

Review

Matching type of livestock to desired biodiversity outcomes in pastures – a review

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Abstract

From a review of the literature, we conclude that the main mechanism by which grazing livestock affect biodiversity in pastures is the creation and maintenance of sward structural heterogeneity, particularly as a result of dietary choice. We identify lack of understanding of the currencies used by animals in their foraging decisions and the spatial scale of these decisions as major constraints to better management. We conclude that there are important differences between domestic grazing animal species in their impact on grazed communities and that these can be related to differences in dental and digestive anatomy, but also, and probably more importantly, to differences in body size. Differences between breeds within species appear to be relatively minor and again largely related to body size. We conclude that there is an urgent need to understand the genetic basis of these differences and also to separate true breed effects from effects of rearing environment. We also review the economic implications of using different animal types and conclude that there is a need for more research integrating these aspects with biodiversity outcomes.

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1. Introduction

Temperate natural and semi-natural grazed grasslands are an important biodiversity and landscape resource within the European Union (EU). The area of this important resource within the EU has diminished considerably during the second half of the 20th century. Annex 1 of the European Council Habitat Directive (European Union, 1992) lists habitats that are considered as being of European importance for their biodiversity value. It has been estimated that this list contains 65 pasture types that are under threat from intensification of grazing and 26 that are under threat from abandonment (Ostermann, 1998). In some cases, there is not only a loss of biodiversity value but also other environmental problems as a result of the loss of these communities. For example, in the hills and mountains of Mediterranean countries there are large areas covered by shrub vegetation and very low biodiversity as a result of the abandonment of grazing. This accumulation of woody biomass increase risks such as fire and erosion and produces big environmental and economical losses (Osoro et al., 1999a). As a result of the threats outlined above, these plant communities, the fauna that depend on them and the landscapes of which they form a part are now highly valued and the subject of numerous agri-environmental and nature conservation schemes. Unfortunately, the management of many of these schemes is based on anecdotal evidence or, at best, on empirical studies with limited applicability, with the result that they may not deliver the biodiversity benefits required (Kleijn et al., 2001). There is a need to draw together evidence from studies of the behavioural ecology of grazing animals with that on the ecophysiology and community ecology of the grazed plants and the impacts of their interactions on other trophic levels in the grassland ecosystem, to form a generalised conceptual framework for the management of this important resource.

Although some grassland areas are managed primarily for nature conservation, these form a relatively small proportion of the total land area in the EU used for grazing. In addition to intensively managed areas of grassland with little biodiversity value, there is a con-

siderable area with greater biodiversity which, although extensively managed, is currently managed primarily for agricultural production. The proportion of such areas is likely to increase as a result of changes to the European Common Agricultural Policy under the Agenda 2000 reforms. It is thus timely to examine the potential impact of management strategies for these areas, in particular the ecological and economic effects of managing primarily for biodiversity within the context of sustainable farming systems compared to managing primarily for efficient and competitive livestock production. Quantification of management effects either solely in ecological terms or solely in agricultural terms is too simplistic. There is a growing body of evidence across Europe of the potential economic benefits arising from maintaining biodiversity in farmed landscapes. A major economic consideration is the employment benefits that accrue from landscapes rich in wildlife resources. It is important, therefore, that research that seeks to identify sustainable livestock systems for maintenance of biodiversity in farmed landscapes also provides an evaluation of the impact of such systems on wider economic issues. We suggest that for long-term sustainability, grazing management methods must deliver not only the environmental goods society at large requires but also contribute to sustainable rural economies.

The most appropriate sustainable management for biodiverse grazed grasslands remains a subject of considerable debate. In particular, the type (species, breed, sex and age) of animal that should be used is often unclear or based on fragmentary anecdotal evidence. In this paper we therefore review the role of the grazing animal in these ecosystems and the mechanisms by which grazing affects biodiversity and consider how these effects change with animal type. We also review the economic implications of using different animal types. We propose current best practice based on the available evidence and identify gaps in knowledge that require further research. While we recognise that in the past, conservation managers have often had to make decisions based on limited evidence, it is our contention that only by careful consideration of evidence from existing controlled experimentation, and in particular studies that seek underlying and general mechanisms, and by

the setting up of further appropriate research can a rational basis for the long-term sustainable management of biodiverse pastures be provided.

2. Mechanisms by which the grazing animal alters sward biodiversity

Most temperate grasslands are sub-climax communities and thus require periodic defoliation to control succession, if they are not to succeed to scrub and ultimately woodland. For example, Milne (1997) stated that 92 of the 134 grassland communities present in the UK require human management to prevent succession. In agricultural systems this defoliation is often the result of mechanical harvesting of the herbage and some communities such as hay meadows have evolved in response to such management. However, many grasslands that are mechanically harvested are also grazed for part of the year and there are considerable areas that are never mechanically harvested. In these communities the grazing animal has a unique ecological role. The fundamental difference between mown and grazed grassland is that in the latter the behaviour of the grazing animal leads to enhanced structural heterogeneity of the sward canopy, often of a highly dynamic nature. This in turn has a vital influence on floral and faunal diversity.

