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SUPER-G

SUSTAINABLE PERMANENT GRASSLAND

Deliverable 2.6

Delivery of ecosystem services from permanent grasslands

Project funded under the Horizon 2020 Research and Innovation Programme

Dissemination Level

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Abstract

Permanent grasslands cover 34% of the European Union's agricultural area (Eurostat, 2020) and are vital for human wellbeing as they contribute to a wide variety of essential ecosystem services. There is limited understanding of how land use and management effects the multifunctionality of European permanent grassland, which limits our ability to understand and predict the effects of land use change and management intensification on the provisioning of vital grassland ecosystem services.

The contribution of land use to ecosystem service (ES) delivery depends on environmental conditions but also on management and in some circumstances ES will be competing. We have collected evidence in four different tasks.

The first task was to carry out a systematic review on the reported effects of land use and management on the delivery of grassland ES. The review showed that preventing the conversion of permanent (PG) grassland to cropland or temporary grassland secures the provision of multiple ecosystem services. The review also showed that intensification of existing PG threatens multifunctionality. These findings are important for the future of PG in view of the impact of our food system, and especially ruminant livestock, on environmental change.

The second task involved four meta-analyses as a follow-up to the systematic review:

(i) A meta-analysis of 34 control-treatment effects from 14 studies revealed a negative linear relationship between nitrogen fertilizer use rate and change in plant species richness, equivalent to approximately 1.5 species/m^2 lost for every 100 kg ha^{-1} yr^{-1} of nitrogen added.

(ii) Liming either reduced or had no effects on the emissions of two potent greenhouse gases (N_2O and CH_4). