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Analysis of ecosystem services provided by grassland-based livestock systems

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Abstract. Characterizing ecosystem services (ES) and their underlying drivers remains a challenge. Issues are related to scale, knowledge and outcomes that are stakeholder-dependent. We characterise plant functional diversity at different scales (field, farm). Then, we analyse its response to environmental and management factors, and its effects on ES. Based on five previously established grass functional types (GFTs), three indicators were defined; among them the percentage of GFT having a fast ($Fast_{GFT}$) growth strategy. The approach was applied on eight farms having three grassland uses (LMU: cutting, grazing by cows and heifers), but differing in their orientation and management. $Fast_{GFT}$ responded positively to N fertiliser application and negatively to field elevation (n=169). Herbage production at field (n=60) and LMU (n=24) levels was positively correlated to $Fast_{GFT}$, while it is negatively correlated with soil C content and species richness. Within farm grassland diversity for $Fast_{GFT}$ allows matching animal feed requirement to available quality of resources, and contributes to create a landscape mosaic. A framework is proposed for evaluating trade-offs between services.

Key words. Landscape – Management – Provision services – Supporting services – Trade-offs.

Une méthode pour caractériser les services écosystémiques fournis par les élevages herbagers

Résumé. *La caractérisation des services écosystémiques (ES) est difficile (échelles, connaissances, porteurs d'enjeux). Nous caractérisons la diversité fonctionnelle des plantes prairiales aux échelles parcelle et ferme, puis nous analysons sa réponses aux facteurs environnementaux et de gestion, et ses effets sur les ES. Basé sur cinq types fonctionnels de graminées (TFG), trois indicateurs ont été calculés parmi lesquels la proportion de TFG ayant une stratégie de croissance rapide (*$Fast_{GFT}$*). L'approche a été appliquée à 8 fermes où les prairies ont trois usages identiques (fauche, pâturage : vaches et génisses), mais diffèrent de par leur orientation de production et leur chargement moyen.* $Fast_{GFT}$ *a répondu positivement à l'azote apporté et négativement à l'altitude. La production de biomasse estimée à l'échelle de la parcelle (n=60) et de la sole (n=24) est positivement corrélée à* $Fast_{GFT}$*, tandis que la teneur du sol en C et la richesse en espèces le sont négativement. La diversité entre prairies au sein d'une ferme permet une cohérence entre le type de prairie et les besoins alimentaires des animaux et crée une mosaïque paysagère. Un cadre d'analyse est proposé pour évaluer les compromis entre ES.*

Mots-clés. *Paysage – Gestion – Type fonctionnel de plante – Compromis.*

I – Introduction

Policy makers are keen to encourage more sustainable livestock systems for maximizing the provision of ecosystem services (ES). We consider production services (e.g. forage), non-marketed services (e.g. C storage, cultural value) and "input services" (e.g. soil fertility) provided by biodiversity. Trade-offs among ES are essential to know for management and policy decisions. Studying ES provided by grasslands for determining trade-offs arise several issues. ES are scale-dependant (field, landscape), and the farm scale is understudied (Lugnot and Martin, 2013). So, within-farm grassland diversity can provide opportunity to lower production costs through fitting grassland types to animal feed requirements. Second, most research on grassland produce outputs suitable for understanding effect of drivers upon ES, but struggle to produce research outcomes easy to handle by stakeholders. Thus particular attention should be paid for building relevant indicators, in addition to their scientific credibility. In this study, we propose an approach whereby stakeholders can characterize the provision of a set of ES in grassland-based livestock systems: forage production services, input services, management services, environmental services (species richness and soil C storage) and cultural services (within and between grassland field diversity). The approach applies on three scales: field, land management unit (LMU: those parts of farms allocated to single groups of animals corresponding to single management units for production, feeding, health care, etc), and set of fields at farm or landscape scales. The LMU scale is needed because averaging data at farm levels loses possible within-farm differences due to differences in the management of animal groups (e.g. cows and heifers). Set of fields at farm or landscape scales are needed for evaluating ES related to within and between grassland field diversity. We discuss strength and weaknesses of the approach for characterizing trade-offs and synergies between ES.