The first, and perhaps most important, mechanism by which grazing animals create sward heterogeneity is selective defoliation as a result of dietary choices. This alters the competitive advantage between plant species both by direct removal of phytomass and by altering the light environment (Bullock and Marriott, 2000). A second mechanism is treading which opens up regeneration niches for gap-colonising species. A third mechanism is nutrient cycling. This has the effect of concentrating nutrients at dung and urine patches and again may alter the competitive advantage between species, both directly and by feedback effects on dietary choice, as cattle in particular will not graze near dung patches (see Bokdam, 2001). Grazing animals also have a role in propagule dispersal. This may be either endozoochory (i.e. by seeds passing through the animal's digestive system) or exozoochory (i.e. by seeds attaching to the animal's coat) dispersal (see Bakker, 1998). For a more comprehensive review of plant responses to herbivory see Bullock and Marriott (2000) and Olf and Ritchie (1998). The relative importance of these mechanisms will depend on the particular type of grassland, for example, treading may have a particularly important role in allowing species colonisation of grasslands undergoing deintensification whereas, in communities that are already more diverse, the balance between species may depend more on the animals' dietary choices. The relative importance of the mechanisms will also interact with grazing pressure. At moderate grazing pressure animals are more able to express their dietary

preferences and thus this mechanism can be more important and can often lead to maximum biodiversity levels (Milne and Osoro, 1997).

The direct effects of grazing on sward canopy structure and the plant community lead to secondary effects on invertebrate diversity both by changing the abundance of food plants and providing breeding sites (for a comprehensive review see Tscharrnke and Greiler, 1995). The direct effects on invertebrate diversity feed through to vertebrate diversity (Vickery et al., 2001). Another secondary effect of the changes in structure and community brought about by grazing is the feedback on the grazing behaviour of the animals by changing the choices available to them.

Given the major role of the animal's dietary choices, it is important to understand the mechanisms driving these choices. It should be stressed that much of our knowledge is derived from simple model systems, such as perennial ryegrass-white clover mixtures (e.g. Rutter et al., 2000) and that there has been relatively little detailed work in more complex communities, at least in temperate lowland environments. However, by starting with some conceptually simple examples, and systematically adding factors for which information is available, we can generate models of spatial and temporal complexity at a number of scales, and hypothesise as to how these phenomena might arise (Parsons and Dumont, 2003). Similarly, the functional responses of animals to vegetation conditions, together with sound theoretical bases, allow the building of mechanistic plant-animal interaction models, that can be used to understand and predict the use and successional development of an environment grazed by a group of herbivores, and to simulate the effect of different management practices (e.g., Armstrong et al., 1997; Péronchon et al., 2001).

Generally, behavioural ecologists have assumed that the animal is striving to optimise its evolutionary fitness. In the context of foraging, rate of energy intake has usually been taken as a surrogate measure for evolutionary fitness (Stephens and Krebs, 1986). However, in many situations animals appear to behave sub-optimally. For example, the carbon:nitrogen ratio of grazed grass is too low to optimally meet the nutritional requirements of both cattle and sheep, yet both species, when offered a free choice with minimal physical constraints consistently chose a diet containing around 70% clover, with an even lower C:N ratio (Rutter et al., 2000). Furthermore, the mixed diet is not due to intake rate maximisation since in this case animals would choose 100% clover as this species can be eaten faster (Rutter et al., 2000). This suggests that rate of energy intake is not the currency that the animal is optimising, and that the true currency remains to be identified. To optimise fitness the animal has to trade-off many currencies, for example nutrient intake with social attraction (e.g., Dumont and Boissy, 2000) and these trade-offs are not fully understood (Rutter et al., 2000).

Further, the relative importance of currencies, and hence of the resultant dietary choices, may change in different habitats. For example, minerals such as sodium and phosphorus are known to influence diet and habitat selection in habitats where they are deficient (reviewed by WallisDeVries, 1998). The relative importance of currencies can also change with the feeding motivation and disease status of animals. When sheep were offered pairs of experimental swards, which varied in nitrogen content and level of contamination with faeces from parasitized sheep, low feeding motivation and subclinical parasitism resulted in an increased rejection of the nutrient-rich but contaminated swards (Hutchings et al., 1999). Later, Hutchings et al. (2000) found that the proportion of clover in the diet of sheep offered grass-clover swards was positively correlated with gastro-intestinal parasite burden. They proposed that this was because of the need to replace protein lost due to parasitism. Additionally, macronutrient intake may influence the capacity of herbivores to detoxify plant secondary compounds (Duncan et al., 2003). It also appears that some sward components, for example *Lotus corniculatus*, may have direct anthelmintic properties (e.g. Aerts et al., 1999). More generally, it has recently been suggested that plant secondary metabolites such as tannins could be included in the diet herbivores select for their antiparasitic effects (Houdik and Athanasiadou, 2003; Paolini et al., 2003). In sheep and goats grazing areas with both heather-gorse and ryegrass-white clover communities different gastro-intestinal parasite burdens have been correlated with percentage contribution of the two communities (Osoro et al., 1995). This is consistent with observed differences between animals in lowland and highland systems in gastro-intestinal parasite burden and foot-rot incidence and appears to be associated with tannins in heather acting as an anthelmintic (Athanasiadou et al., 2001). The wide range of possible currencies and our limited knowledge of the interactions and trade-offs between them constrain our ability to extrapolate from simple model systems to more diverse swards.

