Enhancing Grassland Biodiversity and Its Consequences for Grassland Management and Utilisation

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Key points

1. Grasslands make an important contribution to the biodiversity of rural landscapes.
2. Biodiversity has the potential to support the production function of grassland. The conditions for this are largely unexplored.
3. The enhancement of biodiversity on agriculturally improved, species-poor grasslands is difficult to achieve due to seed limitation and high residual soil fertility.
4. Measures to overcome constraints are addition of propagules, depletion of soil nutrients, and the use of specific sward treatments.
5. Agri-environmental schemes will play an increasing role in achieving the biodiversity targets in the future, however, the efficiency of such schemes needs improvement.

Keywords: species richness, production, agri-environment schemes, seedling recruitment

Introduction

Grassland biodiversity has received a great deal of attention by society and scientists in recent years. As a definition, biodiversity describes the whole variability found among living organisms, and encompasses the diversity within species, between species, and of whole ecosystems. Agriculture represents a dominant form of land use all over the world, and rural landscapes make up a significant part of the earth's total biodiversity. Two reasons are responsible for the increased attention to biodiversity. Firstly, biodiversity is generally perceived as a heritage that mankind needs to preserve for future generations. The convention on biodiversity is a major expression of this perception. Secondly, biodiversity and ecosystem functioning are related. For grassland systems, it has been shown that biodiversity is positively related to the primary production, stability and resilience of a system, as well as the nutrient retention and efficiency (Tilman *et al*., 1996; Loreau, 2000). This raises the hope that contrasting functions of grassland, e.g. production and biodiversity, may be brought together so that management systems can be developed to the benefit of both. However, recent findings from ecological research have not been seriously considered for being implemented in farming practice (Sanderson *et al*., 2004a).

Agriculture and farming activities are closely related to the biodiversity at a particular site or of whole landscapes. Biodiversity has co-evolved with land-use practices since the onset of crop and livestock husbandry in prehistoric times. Agriculture has been responsible for both an increase and loss of biodiversity in rural areas; its actual effect being dependent on the intensity of land-use.

The challenges of current grassland farming with regard to biodiversity are: 1) traditionally managed species-rich grasslands are at risk of being abandoned with an attendant loss of species diversity. How can biodiversity be maintained through agricultural management? 2) Can the diversity of agriculturally improved grasslands with a low species number be enhanced, and which management measures will be effective in this respect (Marriott *et al.*, 2004)? Although the decrease in plant species diversity in grassland through the intensification of grassland use has been well investigated and the processes involved are generally understood, the situation is much less clear for other organisms and the appropriate measures for maintaining or enhancing their diversity have also not been elucidated.

The objectives of this paper are to investigate the potential benefits of biodiversity on the production function of grassland, and to present ways in which biodiversity can be increased on sites that have experienced a history of intensive management leading to a concomitant deterioration of diversity. Finally, consideration will be given to those management measures appropriate to achieving the goal of increased grassland biodiversity and to the consequences for grassland farming.

The potential benefits of utilising biodiverse grasslands

The biodiversity of semi-natural species-rich grasslands has developed over centuries under the influence of traditional human management (Ellenberg, 1996). It is the result of a broad range of environmental conditions interacting with a large variety of grassland utilisation systems for livestock production (Nösberger & Rodriguez, 1996). In temperate climates, there is only a relatively small amount of 'natural' grassland still in existence. Most of the grasslands require regular utilisation if their botanical composition and plant species diversity are to be maintained. Grassland that is abandoned from agricultural use shows successional change with an increasing dominance of tall species and the invasion of woody plants. In many situations, this will cause a decrease in plant species diversity. Across Europe, semi-natural grasslands are becoming increasingly at risk of being abandoned from agricultural use as these grasslands produce low herbage yields compared to intensively managed grasslands, and the feeding value of the herbage often fails to fulfil the energy requirements of livestock of high genetic merit (Peeters & Janssens, 1998; Tallowin & Jefferson, 1999). However, these grasslands are highly valued by society, since they have a high biodiversity and are attractive for tourists and urban populations seeking recreation (Nösberger & Rodriguez, 1996; Schüpbach *et al.*, 2004). In addition, species-rich grasslands are important for agriculture as they provide a reservoir of plant genotypes, which can be, used in future plant improvement schemes (Nösberger & Rodriguez, 1996).

