Low intervention: such as remedial management to reverse the effects of successional change, for example removing scrub invasion from heathland and grassland, and reinstatement of traditional management such as sheep grazing regimes (Bacon 1990; Gibson & Brown 1992; Bobbink & Willems 1993; Clark & Baldock 1994; Fischer & Stöcklin 1997; Mitchley *et al* 1998; Crofts 1999).
- Medium intervention: such as restarting successions with vegetation removal, soil stripping and excavation, using natural recolonisation processes such as local seed rain, seed bank and dispersal vectors (Marrs 1985; Gough & Marrs 1990; Aerts *et al* 1995; Strykstra *et al* 1998)
- High intervention: such as utilizing the above techniques as well as actively introducing materials such as turf and soil transfers, transplants and seed (Wells 1983; Fenner & Spellerberg 1988; Wells *et al.* 1989; Ash *et al* 1993; Davies *et al* 1999; Hopkins *et al* 1999;

The amount of effort expended on restoration is mostly a politico-economic facet. As complete restorations require complete resource commitment, then grades below entire recovery (whether scientifically feasible) are conditioned by complex end point criteria (Cairns 1986; Bradshaw 1997). However, with changing conservation paradigms (Baldwin et al 1994; Adams 1997), and on-going reform of the Common Agricultural Policy, will come the socio-political will to restore large areas of degraded habitats (Martin, 1996; Bignal 1999). Anderson (1995) states, “*with adequate resources and manpower, many degraded habitats can be satisfactorily restored and a wealth of knowledge is now available on which to base appropriate action.*” The Countryside Bill, if implemented will make it a legal duty on the Government, and on other public bodies, to prepare and implement species and habitat recovery programmes, or Biodiversity Action Plans (FOE 2000). This will resource widespread restoration commitments and initiatives.

Grassland management: from traditional to modern

Though the main concepts of *modern* farming methods can be traced back for at least 250 years in Britain (Davies & Davies), it is only from the 1930s, and more particularly the 1950s onwards, that wholesale uptake of ‘intensive’, industrial methods became widespread in Britain (Gordon & Duncan 1994; Hopkins & Hopkins 1994; Hopkins & Pinto 1998). This sea change in grassland management is largely attributable to unparalleled governmental and extra-governmental support starting with the 1947 Agriculture Act and compounded by joining The Common Agricultural Policy with EEC membership in 1972 (Green 1985; Bignal 1999). The major consequence of these socio-economic changes was that *old-fashioned* farming practices rapidly faced obsolescence (Hodgson & Grime 1990). To distinguish between the agricultural before and after, Hopkins (1989) draws the firm distinction between *traditional* farming practices and *modern* farming practices.

Traditional grassland management

Traditional grassland management is denoted by “the constancy of the management practices” (Hopkins 1989), whereby the farmer utilises the naturally occurring vegetation cover in conjunction with the inherent soil fertility. The primary factor is *reactive sustainability* - the pressure to assimilate and work with the natural environmental constraints, rather than trying to comprehensively modify the environment. This is also often referred to as a low input system (Hopkins & Pinto

1998) or low intensity/extensive farming (Bignal & McCracken 1996; Harris & Jones 2000), whereby there are low nutrient inputs and relatively low, but sustainable material outputs.

Traditional grassland management could rarely countenance ploughing and reseeded of grassland, as the stability of the year-on-year forage production was paramount (Evans 1876). However, farmers were always conscious of maximizing the productivity of their grasslands. Before widespread subsidisation, the mechanism that drove this management was necessity rather than profit margins. In practise, this meant that swards were rarely undergrazed, though over-grazing could damage the grassland and thus jeopardise future cropping. Maintaining adequate soil fertility was a fine balance. The only external nutrient inputs were from organic manure from both the animals while grazing, and also from manure collected when the animals were in stalls, which was stored and later spread on the grassland (Grayson 1999).

Traditional farming, as noted above, often delineated meadow from pasture on a relatively strict basis, especially in the medieval period (Lane 1980; Marren 1995). The grasslands themselves, unless on marginal land (Wells *et al* 1976) were to all intents and purposes, permanent. In strict traditional terms, mesotrophic, semi-natural grasslands were often segregated into two functional types. Meadows were grasslands that were managed primarily for the production of hay - the sward allowed to grow, literally 'shut up', from late spring to mid summer, and usually aftermath grazed, following the hay cut in the summer months (Crofts & Grayson 1999). Meadowlands were often areas of grassland that had the highest natural soil fertility, promoting strong and fast sward growth, and a more nutritious crop. The delineation of good meadow areas was often couched in local laws, customs and dictates (Rackham 1986; Marren 1995). Biologically, meadows differ from pastures in the greater number of species present that are relatively intolerant of grazing - at least continuous grazing. The exclusion of grazing in the main growth period therefore allows the development of swards that necessarily contain tall herbaceous species, with the main photosynthetic surfaces aerially concentrated (Grime *et al* 1988).

In contrast to meadows, pastures are grasslands that are essentially grazed by livestock (Rackham 1986; Hopkins 1989). These are grasslands in which no hay crop is taken and

grazing can take place throughout the growth seasons (Croft & Grayson 1999). The tall flowering species are usually absent due to their intolerance to grazing defoliation, and thus generally replaced by low growing rosette forming species which are adapted to avoiding or tolerating the selective predations of livestock (Crofts & Grayson 1999). Although the definitions are relatively straightforward, the continuity of land use of an area of grassland was not necessarily so strictly bound by management type. Many ecologists (Hopkins 1989; Rodwell 1992; Marren 1995) tend to define grassland, particularly mesotrophic grassland, as either meadow or pasture, though the picture is far more complicated. Whereas in the medieval period, the distinction between meadows and pastures may have been strictly observed, by the seventeenth and eighteenth centuries, many grasslands were being managed on a rotational basis, with hay cut one year in three to prevent the 'heart' being taken out of the grassland. This was further encouraged by the use of fertilizers, which meant even poor grasslands could be mown on a rotational basis. Eighteenth century improver farmers were more likely to use the unifying term 'grass grounds' rather than that of meadows and pastures (Broad 1980). Thus management could traditionally differ from year to year, though in some celebrated cases (Cricklade for example) treatment may have not changed for centuries (Rackham 1986). Overall, the land use status of grassland changed (and continues to do so) according to economic pressure, such as the widespread ploughing up of grassland for arable in the early-mid 19th century, and then the laying down of arable to grassland in the late 19th century due to the repeal of the *Corn Laws* (Stoate 1995; Davies & Davies 1997; Davies & Waite 1998).

In Britain, over the last thirty years, the practice of *traditional* grassland management has been largely restricted to nature reserves. These swards are now usually artefacts of wildlife organisations attempting to conserve the scattered remnants of once widespread species-rich grassland (Marren 1995; Jefferson 1999). This is a continuing task as the agri-economic climate is still generally in opposition to low-input agricultural systems (Bignal 1999; FOE 2000). However, traditional grassland management is not necessarily *archaic*. Changes in high-level agricultural policy which may promote lower intensity farming (Hopkins *et al* 1999), coupled with the use of labour-saving modern technologies can allow the resurgence of long-established farming systems.

Modern grassland management

Modern agricultural management adheres to the concept of high input/high output, with intensification at all stages of production (Fisher *et al* 1996). The universal uptake of modern agriculture has not been possible without massive economic support mechanisms (Hopkins & Pinto 1998; Bignal 1999; FOE 2000). The corollaries of both management paradigms have had an enormously polarising effect on the biodiversity of grassland as well as other sectors of the agri-landscape (Gordon & Duncan 1994). The vast amount of grassland that was unimproved prior to WW2 has been subject to intensive applications of inorganic fertilizers (Fuller 1987; Stoate 1996). In 1985, inorganic nitrogen fertilisers were applied to 79% of all permanent grasslands (Elsmere 1986). This huge area of grassland has therefore been biologically depleted by fertiliser use. This is, of course, the basic aim of *modern* farming, in other words, to create grassland uniformity, so that a few highly productive competitive species are favoured at the expense of variation and diversity, leading to uniformly high gross livestock production.

Lowland neutral grasslands have been most susceptible to agricultural intensification by regular ploughing and reseeded, maximum use of inorganic fertilisers and herbicides, change from hay to silage making, drainage and increased stocking densities (Frame *et al* 1994; Fisher *et al* 1996; Stoate 1996; Crofts & Grayson 1999; Everett 2001). The main aim of modern grassland farming is to produce highly productive grass dominated species-poor swards (Gordon & Duncan 1994). The most consistently used productive species include *Lolium perenne* cultivars, *Lolium multiflorum*, *Dactylis glomerata*, *Festuca pratensis*, *Festuca arundinacea*, *Phleum pratense*, and *Trifolium repens* (Rodwell 1992). High priority is given to restricting sward deterioration through colonisation of ‘unwanted’ or indigenous ‘weed’ species (Roberts 1981; Smith & Allcock 1985; Davies 1997). Few agricultural grasslands can be now strictly termed permanent, as they are subject to renovation disturbances such as herbiciding, harrowing and over-sowing, even if production is not significantly affected by ‘weeds’ (Smith & Allock 1985). Impermanent grasslands are now the norm, usually referred to as either short-, medium- or long-term *leys* (MVF 1998), sometimes integrated with arable production. In this way, habitat stability and continuity is very low, thus restricting natural recolonisation and community-level complexity (Gibson & Brown 1991; Gibson 1998). The process of agricultural

improvement of grassland uses a combination of methods, including drainage, ploughing, reseeded, herbicide treatment, high fertiliser input and intensive grazing (Fuller, 1987; Hopkins & Hopkins 1994). Each treatment in itself can greatly change a sward, but in combination, they can manipulate the ecosystem so as to exclude all but the most productive species (Rodwell 1992; Grayson 1999). Agricultural grasslands are managed to ensure high performing swards that are proficient at producing high quality forage, measured in digestibility, crude protein content, and metabolizable energy (MVF 1998; Tallowin & Jefferson 1999).