II – Materials and methods

Method. Based on leaf and phenological plant traits, five elementary grass functional types (GFT) were previously defined according to their plant growth strategy (Duru *et al*., 2013). Among these, three groups ($Fast_{GFT}$) correspond to plants with a fast growth strategy. Two additional indicators of grassland functional composition are considered: Sum_{GFT}, the proportion of grass species in the herbage mass, and functional divergence (Div_{GFT}), an indicator of GFT diversity. Forage production and herbage quality at leafy stage are correlated to $Fast_{GFT}$ (Duru *et al*. 2013). By construction, there is a parabolic relationship between Div_{GFT} and the percentage of $Fast_{GFT}$, the maximum functional diversity being expected for mean values of $Fast_{GFT}$. In this paper, we examine whether such indicators can be used for predicting other ES at field level (input services; species richness and C sequestration) and management services at LMU-farm levels. We assume that an effective management is related to the degree to which forage quality (assessed by $Fast_{GFT}$) match animal feed requirements (dairy cow> beef cow; cow> heifers). Farmers combine fields displaying different vegetation types into several assemblages, each single assemblage being used to feed a particular herd batch. To assess such assemblages, we first compared plant functional composition per farm between LMUs. Then we examined whether there was a between-farm effect of production orientation and stocking density to determine whether or not there is a specialization of plant types at LMU level. Examining vegetation diversity at different space scales for phenology, height and colour can provide the raw data for assessing cultural services. Thus, we use the Div_{GFT} x$Fast_{GFT}$ framework for characterizing the within- and between diversity for a field or a set of fields. For each studied ES, the scale according to the beneficiaries (farmers or society), and indicators of grassland functions and of ES provided are indicated (Table 1).

Table 1. Mapping of grassland properties to grassland services

Types	Scale (beneficiaries)	Grassland functions	Services provided
Forage provision	LMU, field (farmer)	Fast $_{GFT}$ (LMU level)	Stocking rate
Management	LMU (farmer)	Within and among farm GFT distribution	Degree at which forage match animal requirements
Input (fertility)	Field (farmer)	Div_{GFT} N uptake permitted by within field diversity	Biomass/ N supplied
C sequestration	Landscape	$Fast_{GFT}$	Soil C content
Species richness	Field/landscape (society)	$Fast_{GFT}$; Sum $_{GFT}$	number of species
Cultural (field mosaic)	Field-> landscape (society)	$Fast_{GFT}$ x Div_{GFT} mapped at different scales	Visual within and between fields diversity

Case study. The work was done in the Aubrac region (southern part of the French Central Massif (800 – 1400 m a.s.l), on 8 specialized dairy or beef farms having different stocking densities. On their 169 fields, we recorded grassland plant composition and land use practices: fertilizer applications, type of first use [grazing or cutting only, early grazing that removes the apexes (topping)], date of first use, and type of grazing animals. On 60 grassland fields, detailed soil and plant data were recorded for calculating N uptake, soil C content and plant richness. The stocking rate (SR) was considered as a proxy for forage production).

III – Results: ecosystem services provision

At field level, herbage mass was significantly correlated to the percentage of $Fast_{GFT}$. For the less fertilized grazed grasslands (24.4 ± 26 kg N per ha), N uptake was significantly and positively correlated with Div_{GFT} ($r = 0.4$, $n = 38$). Soil C content and species richness were significantly and negatively correlated to $Fast_{GFT}$. For species richness correlation was improved when taking into account Sum_{GFT} which was significantly and negatively correlated.

At LMU and landscape levels, there was a significant positive correlation between SR and the percentage of $Fast_{GFT}$ ($P<0.001$). For pastures alone, the values of SR and $Fast_{GFT}$ were on average higher for dairy cows and lower for heifers. However, there was evidence of variation in SR and of $Fast_{GFT}$ percentages of at least 50% for the same land use type and farm production orientation. Conversely similar grassland functional composition was found for all three types of animal groups (beef and dairy cows, heifers). A minimum SR of 0.5 animal units/ha was observed in the absence of $Fast_{GFT}$. For cut areas alone, there was no relationship between the SR and the percentage of $Fast_{GFT}$. The SR depended mainly on the proportion of the cut area which was topped in early spring ($r = 0.9$; $P = 0.08$). However, SR was positively correlated with N fertilizer rate and timing of the first cut ($r= 0.82$; $p<0.05$).

For management services, there were significant differences in $Fast_{GFT}$ between the three land management units (cut, grazed by cows and by heifers) for 6 of the 8 farms. Except one dairy farm, the cut LMU had the highest percentage of $Fast_{GFT}$. This means that the forage production and the forage quality at leafy stage ($Fast_{GFT}$) were usually the highest for cut areas (except one dairy and one beef farms), and the same was observed for cow grazing areas in comparison with heifer grazing areas (except for one dairy and two beef farms). These data show consistent rankings of animal feed requirements and type of vegetation allocated, except for one dairy farm. Consistently, there was an effect of farm production orientation on the percentage of $Fast_{GFT}$ ($P<0.01$) for all LMU. $Fast_{GFT}$ were significantly lower for beef farms. Among dairy farms and grazing areas, there was a significant difference between $Fast_{GFT}$, as was the case between farms for heifers.