As the relative importance of different currencies to the animal alters over time, so dietary choice changes over many different time scales. This is due both to the physiological state of the animal, that is demand effects, and supply effects such as the availability of herbage and the phenology of the plant. An example of a relatively short-term temporal effect is the change in preference between grass and clover that has been observed over the day, with both dairy cows and sheep including more clover in the diet in the morning and more grass in the evening (Rutter et al., 2000). It has been hypothesised that this might be due to higher sugar levels in the grass at this time (Orr et al., 2001) and hence higher digestibility or, alternatively, that it may be because the animal fills its rumen with relatively slowly digesting material in order to maintain rumen microflora populations during the over-

night fast. At present it is not possible to offer a definitive mechanism. If a similar circadian effect were to be seen in choices between other plant species this could have important implications for the management of diverse plant communities as it might be possible to exploit the effect to manipulate choice and hence effects on sward structure and diversity.

There are also spatial effects at many scales. In hill and upland systems (and range systems in other countries) we know that animals establish home ranges within which they move on daily and longer time scales (e.g. Lawrence and Wood-Gush, 1988). However, most animals in lowland systems in Europe are prevented by enclosure from making choices at the landscape scale and hence much research in these systems relates to choices at the bite or feeding station (i.e. without moving the legs) scale (e.g. Roguet et al., 1998). Although there has been little work at this scale outwith simple model systems, parameters from these studies have been used in mathematical models of foraging movements (e.g. Baumont et al., 2002) that provide a sound basis for generalisation to more diverse systems. Choice of location may also be driven by other factors than food, such as water, shelter and social cohesion (e.g. Dumont and Boissy, 2000) and attempts have been made to include these in models (Beecham and Farnsworth, 1998; Pérochon et al., 2001).

Within a plot, patch size (WallisDeVries et al., 1999) and more generally the spatial distribution of preferred food patches (Dumont et al., 2000) can affect diet selection by herbivores. Independently of herbivore species and of the abundance of the preferred patches, animal selectivity is greater when preferred patches are aggregated rather than dispersed over the whole plot area (for a comprehensive review see Dumont et al., 2002). This is consistent with what would be the optimal trade-off between the benefits of eating a preferred food and the costs of foraging for that food (Thornley et al., 1994), suggesting that the costs of searching for patches is increased when they are dispersed. Thus a rare but preferred species with a dispersed distribution in a grassland community would be predicted to have increased resistance to grazing compared to a similar but aggregated species. Such information could potentially be used to predict local extinction risk for a plant species according to its feed value and within-plot distribution, and to define appropriate grazing management practices at the farm level to ensure its conservation.

3. Effect of animal type

3.1. Body size effects

Animal type has a major effect on dietary choice, in spite of consistent inter-individual differences in selectivity between animals in the same group (e.g., Prache

et al., 1998). The most fundamental effect is that of body size. Small herbivores generally require more energy relative to their gut capacity than large ones and thus have to select higher quality foods. In contrast, larger animals with relatively large gut capacity in relation to their metabolic requirements can retain digesta in the gastro-intestinal tract for longer and thus digest it more thoroughly (Illius and Gordon, 1993). The animal's physiological state will also affect its dietary selection. For example, hungry animals have been shown to be less selective (Newman et al., 1994), though sheep and cattle have also been shown to alter their foraging behaviour differently as a response to fasting (Dumont et al., 1995). It has also been hypothesised that a reduced metabolic rate leads to less selectivity in species and genotypes with low maintenance requirements (WallisDeVries, 1994; Osoro et al., 1999a).