Grassland restoration: reversing the decline in grassland biodiversity

Relatively recent changes in the agricultural management of grasslands have brought about historically immense ecological alterations. Fuller's (1987) survey of lowland grassland showed that in 1984, unimproved grassland occupied only 3% of its 1930 extent. Many factors have contributed to this loss, including, at the extreme, the farmer's subsidy driven mentality to 'tidy-up' the countryside at the expense of biodiversity (Macdonald & Johnson 2000). In order to reverse these trends, within the UK agro-environment schemes, projects have been initiated to promote the management, restoration and creation of grassland habitats (Clark & Baldock 1994; Frame *et al* 1994; Hopkins & Hopkins 1994; MAFF 1998; Pywell *et al* 1997; Dryden 1997; Flora Locale 2000a; Smith & Corkhill 2000). As recent changes in agricultural policy have indicated a shift away from the purely production-orientated grassland management (Fisher *et al* 1996; Bignal 1999), rationales and techniques for encouraging biodiversity in agricultural systems have become more significant (Hopkins & Pinto 1998). It has also been assessed that productive wildflower grasslands are able to support viable animal production systems with certain provisos e.g. limited feed supplementation (Frame *et al* 1994), though this is questioned by Bakker (1994), who suggests that nature conservation and agricultural aims are essentially incompatible.

Re-establishment of species-rich grasslands requires detailed consideration (Gilbert & Anderson 1998). It has long been observed by farmers that permanent grassland is difficult to re-establish on ploughed land (Evans 1876), and such an operation was often assiduously avoided until the predominance of petrochemical based technologies in the mid 20th century (Hopkins 1989; Davies & Davies 1997). Modern intensive grassland

production is a function of impermanence, with grasslands regularly ploughed up and reseeded (Rodwell 1992; MVP 1998). Permanent grassland management is generally eschewed as it allows for the build-up of perceived weed species. Ephemerality can be also seen in aspects of grassland creation for wildlife, which can promote the notion of the easy replication of extant swards. Crofts (1999a) points out that grassland creation is often mistakenly seen as a relatively simple undertaking. Most evidence suggests that extant semi-natural grasslands, even depauperated ones, can be more valuable in overall biodiversity terms than a recently created, provisionally diverse sward (Kendle 1993; Gibson 1995; Gilbert & Anderson 1998). However, there is now considerable need to bolster the dwindling semi-natural grassland resource with creation and restoration (Mitchley *et al* 1998; FOE 2000). There is a new impetus to recreate species-rich grasslands, and such schemes often require the active introduction of wildflower seed or plants to achieve speedy augmentation in diversity (Jones & Hayes 1999).

The science of grassland restoration is in part the mirror image of the science of grassland improvement. The one of the core principles is to attempt to reassemble the pre-disturbance grassland communities (Jordan III *et al* 1987; Flora Locale 2000b). Grassland *renovation* used to refer to the agronomic techniques to increase productivity (MVF 1998), but nowadays it can equally refer to enhancing grassland vegetative diversity. Wells *et al* (1989) give a number of reasons why total sward destruction should not usually be a desired baseline for grassland restoration work:

- The cost of the sward destruction, and seed bed production is often prohibitive.
- There is a loss of land use while the seed mixture is establishing.
- There is an adverse effect on the aesthetic appeal once herbicide has been applied.
- Once sloping land, the destruction of the sward might lead to soil erosion.
- Grassland destruction will eliminate any ‘useful’ species present as well as any beneficial structural features of the existing sward microcosm.

The fifth point raised by Wells *et al* is of particular concern to the present research. Existing habitats are often worth maintaining, even if they are degraded from semi-natural status. To completely overhaul the habitat through transplantation and re-creation would generally be deleterious to biodiversity aims, so species enrichment and habitat diversification are part of a satisfactory compromise (Buckley 1989). The aspect of time-scales involved in the *natural* development of ecosystem diversity has been widely

discussed, but still open to a high degree of conjecture due to the paucity of long-term studies (Gibson & Brown 1991; Gibson & Brown 1992; Stampfli & Zeiter 1999). However, as Way (1989) and Wells (1990) point out, even highly diverse plant communities have been shown to establish on relatively recently disturbed landscapes such as railway cuttings, quarries, and arable land.

Attempts at the restoration of North American prairie grasslands predate related research in this country (Cottam & Wilson 1966). Wathern & Gilbert (1978; 1979) produced some of the first investigations into grassland creation in Britain. However, grassland creation and restoration have been largely associated with the pioneering work of T.C.E. Wells (see Wells 1983; 1987; Wells *et al* 1989). Since the 1970's Wells *et al* have carried out a number of experimental trials starting either with a cultivated field or an existing grass sward. In the latter case, new species were introduced either by seeding into gaps (slot seeding) or by transplanting pot-grown seedlings into the turf. Their experiments have been carried out on a variety of soil types, with varying levels of previous agricultural improvement. Because of the lack of any previous work on the artificial introduction of species into existing grasslands, many of Wells *et al*'s experiments are of necessity of the 'trial and error' type. Wells *et al* (1989) overall, have proved that diverse, ecologically valuable grassland communities, similar to those formerly found, can be established, though many problems remain. Species differ widely and unpredictably in the ease of initial establishment and/or in their long-term survival. Newbold (1989) is forthright in his approach to the *meaning* of Well *et al*'s work, suggesting that it was never intended as research into how grasslands can be created to replicate semi-natural swards. Rather, the scope is limited to showing the creation of "visually attractive areas in biologically impoverished areas."

Despite differences in objectives, all of these investigations have highlighted certain common problems. One of the most important is the low survivorship found in most species. Howell & Jordan III (1989) are adamant that "Matching species to the site conditions is the key to success". Detailed monitoring of the fates of individuals is required to ascertain the causes of mortality (Davies *et al* 1996; Davies *et al* 1999). Much of the science of grassland restoration revolves around the twin problems of residual soil fertility, and the facilitation of natural immigration, colonisation and establishment of *desirable*

species (Wells *et al* 1989; Anderson 1995; Gibson 1995; Crofts 1999a; 1999b; FloraLocale 2000a). For many grassland schemes, soil fertility reduction, and the inoculation and enrichment of depauperate swards with ‘missing’ desirable species are essential for successfully reaching restoration objectives (Davies *et al* 1999; Flora Locale 2000a)

The role of soil fertility and sward productivity in grassland restoration

The abundance of productive grassland habitats in the contemporary landscape is without historical precedence mainly due to modern farming methods (Hodgson 1987). This is in direct conflict with the fact that many researchers have found low-to-intermediate soil fertility in temperate grassland ecosystems to be inextricably linked to the development and persistence of species-rich, diverse communities (Al Mufti *et al* 1977; Grime 1979; Pegtel 1987; Gough & Marris 1990; Mountford *et al* 1994; Snow *et al* 1997). Low-intermediate soil fertility and concomitant low sward phytomass productivity is also usually considered an essential precursor to the creation, restoration and maintenance of species-rich grasslands (Marris & Gough 1989; van der Woude *et al* 1994; Anderson 1995; Dryden 1997; Davies *et al* 1999; Westbury & Dunnett 2000). These conditions allow more narrowly adapted species to regenerate while more vigorous, competitive species are kept in check by the relative nutrient supply limitation (Mitchley 1994). Conversely, high soil nutrient availability is associated with species-poor grasslands, dominated by a handful of competitive, dominant grasses (Grime 1979; Hodgson 1987; Smith 1994; Tilman *et al* 1994; Jefferson 1999). As noted previously, standard agricultural grassland management aims at establishing and maintaining a very species-poor, but highly productive sward with the use of eutrophying levels of inorganic fertiliser input, particularly of the macronutrients, nitrogen, phosphorus and potassium. The extensive usage of inorganic fertilisers has probably been the primary factor in the loss of species diversity in grasslands, as heavy fertilization will as effectively reduce species-richness as selective herbicide use (Way 1989; Hodgson 1987). When attempting to enhance species-richness, the residual soil nutrient capital can be the major obstacle in grassland restoration, and success of reversion to diverse swards pivots about the fulcrum of soil fertility (Marris & Gough 1989; Way 1989; Berendse *et al* 1992; Marris 1993; Mountford *et al* 1994; Parker 1995; Mitchley *et al* 1998).

Mountford *et al* (1994) set out to estimate whether there is a 'safe' level of fertiliser input, which can be applied to species-rich grassland. The answer was an emphatic *no*, with even 25kg/ha⁻¹ of nitrogen fertiliser causing significant deleterious changes in sward composition, such as increases in dominance of competitive grasses such as *Lolium perenne* and *Holcus lanatus*, and succession from MG5 to species-poorer MG6 (Rodwell 1992). Kirkham & Wilkin (1994b) found that the potential output response of species-rich hay meadows (MG5) to fertilizer application was similar to that of a wide range of less diverse, agriculturally improved permanent pastures. The clear outcome of all the nitrogen fertilizer treatments, especially in association with P and K application rates above replacement, was the significant fall in species-richness, and the increased dominance of grasses. Kirkham & Wilkin (1994a) also concluded that lowland meadow vegetation can be sensitive to even low levels of applied fertilizer, with fertilizer application at all levels causing significant depletion in plant species diversity. Even concentrated organic fertiliser in the form of slurry has also been shown to effectively reduce sward species-richness (Frame *et al* 1994). Nutrient persistence in the soil after fertiliser applications have stopped poses long-term restoration problems. Phosphorus and potassium can be locked up in the soil system in plant-unavailable forms. As most soil P is strongly adsorbed by mineral surfaces, and there is no gaseous exchange or significant loss by leaching (Brady & Weil 1999), levels can remain in the soil long after artificial input has stopped. Agricultural soils can therefore be grossly saturated with very high levels and huge reserves of phosphorus, which is relatively immobile and irreducible (Eco-Ag Ltd 1997; Brady & Weil 1999). Researchers have found P to be the major limiting factor on the progress of establishing new conservation grasslands on arable soils, and reverting agriculturally improved grassland to semi-natural (Marrs & Gough 1989; van der Woude *et al* 1994; Aerts *et al* 1995; Hopkins *et al* 1999; Jones & Hayes 1999).

The overwhelming evidence suggests that the key operation in restoring previously intensively managed agricultural grassland, is to cease artificial nutrient input as far as possible (Mountford *et al* 1994; Bakker 1994; Hopkins *et al* 1999). However, cessation of controlled fertiliser inputs is just the first step in restoration. The depletion of residual quantities of soil fertility components is the next. Turf or topsoil stripping is the most effective method of nutrient depletion and is instantaneous in effect (Marrs 1993; Anderson 1995; Pywell *et al* 1997; Hopkins *et al* 1999). However, it also removes useful components

of the grassland biota. Cropping management techniques are generally more benign, based on maximising off take by removal of nutrients through animal biomass (grazing), losses via increased nutrient cycling, and phytomass export (hay or silage) (Marrs 1993). Quantification of the effectiveness of depletion techniques, and relative time-scales is still limited due to the paucity of long-term experimental data (Marrs 1985; Marrs 1993). In some studies, elimination of most nutrient input, in league with grazing and/or hay management can rapidly lead to productivity reductions and increases in sward diversification (Boyce 1994; Davies *et al* 1994; Hayes & Williams 1994; Smith & Corkhill 2000). Snow *et al* (1997) concluded from their study sites of abandoned field and established meadow, that there can be a relatively rapid removal of extractable P concentrations over a nine-year period, to the restoration target range of 5-10 $\mu\text{g/g}^{-1}$. However, in most studies, efforts to reduce overall soil fertility and grassland productivity through cropping are often remarkably slow, and predicted to take decades or even centuries (Marrs & Gough 1989; Gough & Marrs 1990; Olf & Bakker 1991; Kendle 1992; Ash *et al* 1993; Marrs 1993; Anderson 1995; Gibson 1995; Dryden 1997; Mitchley *et al* 1998).

Dispersal, colonisation and reintroductions

Intensive farming and urbanisation have fractured semi-natural habitats into an ever-decreasing complex of *island* fragments (Bobbink & Willems 1993; MacDonald & Smith 1994; Pywell *et al* 1997; Mitchley *et al* 1998). For the majority of plant species, propagule mobility is ever more constrained by the expansion of what is essentially an antagonistic landscape to effective natural migration. In turn, this weakening of the mechanisms of natural colonisation is highly restricting of the *natural* maintenance of biodiversity (Hodgson & Grime 1990; Bakker & Berendse 1999). Therefore, the intensively managed, species-poor landscape is an ever more effective barrier to biological communication between islets within this tenuous wildlife archipelago (MacDonald & Smith 1994). The loss of traditional agricultural dispersal vectors in the man-made landscapes of today, such as transhumance and hay making, is also of critical importance in species' declines (Poschold *et al* 1998; Strykstra *et al* 1998). When attempting to create or restore grasslands through natural regeneration, the isolation of restoration sites from species-rich emigration sources is a crucial limiting factor (Dutoit & Alard 1995). Natural recolonisation of reverting grassland is greatly hindered by seed availability, with sources of inoculae from

species-rich communities much reduced, leading to great difficulties when attempting to re-create previous populations relying solely on natural seed inputs (Marrs & Gough 1989). In addition to this constraint on grassland development, the soil seed banks of improved grasslands are usually depleted of desirable (often stress-tolerant) (Grime *et al* 1988) species from which to recruit pre-disturbance grassland vegetation (van der Valk & Pederson 1989; McDonald 1993; Hutchings & Booth 1996; Willems & Bik 1998). The species with greatest dispersal capacity usually have weedy, generalist life histories (Hutchings & Booth 1996; Poschlod *et al* 1998; Thompson *et al* 1999). These species may also accumulate in the soil as viable seed (van der Valk & Pederson 1989; Davies & Waite 1998), as well as have the highest probability of reaching restoration sites. Many grassland plant species have low seed dispersability in both space and time (Newbold 1989), especially the rarer forb components, due to their lower natural mobility and transient soil seed banks (Buckley 1989; Hodgson & Grime 1990). For example, seeds of most species of calcareous grasslands only effectively disperse within 0.5m from the seed-producing parent plant (Willems & Bik 1998). Dispersal of these species can be patchy and localised even when suitable export and import sites are adjacent to each other (Hutchings & Booth 1996). Therefore, some of the critical concerns for the restoration of species-rich grasslands are the potentials of seed dispersal, propagule migration, recruitment, and re-establishment processes (Dutoit & Alard 1995; Coulson *et al* 2001).

Once soil fertility and sward productivity have been reduced to low-intermediate levels in order to enhance the invasion potential of the sward, it is the presence of proximate propagule source pools, which can dictate the recruitment of further species (Dutoit & Alard 1995; Pegtel *et al* 1996; Willems & Bik 1998). Thus, restoration success may often hinge on the presence of dispersule exporting, semi-natural seed sources within the vicinity of the site (Bobbink & Willems 1993; Wells 1995; Gibson 1998; Bischoff 2002). Availability of target species, whether originating from the soil seed bank, the seed rain, or both, is probably the most important prerequisite for successful restoration attempts. (Willems & Bik 1998). As Strykstra *et al* (1998) observe, "Dispersal has become a serious bottleneck in restoration management". Consideration must be given to the spatial arrangement of patches so that export sources and recruitment areas are connected enabling plants to bridge gaps in space and time (Ehrlén & van Groenendael 1998). Newbold (1989) proposes that setting aside substantial areas around high-grade sites (SSSIs, NNRs) can

facilitate natural colonisation processes so that *passive* habitat recreation can take place. Though this overlooks the restrictions imposed by residual soil fertility, it does allow a slow accretion and expansion of biodiversity to bolster the network of overall resources. Generally, natural colonisation is still viewed as the best method of attempting to recreate the processes and patterns of ancient semi-natural grasslands (Jones 2001), though the natural rate of full species-assembly may take over 100 years (Anderson 1995; Gibson 1995; Gibson 1998). This fact, coupled with the equally long-term task of reducing soil fertility in restoration sites, presents a limited picture for what can be achieved even in the medium-term.

Overall, the evidence seems to suggest that natural recruitment cannot be relied upon to attain, at most, other than very gradual increases in grassland diversity and successional development (Pywell *et al* 1997; Gibson 1998; Smith & Corkhill 2000). Grassland restoration is often greatly hampered due to the lack of local refugia for potential species export (Jones & Hayes 1999). Specialist species may become more and more geographically restricted because they cannot reach suitable sites owing to low dispersal ability (Thompson *et al* 1999). Natural recolonisation may be so slow as to negate attempts to counter on-going ecosystem resource losses. As Buckley (1989) and Dutoit & Alard (1995) propose, the alternative approach to overcoming this predicament is the deliberate inoculation of grasslands with these *missing* components through seeding and transplanting (Wells 1983; Fenner & Spellerberg 1988; Kaule & Krebs 1989; Wells *et al.* 1989; Luscombe & Scott 1994; Davies *et al* 1996, 1999; Kline 1997; Pywell *et al* 1997; Jones & Hayes 1999; Coulson *et al* 2001). Introductions have the advantage in that they bypass the problems of natural dispersal and have the potential to produce rapid results, including the establishment of scarce and attractive species (Gibson 1995). Transplants, in particular, theoretically, have a number of advantages compared to natural recruitment (Davies *et al* 1999). Transplanting allows the rapid establishment of populations of species that may take a very long time to invade by natural processes (Gibson & Brown 1991; Hutchings & Booth 1996; Kline 1997; Francis & Morton 2001), thereby hastening the *re-assembly* of semi-natural communities (Pywell *et al* 1997). It is also a technique that makes the most efficient use of those species with low rates of seed production or complex germination and establishment requirements (Buckley 1989; Parker 1995).

There is a substantial debate amongst conservationists, botanists and restoration ecologists concerning the ethics and efficacy of species introductions and reintroductions (Buckley 1989; Hodder & Bullock 1997; Everett 1999; Jones & Hayes 1999). It has been argued that *natural* species distribution patterns are deleteriously altered by species introductions, and that locally adapted forms (genotypes) already present within a restoration *zone of influence* are compromised by the importation of non-local genetic material (Ackeroyd 1994; Everett 1999; Jones 2001). Scientific evidence at present is limited as to whether *generically* ‘regional’, or even ‘foreign’ plant material can have a significant negative effect on the local ‘native’ genetic stock of a particular area (van Groenendael *et al* 1998). It may seem a logical extrapolation to suggest that locally adapted strains in semi-natural conditions could have a higher fitness over locally non-adapted species (Sackville Hamilton 2001). It is clearly conceivable that there may be micro-selection forces operating to promote genetic advantage under local environmental conditions. Equally though, macro-scale factors such as grassland management systems may override any localised genetic competitive advantages (Crofts & Grayson 1999; Jones & Hayes 1999). These, perhaps conflicting considerations, may advance a precautionary approach, especially where restoration initiatives are adjacent to high-grade sites. Using local propagule material for inoculating neighbouring schemes would seem logically appropriate in most circumstances, though the definition of *local* is once again debatable (Jones 2001). A general principle is that as long as restorationists work within a geographical region, they stay close to the natural dispersal potential of a species. Survival of seedlings or pre-grown plants seems to depend mainly or almost entirely on environmental site factors. As van Andel (1998) states, “A certain species either does or does not become established whatever the source population”. It does seem scientifically acceptable not to risk failure of establishing a cohort by introducing plant material from only one population, thus mimicking the establishment of a founder (van Andel 1998). There has been widespread introduction of *non-local* plant material in the British countryside since before the *Agricultural Revolution* (Lane 1980; Davies & Davies 1997), and the contemporary *sea* of genetically modified (through plant breeding) species, and alien crops which occupy the vast majority of the landscape, poses some pertinent questions about the importance of genetic pollution for most restoration projects.

RESEARCH OBJECTIVES

Given the slow but steady greening of the Common Agricultural Policy, development of Biodiversity Action Plans (BAPs), and the establishment of agri-environment schemes (DOE 1994; Pywell *et al* 1997; Hopkins & Pinto 1998; Mitchley *et al* 1998; SSDC 1998; Bignal 1999), projects to actively restore grassland biodiversity may well become a key component in reversing species declines and habitat losses (Clark & Baldock 1994; Gilbert & Anderson 1998; Dryden 1997; Mitchley *et al* 1998). However, there is a requirement for ecological research to identify the main determinants of successful ecosystem recovery, and the validity and effectiveness of employed restoration techniques. The Society for Restoration Ecology (2000) is a clear advocate of a scientific approach, declaring that, “restorationists need to evaluate the efficacy of their actions”. Edwards *et al* (1997) contend that “restoration ecologists must be scientists”, while Bradshaw (1987; 1993) is adamant that restoration ecology, as a science, must be grounded on rigorous experimentation to test theories. This experimentation also necessitates long-term monitoring to establish fundamental parameters (Dunnett 1995; Dunnett *et al* 1998). However, an exacting approach to restoration is still the exception rather than the rule, and Clark (1997) propounds that, “In many contexts, ecological restoration is at best an ad hoc product of a series of largely uncontrolled experiments”. Parker & Pickett (1997) emphasise the need for “restoration ecology to develop models that combine general principles with unique site conditions”. In grassland restoration, for example, although there is an ever-growing body of work, there is still a considerable amount of research still to be undertaken on aspects of habitat diversification and enhancement, species enrichment, and transplant ecology with regard to lowland mesotrophic grasslands (Wells 1989; Kendle 1992; Davies *et al* 1999; Hopkins *et al* 1999). The present work is therefore part of the on-going process of testing applied methodologies and establishing base-line parameters (Bradshaw 1993; Parker 1995).

This research project is essentially an exploration of a range of methods for diversifying agriculturally improved mesotrophic grassland. It is intended that results from this research provide a quantitative appraisal of practical techniques for grassland restoration. The techniques employed include management treatments (Wells 1971; Oomes & Mooi 1981; Kirkham & Tallowin *et al* 1995; Coulson *et al* 2001); inoculation with transplants (Cottam & Wilson 1966; Wells *et al* 1983; Fenner & Spellerberg 1988;

Wells *et al* 1989; Luscombe & Scott 1994; Davies *et al* 1999; Pywell *et al* 1997); introduction of seed (Wathern & Gilbert 1978; Berendse *et al* 1992; Luscombe & Scott 1994; McDonald 1994; Smith *et al* 1996; Coulson *et al* 2001); and the creation of artificial regeneration gaps (Hillier 1990; Fowler 1994; Hopkins *et al* 1999). In addition, a variety of other subsidiary diversification factors have been assessed, such as transplant sizes; seed bank versus seed rain; and seasonality effects, in order to evaluate their significances in restoration attempts.

This study proposes to build upon central aspects of previous work on grassland restoration, and in particular, studies in plant species enrichment, by investigating certain core questions, which arise from it. Specifically, these are:

- To determine the effects of different grassland management treatments on the productivity and diversification of extant meadow swards. Long-term depauperation of soil nutrient capital through grazing and cutting export regimes are usually considered essential in re-establishing grassland diversity. This research considers aspects of this important issue by applying three pre- and post- hay-cut management types: sheep grazing, cattle grazing, and motorised cutting.
- To determine the role of soil fertility in limiting the success of establishment of introduced individuals, whether by transplant or seed. The overwhelming evidence suggests that the greater the levels of available soil nitrogen, phosphorus and potassium, the higher the degree of invasion and inoculation resistance. Increased soil fertility may effectively reduce the establishment probability of ‘immigrants’ and inoculants. Each species, therefore, may have a critical level of fertility that effectively prevents its reintroduction, introduction, long-term establishment, and regeneration.
- To determine the efficacy of a variety of facilitates in sward diversification, such as use of herbicide to create regeneration gaps, disturbance to reveal regeneration sites for seed bank and seed rain recruitment, and seasonality in inoculant success.

In addition to attempting to evaluate some of the practical problems of species enrichment, the study endeavours to provide further insights into the interesting theoretical questions concerning the organisation of species composition in semi-natural and artificial communities. There is still limited data concerning the dynamics of plant community invisibility (Tilman 1997). Also, the success of certain species and failure of others may reflect the application of certain controlling ‘assembly rules’ acting within the overall community dynamics (Lord *et al* 2000). Wells *et al* (1989) also propose that far more work is needed in order to define the characteristics of the regeneration niche *sensu* Grubb

(1977) with regards to inoculation, if restorationists are to achieve the enrichment of existing grasslands without having to resort to total sward destruction and reseedling.

ACKNOWLEDGEMENTS

I would like to thank Tony Kendle and Alison MacDonald for comments on aspects of restoration ecology, and Owen Davies for supplying me with articles when circumstances made library access more difficult.

REFERENCES

- Ackeroyd J.** (1994) Seeds of destruction. *Natural World* **39**: 26-27.
- Adams W. M.** (1997) Rationalization and conservation: ecology and the management of nature in the United Kingdom. *Transactions of the Institute of British Geographers* **22**: 277-291.
- Aerts R., Huiszoon A., Van Oostrum J. H. A., Van de Vijer C. A. D. M. & Willems J. H.** (1995) The potential for heathland restoration on formerly arable land at a site in Drenthe, the Netherlands. *Journal of Applied Ecology* **32**: 827-835.
- Al Mufti M. M., Sydes C. L., Furness S. B., Grime J. P. & Band S. R.** (1977) A quantitative analysis of shoot phenology and dominance in herbaceous vegetation. *Journal of Ecology* **65**: 759-791.
- Anderson P.** (1995) Ecological restoration and creation: a review. *Biological Journal of the Linnean Society* **56** (suppl.): 187-211.
- Ash H. J., Bennett R. & Scott R.** (1993) *Flowers in the Grass: Creating and Managing Grasslands with Wild Flowers*. English Nature, Peterborough.
- Bakker J. P.** (1994) Nature management in Dutch grasslands. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 115-124.
- Bakker J. P. & Berendse F.** (1999) Constraints in the restoration of ecological diversity in grassland and heathland communities. *Trends in Ecology & Evolution* **14**: 63-68.
- Baldwin Jr, A.D., de Luce J. & Pletsch C.** (1994) Conclusion: constructing a new ecological paradigm. In: *Beyond Preservation: Restoring and Inventing Landscapes*, Baldwin Jr, A.D., de Luce J. & Pletsch C. (eds), University of Minnesota Press, pp. 260-265.
- Berendse F., Oomes M. J. M., Altena H. J. & Elberse W. Th.** (1992) Experiments on the restoration of species-rich meadows in the Netherlands. *Biological Conservation* **62**: 59-65.
- Bigal E.** (1999) Agenda 2000 - the Common Agricultural Policy reform proposals. *British Wildlife* **10**: 172-176.
- Bigal E. M., & McCracken D. J.** (1996) Low-intensity farming systems in the conservation of the countryside. *Journal of Applied Ecology* **33**: 413-424.
- Bischoff A.** (2002) Dispersal and establishment of floodplain grassland species as limiting factors in restoration. *Biological Conservation* **104**: 25-33.
- Blackstock T. H., Rimes C. A., Stevens D. P., Jefferson R. G., Robertson H. J., Mackintosh J. & Hopkins J. J.** (1999) The extent of semi-natural grassland

- communities in lowland England and Wales: a review of conservation surveys 1978-96. *Grass and Forage Science* **54**: 1-18.
- Bobbink R. & Willems J. H.** (1993) Restoration management of abandoned chalk grassland in the Netherlands. *Biodiversity and Conservation* **2**: 616-626.
- Boyce D.** (1994) Survival and spread of pot-grown flowers inserted into a perennial ryegrass ley. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 238-9.
- Bradshaw A. D.** (1997) What do we mean by restoration? In: *Restoration Ecology and Sustainable Development*, Urbanska K. A., Webb N. R. & Edwards P. J. (eds), Cambridge University Press, pp. 8-13.
- Bradshaw A. D.** (1993) Restoration ecology as a science. *Restoration Ecology* **1**: 71-73.
- Bradshaw A. D.** (1987) Restoration: an acid test for ecology. In: *Restoration Ecology: a Synthetic Approach to Ecological Research*, Jordan III N. R., Gilpin M. E. & Aber J. D. (eds), Cambridge University Press, pp. 23-29.
- Bradshaw A. D.** (1983) The reconstruction of ecosystems. *Journal of Applied Ecology* **20**: 1-17.
- Brady N. C. & Weil R. R.** (1999) *The Nature and Properties of Soils*. Prentice Hall, New Jersey.
- Bratton S. P.** (2000) Alternative models of ecosystem restoration. In: *Environmental Restoration: Ethics, Theory and Practice*, Throop W. (ed), Humanity Books, New York, pp. 53-68.
- Bright D.** (1999) Big is beautiful. *Natural World* **57 (winter)**: The Wildlife Trusts, Newark. pp. 31-32.
- Broad J.** (1980) Alternate husbandry and permanent pasture in the Midlands, 1650-1800. *Agricultural History Review* **28**: 77-89.
- Buckley G. P.** (1989) Introduction. In: *Biological Habitat Reconstruction*, Buckley G. P. (ed), Bellhaven Press, London. pp. 1-4.
- Buckley G. P. & Knight D. G.** (1989) The feasibility of woodland reconstruction. In *Biological Habitat Reconstruction*, Buckley G. P. (ed), Bellhaven Press, London, pp. 171-188.
- Buckman J.** (1863) On the composition and cultivation of meadows. *Journal of the Bath & West of England Agricultural Society* **6**: 277-296.
- Cairns Jr J.** (1999) Balancing ecological destruction and restoration: the only hope for the sustainable use of the planet. *Aquatic Ecosystem Health & Management* **2**: 91-95.
- Cairns Jr J.** (1993) Is restoration ecology practical? *Restoration Ecology* **1**: 3-7.
- Cairns J.** (1991) The status of the theoretical and applied science of restoration ecology. *Environmental Professional* **13**: 186-194.
- Cairns Jr J.** (1986) Restoration, reclamation, and regeneration of degraded or destroyed ecosystems. In: *Conservation Biology: the Science of Scarcity and Diversity*, Soulé M. E. (ed), Sinauer Associates Inc., Massachusetts.
- Cavers P. B. & Harper J. L.** (1967) Studies in the dynamics of plant populations: I. the fate of seed and transplants introduced into various habitats. *Journal of Ecology* **55**: 59-71.
- Chambers** (1995) *Chambers Combined Dictionary Thesaurus*. Larousse plc, Edinburgh.
- Clark J. & Baldock D.** (1994) *Renewing The Farmed Landscape*. RSNL Report, Inst. Eur. Env. Policy, London.
- Clark M. J.** (1997) Ecological restoration - the magnitude of the challenge: an outsiders view. In: *Restoration Ecology and Sustainable Development*, Urbanska K. A., Webb N. R. & Edwards P. J. (eds), Cambridge University Press, pp. 353-377.

- Cottam G. & Wilson H. C.** (1966) Community dynamics of an artificial prairie. *Ecology* **47**: 88-96.
- Coulson S., Bullock J. M., Stevenson M. J. & Pywell R. F.** (2001) Colonization of grassland by sown species: dispersal versus microsite limitation in responses to management. *Journal of Applied Ecology* **38**: 204-216.
- CIS (Countryside Information System)** (2000) Institute of Terrestrial Ecology, Cambridgeshire, <http://www.cis-web.org.uk>
- Crofts A.** (1999a) Grassland creation. In: *The Lowland Grassland Management Handbook 2nd Ed*, Crofts A. & Jefferson R. G. (eds), English Nature/The Wildlife Trusts, Lincoln.
- Crofts A.** (1999b) Grassland restoration. In: *The Lowland Grassland Management Handbook 2nd Ed*, Crofts A. & Jefferson R. G. (eds), English Nature/The Wildlife Trusts, Lincoln.
- Crofts A. & Grayson B.** (1999) Grazing. In: *The Lowland Grassland Management Handbook 2nd Ed*, Crofts A. & Jefferson R. G. (eds), English Nature/The Wildlife Trusts, Lincoln.
- Davies A. & Davies I.** (1998) Managing your own wildlife site - the extent of Private Nature Reserves (PNRs) and their potential contribution to conservation in England. *British Wildlife* **9**: 378-383.
- Davies A. & Davies O.** (1997) English agriculturists' attitudes towards grassland vegetation, 1780-1914: an ecological perspective. *Landscape History* **18**: 71-80.
- Davies A. Dunnett N. P. & Kendle T.** (1999) The importance of transplant size and gap width in the botanical enrichment of species-poor grasslands. *Restoration Ecology* **7**: 271-280.
- Davies A. & Waite S.** (1998) The persistence of calcareous grassland species in the soil seed bank under developing and established scrub. *Plant Ecology* **136**: 27-39.
- Davies A., Kendle A. D., Bisgrove R. J. & Marder J.** (1996) Effects of interactions between site, management and species on the planned establishment of wildflowers in grassland. *Aspects of Applied Biology* **44**: 377-384.
- Davies D. A.** (1997) *Improved Upland Pastures: the Bronydd Mawr Story*. IGER Bronydd Mawr, Trecastle, Powys.
- DOE (Department of the Environment)** (1994) *Biodiversity: The UK Action Plan*. HMSO, London.
- Dryden R.** (1997) *Habitat Restoration project: fact sheets and Bibliographies*. Horton P. and Hall J. (eds), English Nature Research Reports 260: English Nature, Peterborough.
- Dunnett N.** (1995) *Vegetation and Climate: a Thirty-Six Year Study in Road Verges at Bibury, Gloucestershire*. Unpublished PhD Thesis, University of Sheffield.
- Dunnett N. P., Willis A. J., Hunt R. & Grime J. P.** (1998) A 38-year study of relations between weather and vegetation dynamics in road verges near Bibury, Gloucestershire. *Journal of Ecology* **86**: 610-623.
- Dutoit T. & Alard D.** (1995) Permanent seed banks in chalk grassland under various management regimes: their role in the restoration of species-rich plant communities. *Biodiversity and Conservation* **4**: 939-950
- Eco-Ag Ltd** (1997) Soil Audit for Newborne Farm, Bruton. Unpublished Report.
- Edwards P. J., Webb N. R., Urbanska K. M. & Bornkamm R.** (1997) Restoration ecology: science, technology and society. In: *Restoration Ecology and Sustainable Development*, Urbanska K. A., Webb N. R. & Edwards P. J. (eds), Cambridge University Press, pp. 381-390.