Grassland that is utilised for intensive livestock husbandry is usually characterised by low species diversity with only a few valuable forage species dominating the grass swards. These species are introduced by sowing, they have a high yield potential and feeding value. High doses of mineral or organic fertilisers are required to maintain the dominance of these species. The herbage is defoliated frequently and stocking rates are high. In addition, grasslands are regularly renovated by reseeding or oversowing. Given this situation, farmers perceive species-rich grassland mainly as a constraint to productive livestock husbandry as traditionally, species-rich semi-natural grasslands have a low herbage production and quality, leading to the common perception of farmers that species-rich grasslands are not a valuable resource for profitable livestock production.

In contrast, recent ecological research on the relationship between biodiversity and ecosystem services suggests that preserving and restoring biodiversity has the potential to support the agricultural function of grasslands (Minns *et al.*, 2001). Three main aspects of this function will be considered: 1) herbage production, 2) the stability and resilience of swards, including susceptibility to weed invasion, and 3) nutrient cycling.

Herbage production

In recent years, grasslands have been the focus of ecological research on the relationship between plant species diversity and productivity (Tilman *et al*., 1996). A prominent experiment was performed on European grasslands at eight different sites. Its results showed an advantage of increasing plant species numbers on the aboveground productivity (Hector *et al*., 1999). Plant communities were established on sterilised soils by random selection from a species pool and were maintained by weeding. A controversy developed over the mechanisms behind this relationship (Loreau *et al*., 2001). It was proposed that facilitation among plant species and niche-differentiation were the major processes involved. However, a 'sampling effect' was also suggested, which may have arisen due to the increased probability of selecting highly productive species with an increasing number of species in the mixture (Wardle, 1999).

The number of functional traits that are represented by the plant species in the mixture is also positively related to production. The inclusion of nitrogen-fixing legumes usually gives a leap in the productivity of unfertilised swards. The addition of common non-legume species has also been shown to support the relationship between diversity and productivity. Such species may have other special traits, i.e. many forbs with deep root systems or the grasses with a shallow, but intensive root system (van Ruijvens & Berendse, 2003).

Ecologists have suggested that the relationship between diversity and productivity should be better exploited to the benefit of grassland farming (Bullock *et al*., 2001; Minns *et al*., 2001). There is, however, little evidence that this can be readily done by standard farming practices. Most of the experiments done in this field were not designed to produce data that could be directly applied to farming nor could it be used in current livestock production systems. When summarising the currently available knowledge, a number of constraints can be identified.

Previous investigations on the diversity-productivity relationship were based on sown grasslands ('experimental grasslands') and yields were followed over a period of up to five years. This is a ley-farming situation where grasslands are established on arable land for a couple of years and then returned to an arable crop rotation (Hopkins, 2000). In the first year in particular after these grasslands are ploughed up or re-established by sowing, but also in the following years, the nutrient flows and organic matter turnover are highly dynamic and in a state of imbalance (Whitehead, 1995). Thus, the sward response to varying species diversity may not reflect the situation of permanent grasslands that in many cases have not experienced any soil disturbance by tillage or seed addition for decades. However in many countries, permanent and semi-natural grassland covers a larger part of the total area farmed than short-term leys.

The botanical composition of newly established swards also shows a dynamic development. The occurrence and cover of sown species as well as of those not sown entering the sward, may change considerably in the early years after sowing. The direction and amount of change is dependent on the site and the management conditions. Deduced from long-term studies, the dynamic of change of the sward's botanical composition after sowing will decrease with time (Arens, 1971). This experience has been indirectly confirmed by recent research with 'experimental grasslands', where weeding of plots were pivotal in maintaining the intended species number and composition of the plots. If weeding was stopped, the differences between plots with a varying number of plant species diminished rapidly (Pfisterer *et al*., 2004).

In order to avoid such artificial systems when studying the effect of species number on productivity, species removal from existing permanent swards and oversowing treatments have been proposed. This would leave the existing swards largely undisturbed, and little vegetation change due to disturbance would occur. However, only a few data from such experiments are available. In one multi-site experiment, Hopkins *et al*. (1999) found little establishment of oversown seed and thus little effect on herbage yield, compared to a control was not oversown. Hofmann & Isselstein (2005) achieved a successful establishment of oversown seeds of wildflower species into an existing species-poor hay-meadow. Four years after oversowing, the herbage yield of the oversown plots was 23% higher compared to the unsown control.