3.2. Species effects

Species effects on selectivity and thus on biodiversity are of great importance and are among the better understood of the effects of grazing animal type. Ruminant species have been classified into three main feeding categories, grazers, intermediate feeders and browsers (Hofmann, 1989) and much literature has accumulated on the morphological and physiological adaptations which allow animals in the different categories to efficiently extract the nutrients from the diet consumed. However, recent analysis shows that body size is of primary importance and that morphological and physiological differences can be discounted once body mass and phylogenetic relationships have been taken into account, even if the fact that grasses and browses are distributed in different ways could explain differences in foraging behaviour between grazers and browsers (Gordon, 2003). Species with narrow mouths and highly curved incisor arcades, such as sheep, are more selective feeders than large herbivores such as cattle. These differences in selectivity emerge when animals graze plant communities where high quality components or those with specific desirable characteristics, are rare or difficult to harvest and are often manifested in differences in scale of selectivity. For example, in the South African veld, cattle avoid grass species with a high proportion of stems and few leaves, whereas stemminess does not reduce acceptability of these species to the same extent in sheep, as they are able to select the more digestible parts of the plant (O'Reagain and Stuart-Hill, 1991). Similarly, goats and sheep more readily consume browse species than cattle, because of their greater ability to select high quality plant parts such as flowers, pods and young shoots (e.g., Olivan and Osoro, 1996; Celaya et al., 2003). In ryegrass-white clover pastures significant differences in vegetation dynamics have been observed when pastures were grazed by cattle, sheep or goats (Del

Pozo and Wright, 1996) or by mixed species flocks (Del Pozo and Osoro, 1997). Cattle (and other large herbivores) are further constrained by the reduction of their bite depth on short swards (Illius and Gordon, 1987). Sheep offered a choice between vegetative and reproductive Cocksfoot (*Dactylis glomerata*) consistently tried to maintain their preference for vegetative swards when sward height was reduced, while cattle switched to the reproductive patches (Dumont et al., 1995). Similarly, in a *Nardus*-dominated community, cattle more readily consumed *Nardus* compared to sheep, as the height or biomass of the preferred inter-tussock species was reduced (Grant and Hodgson, 1986). This again illustrates species differences in scale of selectivity. These differences have important implications for the choice of herbivore to manage biodiverse swards.

Differences in digestive physiology between species are also important, for example, ruminants such as cattle have more efficient digestion than hind-gut fermenters such as horses. The latter therefore rely on high throughput and this can necessitate long grazing times of up to 19 h per day (e.g. Fleurance et al., 2001). However, as a result of their digestive strategy horses are less affected by low forage quality and therefore more readily include tall, fibrous grasses in their diet (Duncan, 1992; Vulink, 2001).

Dental anatomy is also important; horses, with both top and bottom incisors, can graze much closer to the ground than cattle and thus produce a quite different sward structure. The extent to which grazing by horses results in a different plant community compared to grazing by cattle is still the subject of some debate. Many horse grazed pastures, particularly in the UK, are overstocked, leading to poor structure and loss of diversity (Bullock and Armstrong, 2000). This has probably resulted in an unjust, negative perception of grazing by horses as a tool for conservation management. For example, horses have been successfully used for conservation purposes in the Netherlands (Vulink, 2001) and in the Camargue (Duncan, 1992) and in French uplands, horses are valued for their ability to control encroaching tall grass vegetation (INRA, 1979; Loiseau and Martin-Rosset, 1989).

Although species effects on selectivity are relatively well understood, there is less direct experimental evidence for effect of grazing animal species on biodiversity. However, consistent with the differences in selectivity observed between sheep and cattle, *Nardus* cover on a Scottish upland decreased from 55% to 30% over five years under cattle grazing, whereas it increased up to 80% under sheep grazing (Grant et al., 1996). On a French upland, after six years of grazing by cattle or horses in a rotational system, *Nardus* cover decreased and that of more preferred grasses increased in the plots grazed by horses, whereas sward composition was stable in the plots grazed by cattle. Horses also reduced shrub cover

and favoured the implantation of nitrophile species at shrub boundaries as the result of their trampling and localised defecation (INRA, 1979). Much work remains to be done to elucidate additive or compensatory effects of multi-species grazing at different stocking rates and in different temporal sequences (Bakker, 1998). For example, strong competition between cattle and horses for grass has been observed in some mountain areas (Aldezabal, 2001). There is also evidence, for example, that the degree of dietary overlap between sheep and goats grazing the same area varies according to the relative population densities of the two species and the time of the year (Bullock, 1985), with the relative proportion of shrub and grassy areas available (Osoro et al., 2000a) and with the effect of type of flock on the gastro-intestinal parasite burden (Radcliffe et al., 1991).

3.3. Breed effects

The use of traditional or rustic livestock breeds is often recommended for nature conservation management (e.g. Bullock and Oates, 1998). While such recommendations are partly based on the perceived 'hardiness' of these animals it is often hypothesised that the use of commercial breed types may pose a threat to the functional stability of biodiverse grassland communities through ill-adapted animal behavioural responses. Indeed this is implicit in such publications as the *Breed profiles handbook* produced in the UK by the 'Grazing Animals Project' (Tolhurst and Oates, 2001) that give for each breed an assessment of its impact on vegetation. However, much of the direct evidence for effects on biodiversity is anecdotal, as Tolhurst and Oates (2001) admit, and underlying differences in foraging behaviour between breeds have received relatively little attention.