- Ehrlén J. & van Groenendael J. M.** (1998) The trade-off between dispersability and longevity - an important aspect of plant species diversity. *Applied Vegetation Science* **1**: 29-36.
- Elliot R.** (1997) *Faking Nature: the Ethics of Environmental Restoration*. Routledge, London.
- Elsmere J. I.** (1986) Use of fertilizers in England and Wales. 1985. *Rothamstead Experimental Station Report for 1985*. 245-51. Harpenden, Lawes Agricultural Trust.
- Evans M.** (1876) Notes on inoculation of grass land, as practised at Kimbolton. *Journal of the Royal Agricultural Society of England* **12**: 230-236.
- Everett S.** (2001) Going Native. *Country Landowner* (January): 43-45.
- Everett S.** (1999) Putting wild plants where they belong. *Plantlife* (spring): 12-13.
- Ewel J. J.** (1987) Restoration is the ultimate test of ecological theory. In: *Restoration Ecology: a Synthetic Approach to Ecological Research*, Jordan III W. R., Gilpin M. E. & Aber J. D. (eds), Cambridge University Press, pp 31-33.
- Fenner M. & Spellerberg I. F.** (1988) Plant species enrichment of ecologically impoverished grassland: a small scale trial. *Field Studies* **7**: 153-158.
- Fischer M. & Stöcklin J.** (1997) Local extinctions of plants in remnants of extensively used calcareous grasslands 1950-1985. *Conservation Biology* **11**: 727-737.
- Fisher G. E. J., Baker L. J. & Tiley G. E. D.** (1996) Herbage production from swards containing a range of grass, forb and clover species under extensive management. *Grass and Forage Science* **51**: 58-72.
- Flora Locale** (2000a) *Schemes With Wildlife in Mind*.
<http://www.naturebureau.co.uk/floralocale>
- Flora locale** (2000b) *The white clover (Trifolium repens) issue: the role of white clover in the loss of diversity in grassland habitat creationment*.
<http://www.naturebureau.co.uk/floralocale>
- Fowler A. D.** (1994) Soil seed banks and vegetation of limestone grassland patches in Wytham Woods, Oxford. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 272-274.
- Frame J., Fisher G. E. J. & Tiley G. E. D.** (1994) Wildflowers in grassland systems. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 104-114.
- Francis J. L. & Morton A.** (2001) Enhancement of amenity-woodland field layers in Milton Keynes. *British Wildlife* **12**: 244-251.
- FOE (Friends of the Earth)** (2000) *Wildplaces. Briefings - Countryside at Risk*.
<http://www.foe.org.uk/wildplaces>
- Fuller R. M.** (1987). The changing extent and conservation interest of lowland grasslands in England and Wales: a review of grassland surveys 1930-84. *Biological Conservation* **40**: 281-300.
- Gibson C. W. D.** (1998) *South Somerset SSSIs: A Study of Neutral Grassland Succession*. English Nature Research Report **266**: Peterborough.
- Gibson C. W. D.** (1997) *The Effects of Horse and Cattle Grazing on English Species-Rich Meadows*. English Nature Research Report **210**: Peterborough.
- Gibson C. W. D.** (1995) *Chalk Grasslands on Former Arable Land: a Review*. Unpublished report, Bioscan (UK) Ltd, St. Clements, Oxford.
- Gibson C. W. D. & Brown V. K.** (1992) Grazing and vegetation change: deflected or modified succession? *Journal of Applied Ecology* **29**: 120-131.
- Gibson C. W. D. & Brown V. K.** (1991) The nature and rate of development of calcareous grasslands in southern Britain. *Biological Conservation* **58**: 297-316.

- Gibson D. J.** (1988) The relationship of sheep grazing and soil heterogeneity to plant spatial patterns in dune grassland. *Journal of Ecology* **76**: 233-252.
- Gilbert O. & Anderson P.** (1998) *Habitat Creation and Repair*. Oxford University press, Oxford.
- Gordon I. J. & Duncan P.** (1994) Objectives for production and conservation in grasslands: effects of large grazing ungulates. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 20-29.
- Gough B. H. & Marrs R. H.** (1990) A comparison of soil fertility between semi-natural and agricultural plant communities: implications for the creation of species-rich grassland on abandoned arable land. *Biological Conservation* **51**: 83-96.
- Grayson W.** (1999) The agricultural perspective. In: *The Lowland Grassland Management Handbook 2nd Ed*, Crofts A. & Jefferson R. G. (eds), English Nature/The Wildlife Trusts, Lincoln.
- Green B. H.** (1985) *Countryside Conservation: the Protection and management of Amenity Ecosystems*. George Allen & Unwin, London.
- Green B. H.** (1990) Agricultural intensification and the loss of habitat, species and amenity in British grasslands: a review of historical change and assessment of future prospects. *Grass and Forage Science* **45**: 365-372.
- Green B. H. & Burnham C. P.** (1989) Environmental opportunities offered by surplus agricultural production. In: *Biological Habitat Reconstruction*, Buckley G. P. (ed), Belhaven Press, London, pp. 92-101.
- Grime J. P.** (1979) *Plant Strategies and Vegetation Processes*. John Wiley, Chichester.
- Grime J. P., Hodgson J. G. & Hunt R.** (1988) *Comparative Plant Ecology*. Unwin Hyman, London.
- Grubb P. J.** (1977) The maintenance of species-richness in plant communities: the importance of the regeneration niche. *Biological Review* **52**: 107-145.
- Haines-Young R. H., Barr C.J., Black H.I.J., Briggs D.J., Bunce R.G.H, Clarke R.T., Cooper A., Dawson F.H., Firbank L.G., Fuller R.M., Furse M.T., Gillespie M.K., Hill R., Hornung M., Howard D.C., McCann T., Morecroft M.D., Petit S., Sier A.R.J., Smart S.M., Smith G.M., Stott A.P., Stuart R.C. & Watkins J.W.** (2000) *Accounting for Nature: Assessing Habitats in the UK Countryside*, Department of the Environment, Transport and the Regions, London.
- Hambler C. & Speight M. R.** (1995) Biodiversity conservation in Britain: science replacing tradition. *British Wildlife* **6**: 137-148.
- Harris R. & Jones M.** (2000) Grazing on Orkney. *Enact* **8**: 9-12.
- Hayes M. J. & Williams E. D.** (1994) Botanical changes in upland pasture induced by withdrawal of nutrients. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 284-285.
- Helliwell D. R.** (1989) Soil transfer as a method of moving grassland and marshland vegetation. In: *Biological Habitat Reconstruction*, Buckley G. P. (ed), Bellhaven Press, London, pp. 258-263.
- Hillier S. H.** (1990) Gaps, seed banks and plant species diversity in calcareous grasslands. In: *Calcareous Grasslands - Conservation and Management*. Hillier S. H., Walton D. W. H. & Wells D. A. (eds), Bluntisham Books, Huntingdon, pp. 57-66.
- Hodder K. H. & Bullock J. M.** (1997) Translocations of native species in the UK: implications for biodiversity. *Journal of Applied Ecology* **34**: 547-565.

- Hodgson J. G.** (1989) Selecting and managing plant materials used in habitat construction. In: *Biological Habitat Reconstruction*, Buckley G. P. (ed), Bellhaven Press, London, pp. 45-67.
- Hodgson J. G.** (1987) Why do so few plants exploit productive habitats? An investigation into cytology, plant strategies and abundance within a local flora. *Functional Ecology* **1**: 243-250.
- Hodgson J. G. & Grime J. P.** (1990) The role of dispersal mechanisms, regenerative strategies and seed banks in the vegetation dynamics of the British landscape. In: *Species Dispersal in Agricultural Habitats*: Bunce R. G. H. & Howard D. C. (eds), Belhaven, London, pp. 65-81.
- Holmes R.** (1998) Life support. *New Scientist* (**15 August**): 30-34.
- Hopkins A. & Hopkins J. J.** (1994) UK grasslands now: agricultural production and nature conservation. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 238-239.
- Hopkins A., Pinto M.** (1998) Low-input systems. In: *Ecological Aspects of Grassland Management*, Nagy G. & Peto K. (eds), Proceedings of the 17th General Meeting of the European Grassland Federation, Hungary, BGS, Reading, pp. 197-212.
- Hopkins A., Pywell R. F., Peel S., Johnson R. H. & Bowling P. J.** (1999) Enhancement of botanical diversity of permanent grassland and impact on hay production in Environmentally Sensitive areas. *Grass and Forage Science* **54**: 155-162.
- Hopkins J.** (1989) British meadows and pastures. *British Wildlife* **1**: 202-213.
- Howell E. A. & Jordan III W. R.** (1989) Tallgrass prairie restoration in the North American Midwest. In: *The Scientific Management of Temperate Communities for Conservation* Spellerberg J. F., Goldsmith F. B. & Morris M. G. (eds), Blackwell Scientific press, Oxford, pp. 395-413.
- Hutchings M. J. & Booth K. D.** (1996) Studies of the feasibility of re-creating chalk grassland vegetation on ex-arable land. II. Germination and early survivorship of seedlings under different management regimes. *Journal of Applied Ecology* **33**: 1171-1181.
- Ingrouille M.** (1995) *Historical Ecology of the British Isles*. Chapman & Hall, London
- Jefferson R. G.** (1999) Introduction to lowland grasslands. In: *The Lowland Grassland Management Handbook 2nd Ed*, Crofts A. & Jefferson R. G. (eds), English Nature/The Wildlife Trusts, Lincoln.
- Jones A.** (2001) We plough the fields, but what do we scatter? A look at the science and practice of grassland restoration. *British Wildlife* **12**: 229-235.
- Jones A. T. & Hayes M. J.** (1999) Increasing floristic diversity in grassland: the effects of management regime and provenance on species introduction. *Biological Conservation* **87**: 381-390.
- Jordan III, N. R., Gilpin, M. E. & Aber J. D.** (1987) Restoration ecology: ecological restoration as a technique for basic research. In: *Restoration Ecology: a Synthetic Approach to Ecological Research*, Jordan III N. R., Gilpin M. E. & Aber J. D (eds), Cambridge University Press, Cambridge.
- Katz E.** (2000) The Big Lie: Human restoration of nature. In: *Environmental Restoration: Ethics, Theory and Practice*, Throop W. (ed), Humanity Books, New York, pp. 83-94.
- Kaule G. & Krebs S.** (1989) Creating new habitats in intensively used farmland. In: *Biological Habitat Reconstruction*, Buckley G. P. (ed), Bellhaven Press, London, 161-169.