So far, ecological research with 'experimental grasslands' has focused on the primary production; grazing and livestock performance have not been considered. As farmers use the grasslands to feed their livestock and to produce milk, meat and fibre, the benefits of biodiversity for grassland farming should be measured in terms of animal performance (Sanderson *et al*., 2004a). This should include a determination of the feeding value of the herbage, the feed intake, and the production of milk, meat and fibre. The majority of grasslands worldwide are utilised by grazing. In addition, grazing behaviour and herbage intake are dependent on species diversity and sward heterogeneity (Rook *et al*., 2004a). Thus, the response of grazers and their performance to varying plant species diversity needs to be investigated. A pilot experiment in this respect was performed by Sanderson *et al*. (2004b), who sowed forage species mixtures with a varying number of species, and then measured the primary production as well as the performance of grazing animals. A limited response of livestock performance to varying levels of forage species diversity was found.

A further drawback of many biodiversity experiments with regard to their relevance for current grassland farming is the low defoliation frequency. In the BIODEPTH experiment (Hector *et al*., 1999), swards were cut once or twice a year. This is considerably less than the usual frequency on many intensive livestock farms. Hence, systems with a more frequent defoliation need to be included to study the effect of species number on production. There is some indication that the defoliation frequency or - more generally - the disturbance level has an impact on the biodiversity/productivity relationship. Sala (2001) suggested that the species complementarity that is assumed to be mainly responsible for a positive relationship is higher in communities that have a history of a long co-evolution of species. Accordingly, systems with a higher disturbance level should have a less strong species complementarity effect. However experimental verification for this is still missing.

Various experiments with sown grassland showed that a significant effect of plant species number on productivity occurred at a log-linear scale (Hector *et al*., 1999). This means that the lower the species number, the higher is the productivity response per added species. This result could be applied in grassland farming and research. For profitable grassland farming, only a limited number of valuable forage species are usually considered for use in seed mixtures. These are mainly a few productive grasses and legumes. The inclusion of other selected forage species like grassland forbs could lead to a significant increase in production without compromising forage quality. The necessary research in this field could be based on the huge experience in grass clover-systems that has been gathered during the last two decades. Another application in research could arise from the prospect of studying biodiversity effects on production in swards with a comparatively low species number. This would allow not only the investigation of the physiological processes involved in the response of production to biodiversity, but also the use of modelling in order to simulate yield formation, competition and facilitation among species, as well as niche-differentiation in the swards.

Stability and resilience of swards

Ecologists have hypothesised that species-rich grasslands maintain their ecosystem function and production more effectively if they face disturbance or stress through defoliation, disease infection or weed infestation (Knops *et al*., 1999; Pywell *et al*., 2002). For seed mixtures with an increasing number of selected forage species, it was found that weed infestation was unrelated to the number of sown species. However, weeds played a decreasing role with increased evenness of the sown plant community (Tracy *et al*., 2004). It was concluded that maintaining an even distribution of competitive forage species in the mixture rather than the forage species number would be important in reducing weed invasion (Tracy *et al*., 2004).

An important agronomic characteristic of grass swards is the variability of herbage production during the growing season. Most of the experiments on grassland biodiversity and ecosystem functioning include infrequent defoliation by cutting, so that so far, there is no experimental proof that diverse systems lead to a lower variability.

Nutrient cycling

Increasing plant species diversity may increase the nutrient uptake and nutrient efficiency of the vegetation. Plant species with different functional traits exploit different resources for their nutrients; examples being nitrogen fixation by legumes or the exploitation of soil nutrients in the lower horizons by deep rooting forbs. Nutrient retention was also found to be related to plant species diversity. Nitrate leaching in grasslands was lower with an increasing number of species, as excess nitrate in the soil occurred less frequently with diverse systems (Reich *et al*., 2001; Scherer-Lorenzen *et al*., 2003).