We are aware of only a small number of direct breed comparisons under controlled conditions. Newborn et al. (1993) found, on the basis of change in species abundance, that Hebridean sheep selected more *Molinia caerulea* from a mosaic of this species with *Calluna vulgaris* that did Swaledale sheep. Osoro et al. (1999c) showed that large Latxa dairy ewes grazing a sward whose main components were *Agrostis capillaris*, *Festuca rubra*, *Nardus stricta* and *C. vulgaris*, selected a diet of higher digestibility than small Gallega ewes. However, there was an interaction with availability of preferred herbage species and when this was low, the Gallega ewes performed better. Similar interactions were observed in perennial ryegrass-white clover pastures (Osoro et al., 2002). Breed effects on selectivity between plant species in this trial were generally small. Wallis-DeVries (1994) found that a consistently higher proportion of bites was taken on short patches with more digestible herbage by Meuse–Rhine–Yssel (MRY) dual purpose steers than by Hereford beef steers. The MRY steers were of a similar liveweight but were less mature

and therefore had a high maintenance requirement relative to their body size and gut capacity and thus a need to be more selective. Within breed, small genotype Aberdeen Angus steers have been shown to graze a *Festuca arundinacea* dominated sward more selectively than a large genotype, with a resultant increase in the area covered by heavily utilized patches but greater herbage mass in less utilised patches (Cid et al., 1997). Thus at the end of the growing season, sward height structure was more heterogeneous in the paddocks grazed by the small genotype, though mean herbage mass was similar. This more heterogeneous structure has potential for positive effects on biodiversity.

The empirical comparisons discussed above, support the hypothesis that breed differences, like species differences, can largely be explained by differences in body size and the consequent allometric relationships with food intake, digestibility and selectivity (e.g. Illius and Gordon, 1987). However, D'hour et al. (1994) observed that Salers heifers have a shorter daily grazing time and a higher biting rate than Limousin heifers of similar weight, which could indicate a higher selectivity of the Limousins. Salers were also better able to increase their grazing time and biting rate during the grazing down of a paddock. Here, the difference was probably the consequence of a greater intake capacity and rumen size for the Salers (Petit et al., 1995).

Not all breed comparisons in the literature are consistent. In a comparison of the diet of three cattle breeds considered to be well-adapted to harsh environments on a desert rangeland, De Alba Becerra et al. (1998) observed breed × season interactions for a few diet components. However, these effects were weak and inconsistent, and did not allow any management implications to be made. Du Toit and Blom (1995) concluded that Dorper and Merino sheep selected very similar diets on a South African veld, whereas in a further study Du Toit (1998) observed that Merino sheep consistently selected more grass while Dorper sheep selected more Karoo bushes during the growing season.

There is little evidence concerning breed effects on nutrient cycling and the impact of this on biodiversity. However, a recent study by Berry et al. (2003) comparing Brown Swiss dairy cows and Highland suckler cows grazing improved Alpine pastures, showed that the Highland animals had excessive N intakes relative to their growth and thus had high proportional urinary return rates to the pastures, although the absolute levels per area were similar due to the higher herbage intakes of the dairy animals. On unimproved alpine pasture, they showed that Highland cows could maintain N intake by selective grazing and thus N losses to the atmosphere in this environment could still be high. The feedback on vegetation was not studied but the results suggest that there may be breed and system effects via this route that need to be quantified.

3.4. Effects of learning and experience

Most anecdotal reports of breed differences in selectivity and impact on sward structure and biodiversity, and indeed some of the more formal comparisons discussed above, suffer from a failure to separate true genetic differences between breeds from environmental effects, particularly prior experience of biodiverse pastures during early life that may affect subsequent selection. For example, it is reported that cattle brought into the New Forest in the UK are less able to cope with the very short swards in this area (Sanderson, 1998), but it not clear if this a genetic or learning effect. Learning early in life is known to affect intake of relatively undesirable forages (Distel and Provenza, 1991) and foraging skills of domestic ruminants (Flores et al., 1989). Consequently, sheep, cattle and goats placed in unfamiliar and complex environments spend up to 20% more time eating, but ingest as much as 40% less food than animals experienced in these environments (Provenza and Balph, 1987).