- Kellman M.** (1996) Redefining roles: plant community reorganization and species preservation in fragmented systems. *Global Ecological & Biogeographical Letters* **5**: 111-116.
- Kendle A. D.** (1993) *The Restoration of Species-rich Grassland on Reclaimed Land*. Unpublished paper, University of Reading.
- Kendle A. D.** (1992) The management of man-made habitats. *Aspects of Applied Biology* **29**: 25-32.
- Kirkham F. W. & Tallwin J. R. B.** (1995) The influence of cutting date and previous fertilizer treatment on the productivity and botanical composition of species-rich hay meadows on the Somerset Levels. *Grass and Forage Science* **50**: 365-377.
- Kirkham F. W., Mountford J. O. & Wilkins R. J.** (1996) The effects of nitrogen, potassium and phosphorus addition on the vegetation of a Somerset peat moor under cutting management. *Journal of Applied Ecology* **33**: 1013-1029.
- Kirkham F. W. & Wilkins R. J.** (1994a) The productivity and response to inorganic fertilizers of species-rich wetland hay meadows on the Somerset Moors: nitrogen response under hay cutting and aftermath grazing. *Grass and Forage Science* **49**: 152-162.
- Kirkham F. W. & Wilkins R. J.** (1994b) The productivity and response to inorganic fertilizers of species-rich wetland hay meadows on the Somerset Moors: the effect of nitrogen, phosphorus and potassium on herbage production. *Grass and Forage Science* **49**: 163-175.
- Kline V. M.** (1997) Planning a restoration. In: *The Tallgrass Restoration Handbook for Prairies, Savannas, and Woodlands*. Packard S. & Mutel C. F. (eds), Society for Ecological Restoration, Island Press, Washington D.C., pp. 31-46.
- Lane C.** (1980) The development of pastures and meadows during the sixteenth and seventeenth centuries. *Agricultural History Review* **28**: 18-30.
- Light A.** (2000) Restoration or domination? In: *Environmental Restoration: Ethics, Theory and Practice*, Throop W. (ed), Humanity Books, New York, pp. 95-111.
- Lord J. M., Wilson J. B., Steel J. B., Anderson B. J. & Bastow Wilson J.** (2000) Community reassembly: a test using limestone grassland in New Zealand. *Ecology Letters* **3**: 213-218.
- Luscombe G. & Scott R.** (1994) *Wildflowers Work: a technical guide to creating and maintaining wildflower landscapes*. Landlife, Liverpool.
- Lyster S.** (2000) Stop, engage and reverse. *Natural World* **58**: The Wildlife Trusts, Newark.
- Macdonald D. W. & Johnson P. J.** (2000) Farmers and the custody of the countryside: trends in loss and conservation of non-productive habitats 1981-1998. *Biological Conservation* **94**: 221-234.
- MacDonald D. W. & Smith H.** (1994) Dispersal, dispersion and conservation in the agricultural system. In: *Species Dispersal in Agricultural Habitats*, Bunce R. G. H. & Howard D. C. (eds), Belhaven, London, pp. 18-35.
- McDonald A. W.** (1993) The role of seed bank and sown seeds in the restoration of an English flood-meadow. *Journal of Vegetation Science* **4**: 395-400.
- Marren P.** (1995) Harvests of beauty: the conservation of hay meadows. *British Wildlife* **6**: 235-243.
- Marrs R. H.** (1993) Soil fertility and nature conservation in Europe. Theoretical considerations and practical management solutions. *Advances in Ecological Research* **24**: 241-300.

- Marrs R. H.** (1985) Techniques for reducing soil fertility for nature conservation purposes: a review in relation to research at Roper's Heath, Suffolk, England. *Biological Conservation* **34**: 307-332.
- Marrs R. H. & Gough M. W.** (1989) Soil fertility - a problem for habitat restoration. In: *Biological Habitat Reconstruction*. Buckley G. P. (ed), Belhaven, London, pp. 29-44.
- Marshall Mr** (1789) *The Rural Economy of Gloucestershire*. Gloucester, pp. 170-195.
- Marshall P.** (1992) *Nature's Web: Rethinking Our Place on Earth*. Cassell, London.
- Martin R.** (1996) The farmer, the taxpayer and the Trust. In: *Nature in Somerset*, Fancett K. (ed), Somerset Wildlife Trust, Bridgwater, pp. 14-17.
- MAFF (Ministry of Agriculture, Fisheries and Food).** (1998) *The Countryside Stewardship Scheme: Information and How to Apply*. Ministry of Agriculture, Fisheries and Food. London
- McDonald A. W.** (1994) The role of aftermath grazing in a flood-meadow community. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 308-309.
- Mitchley J.** (1994) Sward structure with regard to conservation. In *Grassland Management and Nature Conservation*, Hagger, R.J. & Peel, S. (eds), British Grassland Society Occasional Symposium **28**, pp. 43-53.
- Mitchley J.** (1988). Control of relative abundance of perennials in chalk grassland in southern England. II. Vertical canopy structure. *Journal of Ecology* **76**: 341-350.
- Mitchley J., Burch F. & Lawson C.** (1998) *Habitat Restoration Project: Development of Monitoring Guidelines*. EN Research Reports **284**: Peterborough.
- MVF (Mole Valley Farmers Ltd)** (1998) *Grass Seed and Ley Mixtures*. Mole Valley Farmers Ltd, Devon.
- Moore N. W.** (1987) *The Bird of Time: the Science and Politics of Nature Conservation*. CUP, Cambridge.
- Morgan J. W.** (1999) Have tubestock plantings successfully established populations of rare grassland species into reintroduction sites in western Victoria? *Biological Conservation* **89**: 235-243.
- Mountford J. O., Lakhani K. H., & Kirkham F. W.** (1993) Experimental assessment of the effects of nitrogen addition under hay-cutting and aftermath grazing on the vegetation of meadows on a Somerset peat moor. *Journal of Applied Ecology* **30**: 321-332.
- Mountford J. O., Tallowin J. R. B., Kirkham F. W. & Lakhani K. H.** (1994) The effect of inorganic fertilizers in flower-rich hay meadows on the Somerset Levels. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 74-85.
- Newbold C.** (1989) Semi-natural habitats or habitat re-creation: conflict or partnership? In: *Biological Habitat Reconstruction*, Buckley G. P. (ed), Bellhaven Press, London. pp. 9-16.
- Olf H. & Bakker J. P.** (1991) Long-term dynamics of standing crop and species composition after the cessation of fertilizer application to mown grassland. *Journal of Applied Ecology* **28**: 1040-1052.
- Oomes M. J. M. & Mooi H.** (1981) The effect of cutting and fertilizing on the floristic composition and production of an *Arrhenatherion elatioris* grassland. *Vegetatio* **47**: 233-239.
- Packard S. & Mutel C. F.** (eds) (1997) *The Tallgrass Restoration Handbook for Prairies, Savannas, and Woodlands*. Society for Ecological Restoration, Island Press, Washington D.C.

- Parker D. M.** (1995) *Habitat Creation - a Critical Guide*. **21**: English Nature Science, Peterborough.
- Parker V. T. & Pickett S. T. A.** (1997) Restoration as an ecosystem process: implications of the modern ecological paradigm. In: *Restoration Ecology and Sustainable Development*, Urbanska K. A., Webb N. R. & Edwards P. J. (eds), Cambridge University Press, pp. 17-32
- Pegtel D. M.** (1987) Soil fertility and the composition of semi-natural grassland. In: *Disturbance in Grasslands*, Van Andel J., Bakker J. P. & Snaydon R.W. (eds), Junk, Dordrecht, pp. 51-66.
- Pegtel D. M., Bakker J. P., Verweij G. L. & Fresco L. F. M.** (1996) N, K and P deficiency in chronosequential cut summer-dry grasslands on gley podzol after cessation of fertilizer application. *Plant and Soil* **178**: 121-131.
- Poschold P., Kiefer S., Tränkle U., Fischer S. & Bonn S.** (1998) Plant species richness in calcareous grasslands as affected by dispersability. *Applied Vegetation Science* **1**: 75-90.
- Pye-Smith C.** (2000) Counting on cowslips. *Plantlife (spring)*: 10-11.
- Pywell R., Peel S., Hopkins A. & Bullock J.** (1997) Multi-site experiments on the restoration of botanically diverse grassland in ESAs. In: *Grassland management in Environmentally Sensitive Areas. Occasional Symposium No. 32*. Sheldrick R. D. (ed), British Grassland Society, pp. 160-165.
- Rackham O.** (1986). *The History of the Countryside*. J. M. Dent & Sons Ltd., London
- Ratcliffe D. A.** (1984) Post-medieval and recent changes in British vegetation: the culmination of human influence. *New Phytologist* **98**: 73-100.
- Roberts, H. A.** (1981) Seed banks in soils. *Advances in Applied Biology* **6**: 1-55.
- Rodwell J. S.** (1992) *British Plant Communities Volume 3. Lowland Grassland and Montane Communities*. Cambridge University Press.
- Sackville Hamilton N. R.** (2001) Is local provenance important in habitat creation? A reply. *Journal of Applied Ecology* **38**: 1374-1376.
- Sheail J.** (1995) Elements of sustainable agriculture: the UK experience, 1840-1940. *Agricultural History Review* **43**: 178-192.
- Smith A. & Allcock P. J.** (1985) The influence of species diversity on sward yield and quality. *Journal of Applied Ecology* **22**: 185-198.
- Smith R. S.** (1994) Effects of fertilisers on plant species composition and conservation interest of UK grasslands. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 64-73.
- Smith R. & Corkhill P.** (2000) Diversifying upland meadows. *Enact* **8**: 18-21.
- Smith R. S., Corkhill P., Shiel R. S. & Millward D.** (1996) The conservation management of mesotrophic (meadow) grassland in Northern England. 2. Effects of grazing, cutting date, fertilizer and seed application on the vegetation of an agriculturally improved sward. *Grass and Forage Science* **51**: 292-305
- Smith R. S., Pullan S. & Shiel R. S.** (1996) Seed shed in the making of hay from mesotrophic grassland in a field in Northern England: effects of hay cut date, grazing and fertilizer in a split-split-plot experiment. *Journal of Applied Ecology* **33**: 833-841.
- Snow C. S. R., Marrs R. H. & Merrick L.** (1997) Trends in soil chemistry and floristics associated with the establishment of a low-input meadow system on an arable clay soil in Essex. *Biological Conservation* **79**: 35-41.
- SER (Society for Ecological Restoration)** (2000) *Internet Resources Site*. <http://www.ser.org>