Enhancing the biodiversity of grasslands with a history of agricultural improvement

Maintaining species-rich semi-natural grasslands that have not experienced a history of agricultural improvement is a primary target of nature conservation activities in the rural landscape (Söderstrom *et al*., 2001; Jeangros & Thomet, 2004). In countries where most of the grasslands were 'improved' during a period of intensification of livestock husbandry and thus, are species-poor, priority has also been given to the restoration of biodiversity (Marriott *et al*., 2004). Today, a trend towards extensification of grassland use can be seen in many countries where dairy cows and beef cattle feeding ratios are more and more based on highly digestible forages from arable land rather than on grass (Feehan *et al*., 2005). Therefore, developing extensive grassland systems primarily for biodiversity rather than for livestock production is a new target in a changing agri-environment, with a need to manage a relatively large grassland area with relatively few stock (Rook *et al*., 2004b). Restoration activities on species-poor agriculturally improved grassland are mainly focussed on vegetation. It is commonly accepted that increased plant species diversity will also benefit the diversity of other living organisms, such as mammals, birds, invertebrates, or soil organisms (Duelli & Obrist, 1998). However, there is also evidence from research on semi-natural grassland, which shows that single taxa are not necessarily good indicators for total biodiversity (Vessby *et al*., 2002). Therefore, restoration success should generally be evaluated by measuring a group of organisms rather than single taxa.

In order to enhance biodiversity, extensification objectives for grassland management are generally embedded in the many agri-environment schemes. Extensification means reduction or cessation of fertilisation, reduction of stocking rates and cutting frequencies, and the abandonment of sward improvement measures, like the application of herbicides or reseeding (Barthram *et al*., 2002; Smith *et al*., 2003, Marriott *et al*., 2004). The efficiency of methods for the enhancement of biodiversity is discussed in separate sections for grassland vegetation and grassland fauna.

Plant species diversity

Many attempts at enhancing plant species richness on species poor grasslands by switching from intensive to extensive management have failed, at least in the short term (Dyckmans *et al*., 1999; Marriott *et al*., 2004). If at all, species number recovered only after several years of extensive management (Jeangros & Bertola, 2002; Smith *et al*., 2003). According to van Diggelen & Marrs (2003), several reasons have to be considered for this result. They identified the necessary steps for a successful restoration of species-rich plant communities on agriculturally improved land: 1) the abiotic conditions have to be within the tolerance limits of the target vegetation; 2) propagules from species of the target community must be available, they must be viable and able to establish seedlings on the sites; and 3) grassland management needs to be adapted to the requirements of the introduced species.

(1)
Unimproved species-rich grasslands are characterised by a low nutrient availability in the soils. For species-rich grasslands on mineral soils, the phosphorus concentration is usually low and this is a key factor for the diversity of the swards (Janssens *et al*., 1998; Critchley *et al*., 2002). Various investigations have demonstrated that a moderate to high soil nutrient concentration is a major constraint to the restoration of diverse swards (Peeters & Janssens, 1998; Bakker & Berendse, 1999). After the onset of extensive management, the soil nutrient concentration may remain at a high level for some years, and productive forage species will maintain their vigorous growth and competitiveness (Koch & Masé, 2001). This will reduce the availability of regeneration niches for seedling recruitment (Grubb, 1977), and emerging seedlings will be eliminated through competition and shading by the existing sward (Muller *et al*., 1998; Isselstein *et al*., 2002). Peeters & Janssens (1998) have pointed out that unless the residual soil fertility and the soil phosphorus concentration have markedly decreased, restoration will not be successful. From earlier ecological research, it was concluded that on mesotrophic grassland, an annual herbage production above 6 t DM/ha is incompatible with a high plant species number (Oomes, 1992). High soil fertility has an adverse effect on the restoration success even if species-rich grasslands are created on ex-arable land and no existing vegetation suppresses seedling growth. Emerging arable weeds and ruderals will limit the establishment of the desired species (Hopkins *et al*., 1999; Pywell *et al*., 2002). In order to reduce the soil fertility and the nutrient availability, various depletion measures have been studied. Deturfing and topsoil removal is a most drastic but effective technique for the reduction of soil nutrients and the limitation of crop growth. Using this method, species-rich swards could be restored within a comparatively short time span (Hopkins *et al*., 1999). Another technique employing deep cultivation to dilute the nutrient concentration was shown to reduce topsoil P and K concentrations, and to facilitate the establishment of sown forbs (Pywell *et al*., 2002). Deturfing and deep cultivation are techniques which are not particularly favoured if sites are to enter agri-environment schemes (Walker *et al*., 2004). Therefore, beyond the depletion of soil nutrients, an urgent need exists for the development of restoration techniques that are effective in the presence of elevated nutrient concentrations (Critchley *et al*., 2002).

In addition to the overriding importance of soil nutrients for the restoration of plant species diversity, soil biotic diversity also plays a role (Wardle *et al*., 2004). High input grassland systems tend to have a lower diversity of soil fauna, and favour bacterial-pathways of decomposition. In comparison, low-input systems have higher soil fauna diversity and favour fungal-pathways. Obviously, low-input management has a potential to increase soil biodiversity and therewith ecosystem self-regulation (Bardgett & Cook, 1998). The fungal:bacteria biomass ratio was shown to be useful in the indication of the long-term intensity of grassland management with higher values in low-input grasslands (Bardgett & McAlister, 1999). However, the conversion of intensive grassland management to low-input management did not result in a rapid change of the fungal:bacterial biomass ratio (Bardgett & McAlister, 1999), indicating that the potential for a rapid enhancement of plant species diversity would also be low.

(2)
Several experiments aimed at restoring extensive grasslands have shown a decrease in herbage production ranging from 0.5 to 0.8 of the value before the extensification (Oomes, 1990; Berendse *et al*., 1992; Dyckmans *et al*., 1999). Such loss of herbage yield is likely to be accompanied by a decreased percentage yield of competitive plants like *Lolium* spp. (Hofmann & Isselstein, 2005). In principle, the reduced herbage growth should facilitate the establishment of emerging seedlings, and yet, species number often remains low. The reason for this is that no propagules of the desired species are available, neither in the soil seed bank nor from the adjacent vegetation. Accordingly, the addition of propagules is necessary to induce an increase in diversity (Berendse *et al*., 1992; Bakker & Berendse, 1999; Pywell *et al*., 2002; Matejkova, *et al*., 2003).

Grasslands have transient soil seed banks. After species have disappeared from the vegetation, they will stay in the soil seed bank only for a limited time, with the duration depending on the vegetation type and the site conditions (Matus *et al*., 2003). Intensively used landscapes are fragmented, many semi-natural habitats are lost and the adjacent vegetation of intensive grassland is often poor in species. Agricultural techniques that had formerly allowed grassland species to set seed, and supported the exchange of propagules between different sites (e.g. traditional haymaking, communal grazing or shepherding, etc.), have been abandoned and this has further limited seed availability and seedling recruitment (Poschlod *et al*., 1998). Thus, restoration of species diversity is often seed-limited (Bakker & Berendse, 1999).

(3)
If plant species are reintroduced into grasslands, there is a need to implement management measures that support the establishment success such as appropriate cutting dates, grazing regimes and other sward treatments (Smith *et al*., 2000; Marriott *et al*., 2004). It is necessary to apply such measures before the seeds from the desired species are over-sown into the existing swards. These measures comprise the lowering of the sward density by infrequent cutting and taking a hay crop immediately before over-sowing or by mechanical disturbance of the sward, e.g. through harrowing. Both these measures reduce the tiller density and increase the availability of gaps in the canopy, which is a prerequisite for germination and emergence (Hopkins *et al*., 1999; Isselstein *et al*., 2002; Losvik & Austad, 2002; Hofmann & Isselstein, 2004a).

Even more important is the management after seeds have been sown. Various experiments have shown that defoliation of the existing sward following seedling emergence is pivotal for the survival of the seedlings (Marriott *et al*., 2004). This is particularly important when the production of the existing sward is still moderate to high and seedlings suffer from shading. Defoliation increases the amount of light available for the seedlings and thereby enhances seedling survival (Hofmann & Isselstein, 2004a). On a site with high residual fertility, it was demonstrated that frequent defoliation, irrespective of whether it was done by continuous sheep grazing or cutting, significantly increased seedling survival and establishment compared to infrequent defoliation (Isselstein *et al*., 2005). An alternative approach for successful restoration on a moderately fertile site was developed by Pywell *et al*. (2004). Sowing of the parasitic plant *Rhinanthus* spp., significantly increased germination and establishment of a blend of over-sown wildflower species. This was obtained by a reduction in competitiveness of the existing sward by *Rhinanthus* and by the dead *Rhinanthus* shoots leaving gaps for seedling colonisation.