There is experimental evidence than briefly exposing animals to new plant species at a young age affects their subsequent grazing choices (e.g., Ramos and Tenessen, 1992; Ganskopp and Cruz, 1999). It is known that differences in preferences arising from early experience can persist for up to 2 years (Arnold and Dudzinski, 1978). This may particularly be the case on diverse grasslands and rangelands. For example, on a tropical savannah, the diet of goats varied with the origin and year of birth of the animals, even though they grazed the same pastures for four years. The selection of one to several plant species also characterized animals with different lineage (Biquand and Biquand-Guyot, 1992). On a Mediterranean shrubland, lambs bred with their mother on oak coppices browsed for 15% longer as yearlings than animals that had never previously been exposed to shrubs and trees, and this difference persisted over the whole grazing season (Lécrivain et al., 1996). However, other experimental evidence suggests that effects of experience in young animals are often of short duration. Lambs exposed to *Senecio jacobaea* before weaning selected more of this species for 3 weeks than lambs without previous experience, but after 3 months of grazing any selective differences had disappeared (Sutherland et al., 2000). Similarly, yearling sheep exposed to *Euphorbia esula* as lambs consumed it more than naïve sheep, but within 3–4 weeks the 'naïve' sheep readily grazed the plant (Olson et al., 1996).

Secondary evidence about breed and background effects on diet selection is also patchy. There is some good information about breed and background effects on animal movements at a landscape scale. For example, grazing patterns in foothills rangeland varied with cow breeds. Tarentaise cows were observed at greater distances from water and used steeper slopes than Hereford cows (Bailey et al., 2001). In an experiment in which

Scottish Blackface or Suffolk ewes raised either lambs of their own breed or of the other breed (Dwyer and Lawrence, 2000), the distances between Blackface ewes were greater than between Suffolks but Blackfaces had their lambs much closer to them, whatever the breed of the lamb. The ewes had a choice of using upland or lowland pasture; the Blackface ewes made much more use of upland and this persisted in the lambs that they had reared whatever the lamb breed, although there were also some additive effects of lamb breed. Information about breed effects on movement at a bout or feeding station scale is lacking, for example, bites per feeding station and distance between feeding stations. There is information about such movement from single breeds grazing homogeneous pastures (e.g. Roguet et al., 1998; Harvey et al., 1998). However, we have no idea if and how breeds differ in these parameters, nor how any such effects would be modified in heterogeneous pastures or how they would interact with the background of the animals, either immediately prior to moving to the target area or during early life. Because of these gaps in our knowledge, we are currently ill-placed to predict effects of grazing by different breeds on biodiversity.

3.5. Sex and age effects

Consistent with the fundamental effect of body size on dietary choice, young animals and females usually show greater selectivity than older animals or males. Ferrer-Cazcarra and Petit (1995) compared the grazing behaviour and selectivity of mature dry cows, 18-months old heifers and 7-months old female calves of the Charolais breed on homogeneous cocksfoot regrowths, and concluded that the selectivity of calves was greater than that of older cattle, on the basis that the nitrogen concentration in their faeces was higher and the fibre concentration lower and also the C33 alkane concentration in the faeces was higher indicating that more leaf material had been consumed. Similarly, in a free-ranging feral cattle population in southwest Spain, small and medium-sized animals (sub-adults of both sexes and adult females) were more selective in their diet than adult males, and altered their foraging behaviour to maintain intake of preferred foods when forage availability decreased (Lazo and Soriguer, 1993) They achieved this by increasing their step rate and decreasing their bite:step ratio. Thus, sexual dimorphism also explains niche segregation between adult males and other age-sex classes.

4. Economic implications of using different animal types

If traditional breeds do prove to have a role in improving sward biodiversity it will also be necessary, if possible, to achieve viable economic results which are

also socially acceptable. This implies a critical analysis of the inputs, economic feeding policies and quality of the products marketed. Several reports in the UK have highlighted the current need for research to identify the financial costs of achieving sustainable livestock agriculture (Biodiversity Research Support Project, 1999; Asken Ltd, 2001).

The economic viability of livestock production can be subject to large variations due to factors beyond the producer's control, such as level of government intervention and world market prices. Currently EU livestock production systems are unable to compete with world market prices. They are dependent on Common Agricultural Policy (CAP) subsidies for their viability. With threat of modulation reducing direct subsidy payments to farmers and a move from headage to area payments, these production systems in marginal areas may become less economic. The CAP Mid-term Review proposes to move a proportion of modulated money from Pillar 1 of the CAP to the Rural Development Regulation Programme (RDR) (Commission of the European Communities, 2003). This is seen as an important tool to encourage farmers to move away from low cost high volume commodity production. The range of measures included in the RDR will increase both in their financial allocations and in their scope. Those farmers operating extensive livestock production systems and using traditional breeds to improve biodiversity will benefit from such changes.

Traditional breeds may have an economic cost in terms of reduced economic output and/or production efficiency. In a specialist, capital-intensive, livestock system, commercial breeds have been shown to outperform traditional breeds, producing more food at lower cost (Yarwood and Evans, 1999). On the other hand, traditional breeds may be better suited to marginal lands and economically marginal conditions such as may arise when biodiversity is the major management goal and may also be able to command a market premium. This advantage is generally claimed to result from reduced veterinary intervention, ease of breeding and fewer special feed costs. For example, D'hour et al. (1998) found in a French upland area that local Salers cows maintained their reproductive performance when they were grazed on mature pastures in the autumn and underfed during the long winter, whereas numbers of calvings and of calves weaned were reduced in underfed Limousins. Ease of handling is often suggested as another advantage of traditional breeds but the results of Le Neindre et al. (1996) show that this is not always the case. They found no difference in handling assessment between Limousin and Salers at 8 months of age for those animals that had frequent contact with their breeders, but did find a significant effect of rearing environment with extensively reared animals being more reactive. Quantification of these various breed and

rearing environment effects is still rare and is urgently needed in order to underpin the development of sustainable livestock systems.