- SWT (Somerset Wildlife Trust)** (1998) *Reserves Acquisition Policy*. Unpublished report, SWT, Taunton, Somerset.
- SSDC (South Somerset District Council)**. (1998) Lowland neutral hay meadows and pastures - habitat action plan. *South Somerset Biodiversity Action Plan*. Somerset Environmental Records Centre, Somerset.
- SSDC (South Somerset District Council)**. (1999) *A Strategy for Nature Conservation in South Somerset*. Conservation & Environment Unit, SSDC, Somerset.
- Stampfli A. & Zeiter M.** (1999) Can plant-species decline due to abandonment of meadows be reversed by mowing? A case study from the southern Prealps. *Journal of Vegetation Science* 10: 151-164.
- Stoate C.** (1995) The changing face of lowland farming and wildlife. Part 1. 1845-1945. *British Wildlife* 6: 341-350.
- Stoate C.** (1996) The changing face of farming and wildlife. Part 2 1945-1995. *British Wildlife* 7: 162-172.
- Strykstra R. J., Bekker R. M. & Bakker J. P.** (1998) Assessment of dispersule availability: its practical use in restoration management. *Acta Botanica Neerlandica* 47: 57-70.
- Tallowin J. R. B. & Jefferson R. G.** (1999) Hay production from lowland semi-natural grasslands: a review of implications for ruminant livestock systems. *Grass and Forage Science* 54: 99-115.
- Tallowin J. R. B., Smith R. E. N. & Kirkham F. W.** (1995) Restoration of floristic diversity to a de-intensified species-impooverished grassland in the UK: a case study. In: *Floristical Diversity of Grassland*. Annales Universitatis Mariae Curie-Sklodowska Lublin-Polonia, Vol. L, Marie Curie University, Lublin: pp. 237-245
- Thirsk J.** (ed) (2000) *The English Rural Landscape*, OUP, Oxford.
- Thomas K.** (1983) *Man and the Natural World: Changing Attitudes in England 1500-1800*. Penguin Books,, Middlesex.
- Thompson K., Gaston K. J. & Band S. R.** (1999) Range size, dispersal and niche breadth in the herbaceous flora of central England. *Journal of Ecology* 87: 150-155.
- Throop W.** (2000a) Introduction. In: *Environmental Restoration: Ethics, Theory and Practice*, Throop, W. (ed), Humanity Books, New York, pp. 11-23.
- Throop W.** (2000b) Epilogue. In: *Environmental Restoration: Ethics, Theory and Practice*, Throop W. (ed), Humanity Books, New York, pp. 237-238.
- Tilman D.** (1997) Community invasibility, recruitment limitation, and grassland biodiversity. *Ecology* 78: 81-92.
- Tilman D., Dodd M. E., Silvertown J., Poulton P. R., Johnston A. E. & Crawley M. J.** (1994) The Park Grass experiment: insights from the most long-term ecological study. In: *Long-term Experiments in Agricultural and Ecological Sciences*. Leigh R. A. & Johnston A. E. (eds), CAB International, pp. 287-303.
- Urbanska K. A., Webb N. R. & Edwards P. J.** (1997) Why restoration? In: *Restoration Ecology and Sustainable Development*, Urbanska K. A., Webb N. R. & Edwards P. J. (eds), Cambridge University Press, pp. 3-7.
- Usher M. B.** (ed) (1986) *Wildlife Conservation Evaluation*. Chapman & Hall, London.
- van Andel J.** (1998) Intraspecific variability in the context of ecological restoration projects. *Perspectives in Plant Ecology, Evolution and Systematics* 2: 221-237.
- van der Valk A. G. & Pederson R. L.** (1989) Seed banks and the management and restoration of natural vegetation. In: *Ecology of Soil Seed Banks*, Leck M. A., Parker V. T. & Simpson R. L. (eds), Academic Press, San Diego, pp. 329-346.

- van der Woude B. J., Pegtel D. M. & Bakker J. P.** (1994) Nutrient limitation after long-term nitrogen fertilizer application in cut grasslands. *Journal of Applied Ecology* **31**: 405-412.
- van Groenendael J. M., Ouborg N. J. & Hendriks R. J. J.** (1998) Criteria for the introduction of plant species. *Acta Botanica Neerlandica* **47**: 3-13.
- Wathern P. & Gilbert O. L.** (1978) Artificial diversification of grassland with native herbs. *Journal of Environmental Management* **7**: 29-42.
- Wathern P. & Gilbert O. L.** (1979) The production of grasslands on subsoil. *Journal of Environmental Management* **8**: 269-275.
- Way J. M.** (1989) Reconstruction of habitats on farmland. In: *Biological Habitat Reconstruction*, Buckley G. P. (ed), Bellhaven Press, London, pp. 102-114.
- Wells T. C. E.** (1990) Establishing chalk grassland on previously arable land using seed mixtures. In: *Calcareous Grasslands - Ecology and Management*, Hillier S. H., Walton D. W. H. & Wells D. A. (eds), Bluntisham Books, Huntingdon, pp. 169-170.
- Wells T. C. E.** (1983) The creation of species-rich grasslands. In: *Conservation in Perspective*, Warren A & Goldsmith F. B. (eds), John Wiley & Sons Ltd, London, pp. 215-246.
- Wells T. C. E., Bell S. & Frost A.** (1981) *Creating attractive grasslands using native plant species*. N.C.C., Peterborough.
- Wells T. C. E., Cox R. and Frost A.** (1989) Diversifying grasslands by introducing seed and transplants into existing vegetation. In: *Biological Habitat Reconstruction*, Buckley G. P. (ed), Bellhaven Press, London. pp. 283-297.
- Wells T. C. E., Sheail J., Ball D.F. & Ward L.K.** (1976). Ecological studies on the Porton Ranges: relationships between vegetation, soils and land-use history. *Journal of Ecology* **64**: 589-626.
- Westbury D. B. & Dunnett N. P.** (2000) The effect of the presence of *Rhinanthus minor* on the composition and productivity of created swards on ex-arable land. *Aspects of Applied Biology* **58**: 271-278.
- Westbrook D.** (2000a) Where are all the cowslip fields? *News (Jan)*, Somerset Wildlife Trust, Bridgwater, Somerset, p.10.
- Westbrook D.** (2000b) Taunton Deane's biodiversity blueprint. *News (May)*, Somerset Wildlife Trust, Bridgwater, Somerset, pp. 12-14.
- White P.** (1996) Grasslands: a habitat in crisis. In: *Nature in Somerset*, Fancett K. (ed), Somerset Wildlife Trust, Bridgwater, pp. 3-8.
- White P. S. & Walker J. L.** (1997) Approximating nature's variation: selecting and using reference information in restoration ecology. *Restoration Ecology* **5**: 338-349.
- Whyte M.** (1997) The loss of unimproved grasslands in Somerset, from the 1930s to the 1990s. *Proceedings of the Somerset Archaeological & Natural History Society* **139**: 215-220.
- Willems J. H. & Bik L. P. M.** (1998) Restoration of high species density in calcareous grassland: the role of seed rain and soil seed bank. *Applied Vegetation Science* **1**: 91-100.
- Yeo M. J. M., Blackstock T. H. & Stevens D. P.** (1998) The use of phytosociological data in conservation assessment: a case study of lowland grassland in mid Wales. *Biological Conservation* **86**: 125-138.
- Young T. P.** (2000) Restoration ecology and conservation biology. *Biological Conservation* **92**: 73-83.

Younger A. & Smith R. S. (1994) Hay meadow management in the Pennine Dales, Northern England. In: *Grassland Management and Nature Conservation*, Hagger R. J. & Peel S. (eds), British Grassland Society Occasional Symposium **28**, pp. 137–143.