It has to be emphasised that during seedling recruitment, the requirements of plants with regard to suitable microhabitats may change. Germination and emergence are mainly enhanced by the availability of gaps with bare soil. Seedling survival and establishment are dependent on defoliation of the existing vegetation. Moreover, adult plants may again have different requirements as has been shown for species typical for traditional hay meadows. These species are susceptible to frequent defoliation, and yet, seedling establishment was enhanced by frequent cutting (Hofmann & Isselstein, 2004a).

Restoration attempts by introducing propagules from desired species have to consider species-specific requirements for successful establishment. Species vary in their response to competition by the existing sward, to drought and other types of environmental stress and this has implications for seedling recruitment (Hofmann & Isselstein 2004b). More research is needed to identify the specific requirements of the desired species with regard to seedling recruitment so that management measures on the grass sward can be more successfully targeted at obtaining the establishment of a high number of seedlings.

Seed provenance

The availability and origin of wildflower seeds to be used in grassland restoration have led to concerns among ecologists and agronomists. It is commonly accepted that the introduced species should be adapted to the site and management conditions (Walker *et al*., 2004) and should originate from a local source. Collecting seeds from species-rich grasslands that are similar to the target vegetation of the restoration site, and that are located in the same region would undoubtedly be the best technique. The introduction of ecotypes from other regions bears the risk of failure with regard to establishment and persistence. It may also pose a threat to indigenous populations of the species through hybridisation and competitive exclusion (Keller *et al*., 2000).

Germination under controlled conditions of several grassland and arable species from different provenances has been investigated by Keller & Kollmann (1999). There was considerable variability among provenances for the investigated species, and a relationship with the climatic conditions of the sites where the seeds had been collected was found. These adaptations were seen as an argument against the introduction of foreign species for the enhancement of biodiversity (Keller & Kollmann, 1999). However, the collection of seeds from semi-natural grasslands is laborious and increases the cost of restoring biodiversity. In Switzerland, where the establishment of species-rich hay meadows is encouraged by agri-environment schemes, a commercial system of seed multiplication has been set up in order to provide wildflower seeds at a reasonable cost, however a problem may arise with this technique as the genetic variation within a species may be reduced by repeated seed multiplication. This potential drawback has not been investigated to any great depth (Rüegger & Zanetti, 2001).

The selection of appropriate genotypes for restoration is mainly seen in relation to their potential to restore specific species assemblages or communities. However, as Gray (2002) has pointed out, restoration should also consider the functioning of ecosystems, which would include the process of evolutionary change. Thus, in a long-term perspective, the genetic diversity of introduced species must be such that it enables the species to cope with future abiotic and biotic change and thereby to escape extinction. There is no general answer to the question on the necessary extent of genetic diversity. On isolated restoration sites where genetic exchange with neighbouring habitats is not likely to occur, the genetic diversity of introduced species needs to be higher. Similarly, the size and degree of disturbance of the site at the beginning of restoration is of importance as more disturbed sites are more likely to change in habitat conditions than less disturbed ones (Gray, 2002).

Grazing as a management tool

Utilising semi-natural grasslands by grazing livestock has been shown to be effective in the maintenance of biodiversity (Bakker, 1994; Spatz, 1994; Stammel *et al*., 2003). Evidence also shows the potential of grazing for restoring biodiversity on semi-natural unimproved grassland that had been abandoned from agricultural use for some years, and therefore had lost species (Pykala, 2003; Lindborg & Eriksson, 2004; Hellström *et al*., 2005). Grazing is also considered to have potential for the restoration of biodiversity on agriculturally improved species-poor grasslands. On a local scale, grazing increases sward structural heterogeneity by selective defoliation due to dietary choice, treading, nutrient cycling and propagule dispersal (Rook *et al*., 2004a,b). Grazing at low stocking rates compared to moderate or high stocking, markedly increased sward heterogeneity (Correll *et al*., 2003; Isselstein *et al*., 2003).

Within a growing season, patches of tall and short grass develop with time and remain relatively constant (Correll *et al*., 2003). Therefore, at any given time, a range of microhabitats exists within a paddock providing a range of microsites for the different phases of the development of a population. Patches with short grass would enhance seedling recruitment, whereas patches of tall grass would allow adult plants to produce and distribute diaspores. Although such a situation seems likely to occur on extensively grazed grassland, the experimental proof is still scarce. In an ongoing Europe-wide, multi-site experiment on improved, mesic grasslands, extensive grazing showed an immediate effect on the sward structure compared to moderate stocking, but such a rapid effect was not seen on either the botanical composition of the sward or the species number (Rook *et al*., 2004b; Scimone *et al*., 2004).