Whilst products from commercial breeds can be produced more economically (at least in conventional livestock farming systems) and meet the demands of the mass market, there is evidence that products from traditional breeds can fetch premium prices (Rosa and Mancini, 1997; Kuit and van der Meulen, 1999; Rodrigues et al., 1999) as consumers perceive, rightly or wrongly, that they are of superior sensory or nutritional quality or because they associate these products with the image of a particular region or tradition. In some cases it may be possible to demonstrate this superior quality (Yarwood and Evans, 1999) but in some other cases it appears to be at best anecdotal (Dransfield et al., 2002). The UK (Rare Breeds Survival Trust, 2003) has funded scientific analysis which shows that traditional breeds produce meat of the highest quality (RBST website 200). However, the true genetic effect is often difficult to separate from the effects of rearing environment and effects during processing. In Asturias (northern Spain) there are two local cattle breeds, Asturiana de Los Valles and Asturiana de La Montaña. Higher selection pressure in the former for high growth potential and conformation has led to loss of maternal aptitude, whereas the latter has good maternal aptitude and easy calving but lower growth rates and poor conformation. This later breed with a lesser growth rate is better adapted to the restricted conditions of the mountain vegetation (Osoro et al., 1999b) and sensory quality of its meat is preferred in consumer tests (Osoro et al., 2001). Kuit and van der Meulen (1999) found that in the Netherlands local beef breeds from nature reserves were considered a high quality product enabling a premium price of 20% above wholesale prices when sold through small niche markets. Rodrigues et al. (1999) identified seven breeds of cattle in Portugal producing meat with a Protected Designation of Origin (PDO) providing farmers with higher incomes. Similarly Parmesan cheese produced from the milk of Reggiana cattle in Italy fetches a premium price due to the perceived quality of the cheese (Rosa and Mancini, 1997). Production of cheese with PDO in French mountainous areas has sometimes imposed amongst technical specifications the use of milk from local cow breeds with a low to moderate milk potential (Hauwuy et al., 2000). All these quality benefits are based on consumers' perception of what constitutes a quality product and can vary between different individuals and regions (Scottish Food Strategy Group, 1993).

It is often the production system associated with the breeds, rather than the breed itself, that results in higher prices. Kuit and van der Meulen (1999) note that not only do the genetic characteristics of traditional breeds contribute to taste and structure of the meat but also the

vegetation consumed, the slow extensive production system, and the meat processing (ageing). Bignal et al. (1999) also make similar claims in the case of beef from Highland cattle, suggesting that the production process, such as welfare aspects and the environmentally-friendly way cattle are produced are the main marketing assets, rather than the breed itself. This is supported by Ashworth (2000) who undertook a study of consumers' willingness to pay a premium for meat products and found that in the UK greatest support was for a premium associated with animal welfare, though the perception may be different in other countries. It should again be pointed out that good assessments of welfare in these extensive systems are often lacking and marketing is often on the basis that these breeds were originally developed for harsh environments and thus must be better adapted, rather than on objective welfare assessment. Also, as indicated earlier, the impact of breed *per se* on the environmental outcomes remains contentious.

Traditional breeds often have a dual-purpose, producing products other than meat. In Central France and South Italy, local cattle breeds are still sometimes used for both milk (cheese) and meat production. In the UK a market is developing for wool products from different breeds, for example in the north of England Swaledale Woollens and Wensleydale Longwool Sheep shops (Angell, 1997) have developed, basing their identity on the breeds and tradition of their local areas. The production of Cashmere goats in Spain, in addition to producing meat, has the potential to provide employment for local women through the processing of the fibre into high quality products (Osoro et al., 1999a).

Some farm families use traditional breeds as a tourist attraction (Yarwood and Evans, 1999). They attract visitors to the countryside which in turn has an economic multiplier effect on the local economy from visitor spending. The tourism industry is also important in the consumption of direct and indirect products and goods from traditional livestock (Rahmann, 1997). However, as Bignal et al. (1999) highlight, marketing of extensively reared native livestock breeds needs organisation.

The benefits of traditional breeds can be inter-linked and reinforcing. For example, grazing by Delle Langhe sheep in Torino province of Italy has reduced weed and shrubby species, creating a more pleasant landscape, a reduction in fire and hydrogeological risks and consequently a positive effect on tourism (Battaglini et al., 2001). The additional tourists attracted to the area then create a market for the products from the sheep. However, it may have been possible to crate this effect with other breeds.