Within-(Div_{GFT} values) and between-(differences in $Fast_{GFT}$ values) field diversity, proxies of cultural services were examined for a set of fields among farms or landscapes. The more the within-field or between-field diversity, the more heterogeneous were the grasslands in terms of height and phenology. At the farm scale, the analysis of the three LMU showed that for cow grazing and cutting areas, there was a trend to observe higher values of $Fast_{GFT}$ for dairy farms than for beef farms. Within the range of 40-60% for $Fast_{GFT}$, the three LMU types were observed for both types of farm enterprise. In dairy farms, the heifer LMU enlarged the between-LMU differences due to their low values of $Fast_{GFT}$, while for beef farms, it was the cut LMU type which enlarged the differences between LMUs due to their high values of $Fast_{GFT}$. For the whole data set, we considered three components of plant diversity Div_{GFT}, $Fast_{GFT}$. and Sum_{GFT}. Same patterns between Div_{GFT} and $Fast_{GFT}$ were observed whatever the percentage of grass species (Sum_{GFT}), excepted for very low $Fast_{GFT}$ values. Comparison of analysis at field and LMU scales show that this is the LMU level that mostly structures grassland diversity: grassland diversity is greater between than within LMUs. It means that differences in farm orientation and stocking density are required to maintain a grassland mosaic at landscape level.

IV – An integrated framework for linking management and services

$Fast_{GFT}$ increased with nutrient availability and decreased with temperature which is negatively related to field elevation. Stress factors for nutrient availability and average temperature (resulting from field elevation) act in the same direction, favouring species having fast growth strategy when the stress level is low. The effects of defoliation management add to those of stresses. Disturbances modify the effect of stress, either by reducing or by amplifying it. For given climatic and soil conditions, mowing promotes acquisitive types, while grazing promotes conservative types. Functional diversity being characterized here by Div_{GFT}, the direction of effect for stress factors (fertilisation rate and field altitude) depended on the dominant plant strategy. Previous research on the intermediate stress hypothesis supports the idea that maximum diversity was only observed when considering stress and disturbance factors simultaneously. In our framework, both are roughly mediated by the proportion of $Fast_{GFT}$. A high level of Div_{GFT} results from the coexistence of species with both types of growth strategy.

Based on the farm sample studied, we found that even a single farm could contain a wide range of within- and between-field functional plant diversity, and that contrasting land use within a farm can create as large diversity on a small spatial scale as observed at the landscape scale. As observed in a very different context, GFT assemblages are the result of deliberate management choices resulting from farm production orientation and from assets and constraints such as available facilities and field topography (Martin *et al.* 2009). Differences in GFT diversity at LMU scale are the result of land use and farm enterprise types. Usually cut grasslands have the highest proportion of fast growing species, firstly because they receive more fertilizer and secondly due to the direct effect of management regime. Dairy farms have a higher proportion of $Fast_{GFT}$ for both cut and grazed areas, consistently with the highest digestibility of these plant types. Between-farm comparisons can show whether there is scope for reducing the cost of feedstuffs. For example, the fourth dairy farms have similar milk production per cow (around 5000 kg / year) while the percentage of $Fast_{GFT}$ varied greatly: it was highest for one dairy farm and lowest for another dairy farm. Since a high percentage of $Fast_{GFT}$ requires high fertilizer input, this means that production costs could be reduced if enough land is available. The method also allows discrepancies to be detected, for example for dairy heifers in farm one dairy farm that used high-quality herbage. It allows a large number of ES to be evaluated at different spatial scales, and the main trade-offs between ES to be analysed. $Fast_{GFT}$ was a good proxy for forage production at field and LMU levels. For low N rates, we verified that the coexistence of GFT having different strategies for resource acquisition leads to higher input efficiency for herbage production as suggested by Fornara and Tilman (2009). For management services, we found that between-farm differences are related to consistent allocation of vegetation types or forage resources to different animal groups in order to save labour or feedstuffs costs. Furthermore, our framework provides a basis for comparing within- and between-field plant functional diversity; this could simplify the gathering of stakeholders' perceptions about cultural services. It allows the main trade-offs between ES to be examined. Using the approach at LMU scale, we have shown that such trade-offs were not usually a problem for managers because the targeted ES mainly depended on the group of animal (cow vs heifer) or the land management (grazing vs cutting) considered. Thus, the diversity of animal groups on a farm, and the diversity in farm enterprises in a region lead to a diversity of vegetation types in a landscape which is enhanced by environmental factors such as field aspect and elevation. This explains why such diversity in agriculture creates a mosaic of vegetation types and a great landscape heterogeneity that contribute to cultural services, and more broadly to multiple ES.

The approach based on GFT is easy to understand by stakeholders. Farmers give positive feedback when their land was depicted as GFT through a graph bar or a map. It should help advisors to understand the implications of different management choices on grassland diversity. It also provides lessons to examine the impacts of policies to support biodiversity with subsidies based on stocking rate thresholds calculated for a set of fields or the whole farmland. The field scale may be sufficient for assessing their impact on plant diversity, while the farm scale is still needed to understand the drivers of management practices.

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