The effect of livestock grazing on biodiversity is not only visible on a local scale, but also at a landscape scale. Traditional grazing systems, such as communal grazing or extensive set stocking, are characterised by relatively unrestricted grazer access to the whole pasture land. Thus, 'natural' grazing behaviour will be expressed and preferences for grazing areas, resting areas, etc., will be seen in the development of a mosaic of different plant communities. Today, examples of such conditions of high community diversity can still be observed in traditionally managed alpine grasslands with summer grazing of dairy cows for hard cheese production (Spatz, 1994). In a recent investigation on abandoned alpine grassland, it was shown that abandonment from grazing led to a significant long-term decline in species number. This effect occurred markedly at the landscape scale, and it was suggested that the reason was mainly community displacement rather than competitive exclusion at the local scale (Dullinger *et al*., 2003). This result emphasises the need to consider biodiversity at a landscape scale (Eriksson *et al*., 2002), and to maintain and re-establish large scale stocking systems. Recent nature conservation concepts have taken up this consideration and in many countries, large reserves with mega-herbivore grazing have been established (Redecker *et al*., 2002). Grazers such as Heck cattle, Konik horses, Red and Roe deer are kept outdoor all year round. These animals are not utilised for livestock production purposes, though in theory they could be.

Employing extensive grazing to restore biodiversity within an agricultural system could offer economic advantages over non-agricultural mega-herbivore grazing, as the sale of the livestock products can be used to balance the animal husbandry costs. Despite such income, additional support by agri-environment schemes will still be indispensable to maintain such grazing systems, but the need for support by public budgets is likely to be higher for the non-agricultural systems. Within agricultural production, when grazing is compared with cutting, grazing seems to be more advantageous. Hay or silage from extensively managed improved grassland often has poor feeding quality, and their use is not advised in intensive beef, dairy or sheep farming (Dyckmans *et al*., 1999; Isselstein *et al*., 2001). However, when the herbage is grazed, livestock may achieve an individual performance that is comparative to the standards in intensive systems (Fothergill *et al*., 2001, Hofmann *et al*., 2001; Isselstein *et al*., 2004), which gives some room for the integration of such grassland in modern livestock farms.

Fauna diversity

As with the restoration of plant species diversity on agriculturally improved species-poor grassland, the reversal from intensive to extensive management does not immediately lead to an increase in the diversity of the fauna. The mechanisms involved in the exclusion of many animal species during the intensification of grassland management are obviously not simply reversed and, in addition, are far from being fully understood (Robinson & Sutherland, 2002). The decline of animal species has been particularly marked amongst habitat specialists, and many of the taxa still common on farmland are habitat generalists. During the intensification of agriculture, landscape diversity showed a dramatic reduction, farm number and farm labour declined, and agricultural yields markedly increased (Robinson & Sutherland, 2002).

For birds, it has been shown that with the intensification of grassland management, the suitability of habitats for breeding and feeding declined (Vickery *et al*., 2001). However, the relative significance of the individual factors associated with grassland intensification, whether it is the chemistry or hydrology of the site, the defoliation frequency, or the application of fertilisers and agrochemicals, etc., remains unclear (Vickery *et al*., 2001). Multivariate analyses of long-term field data by Benton *et al*. (2002) suggest that the effect of management on bird populations is mainly an indirect one through changes in the invertebrate fauna, i.e. the quality and quantity of the food available for birds. In addition, it seems obvious that processes operating at the landscape or regional level have a strong effect on bird species diversity and abundance as birds easily move over larger distances.

Vickery *et al*. (2001) proposed that low input livestock systems should be established with low amounts of organic fertilisers and moderate levels of grazing pressure, in order to increase sward heterogeneity for the enhancement of bird population and species diversity. Monitoring of a large-scale grassland extensification project within an agri-environment scheme in Switzerland, revealed variable effects on grassland birds (Walter *et al*., 2004). Holistic approaches that consider the various factors affecting bird populations in grasslands at the local and the landscape scale need to be investigated and developed for the benefit of farmland birds (Chamberlain *et al*., 2000).