There is generally reluctance amongst commercial farmers to switch to traditional breeds, which are considered to be unprofitable and inefficient (Yarwood and Evans, 1999). However, with the decline in CAP subsidies

and a move towards more extensive farming practices on some marginal land, opportunities exist to develop niche markets and attract premium prices. In particular, traditional breeds are favoured by an increasing number of part-time farmers (Yarwood and Evans, 1999). Because of their hardiness and adaptation to environment, traditional breeds are often seen as requiring minimal supervision, thus saving on health costs and labour resources, but hard evidence for this effect is lacking.

5. Management options

In this section, we consider some options for using different animal types for management of biodiversity in grazed pastures that we believe can be justified given our current state of knowledge. To do so it is necessary to consider the goals of our conservation management. To a great extent this is an issue of scale. Within grassland communities, and most grazing systems only include this component, spatial heterogeneity appears to be the key to maximizing biodiversity and the role of the grazing animal in this respect has already been elucidated (Parsons and Dumont, 2003). However, it should be noted that at a landscape scale woodland pastures (Pott, 1998; Vera, 2000) harbour the highest biodiversity as they contain both grassland and forest species and we may need a different mix of grazers and browsers to manage such landscapes. Vera (2000) goes so far as to argue that long-term preservation of biodiversity requires the development of wilderness areas with wild herbivores in addition to the existing semi-natural landscapes. In any case, the formerly widespread practice of grazing woodland pastures by communal grazing offers a challenge to formulate analogous grazing systems that achieve similar biodiversity but are socio-economically viable. In some areas, large-scale ranching systems with low labour costs and benefits from ecotourism and local quality products may constitute a feasible alternative. However, it would often lead to an unacceptable decrease in human density and activity, notably in most sensitive areas.

If we seek to manage at the landscape or habitat scale, we may well wish to include cultural aspects as well as biological aspects. In this case, the species and breed of animal employed might be deliberately chosen to reflect traditional local practices as a goal in its own right. However, the possibility that this might compromise biodiversity outcomes *per se* needs to be considered.

In our current state of knowledge there appears to be more opportunity to exploit the background of animals and to manipulate their grazing selectivity to produce the biodiversity outcomes than to rely on the genetics of the animal to produce results. Bailey et al. (1998) have suggested some possibilities for managing the grazing

distribution of livestock by increasing or decreasing attractiveness of underutilized or overused sites, respectively. Both the choice of grazing animals and the configuration of the areas grazed offer possibilities. Osoro et al. (1999c, 2000b) demonstrate the opportunities to control grazing selectivity, animal production, and, most probably, biodiversity by improving smaller or greater parts of nutritionally poor semi-natural vegetation in extensive systems.

In so far as genetics play a role, the main choice is on the body size of the animals used. However, this tells us little more than the overall selectivity of the animals, not their choices in particular situations or their spatial foraging patterns. There is also scope for exploiting temporal behaviour patterns to manipulate dietary choices so as to ensure that, whilst animals are productive and provide the farmer with an acceptable economic return, they also make the desired choices when grazing biodiverse pastures. An example of this might be the use of folding systems (such as practised in the past in many chalk downland systems) in which animals are removed to fallow arable land for part of the day as a means of importing nutrients to the arable land, but having also the secondary benefit of reducing fertility and thus potentially enhancing biodiversity in the pasture element of the systems.

6. Future research needs

The central research need that we identify is to provide a better basis for the choice of animal type to manage biodiverse grazed grasslands. The wide choice of animal types means that individual empirical comparisons, while of value to specific situations, are unlikely to greatly further our knowledge. Therefore, more mechanistic approaches are required. At present our ability to generalise is largely limited to the effect of body size on overall selectivity, the major differences between ruminants and equids and the browser-grazer gradient. We suggest that the following areas are critical to further progress:

- Determining to what extent elements of foraging behaviour and selectivity are genetically determined and to what extent they are learned. This will allow better sourcing of animals intended for use in conservation schemes, whether by employing different breeds or animals from different backgrounds.
- For those elements that are genetically determined, utilising advances in genetics to identify the genetic basis of the observed differences. This will not only offer the opportunity for breeding animals more suited to management objectives but also enhance our understanding of the co-evolution of grazing animals and their food plants.
- Identifying the currencies that determine the choices different types of animals make in different situations. This should allow us to predict more accurately the choices that animals will make without needing to carry out empirical preferences tests in each plant community and between each animal type.
- Improving and generalising our understanding of the effects of animal type on spatial distribution of foraging. This is crucial if the important effects of grazing on structural heterogeneity are to be understood.
- Integrated modelling of biological and socio-economic outcomes of using different animal types. This is necessary for generalisation of experimental results and for the application of potential benefits using decision support systems.

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