Other groups of grassland fauna showed a slightly clearer response to a switch from intensive to extensive management. The abundance of grasshoppers and butterflies usually increases within a relatively short time. The number of species, however, increases much slower (Walter *et al*., 2004; WallisdeVries *et al*., 2005). In a comparison of intensively and extensively utilised grasslands in Germany and Switzerland, Kruess & Tscharntke (2002) and Jeaneret *et al*. (2004) found on extensive grasslands, higher species numbers for solitary bees, wasps, their natural enemies and for carabids. The mechanism through which extensification enhances the diversity of these creatures is mainly by an increasing plant species number and in particular an increased sward height and standing crop at pasture (Söderstrom *et al*., 2001; Dennis *et al*., 2004; WallisdeVries, 2005).

If species-rich grasslands were established by sowing diverse mixtures on ex-arable land, a diverse fauna (butterflies, grasshoppers) was obtained in a relatively short time. However, no rare species occurred (Bosshard, 2001), indicating that the restoration of the animal diversity comparable to unimproved semi-natural grassland is difficult.

The role of agri-environmental schemes

In many countries, agri-environment schemes (AES) play a key role in attempts to maintain and restore grassland biodiversity (Kleijn & Sutherland, 2003). It is estimated that in the European Union, at least 20% of the farmland is managed under an AES (Rounsevell *et al*., 2005). Such schemes have two objectives. Firstly, they are designed to reverse the deteriorating effect of intensive grassland farming on the biotic and abiotic resources, and to strengthen the multi-function of grassland (Jeangros & Thomet, 2004). Secondly, they have gained increasing importance in the profitability of grassland farming, where a significant percentage of the farm income is now obtained through these schemes.

Agri-environmental schemes differ markedly with regard to their targets. There are schemes that have precise prescriptions in order to achieve a precisely set target, and there are schemes that follow a broader approach with a range of targets, and support extensive farming in more general ways. An example of the former type of AES are the various schemes to protect meadow birds; an example for the latter, is the support of organic farming or the set aside of farmed land. Most of the schemes are measure-orientated rather than result-orientated (Bertke *et al*., 2005). This means that farmers, when they join a scheme, have to follow detailed management prescriptions with regard to the input of fertilisers and agrochemicals, the date and frequency of cutting, or the stocking rate, etc. As long as they farm is managed according to the prescription, the farmers receive the payments. In comparison, result-orientated schemes would set a precise target and would leave it up to the farmer as to how he/she achieves the target. Thus, the performance in terms of its environmental or biodiversity effect rather than the measure itself would be honoured by the payments (Gerowitt *et al*., 2003).

In recent years, several monitoring studies and meta-studies have been set up in order to investigate the efficiency of AES in grasslands. The results show that overall the AES have only had a small effect on biodiversity (Rounsevell e*t al*., 2005). However, taxa differed in their response to AES (Kleijn & Sutherland 2003); the effects on the number of plant species were often small, whereas invertebrates showed a stronger response (Kleijn & Sutherland 2003, Walter *et al*., 2004).

Why have AES been of relatively minor efficiency? Several reasons have been advanced: (i) the measures have little or no effect on biodiversity or on the desired species, thus the wrong measures have been chosen; (ii) single measures have little effect, so complex measures are necessary to achieve the desired result. However, in many cases the effects of complex measures and the interactions between measures are not sufficiently understood (Chamberlain *et al*., 2000; Robinson & Sutherland, 2002). This is particularly true for the effect of factors operating at the landscape scale that are likely to interact with factors operating at the local scale (Söderstrom *et al*., 2001; Eriksson *et al*., 2002). (iii) Measures that are known to be responsible for the decline of species number during the intensification of grassland use are often simply reversed in order to restore biodiversity. However, due to a hysteresis effect, the reversal of such factors does not give the desired benefit. Thus, more complex measures are required to overcome this constraint.

In order to improve the efficiency of AES, there is a strong need to increase scientific knowledge on how biodiversity targets can be achieved, and which measures have to be taken on species-poor grasslands that have seen a switch from production to biodiversity-orientation. This knowledge is urgently required in the farming community, so that farmers can take the appropriate action. In addition, the design and administration of schemes should rely more on the accomplishment of results. This would include the farmers' knowledge and experience on their particular site, which would improve the efficiency compared to that generally attained with standardised prescriptions for management.

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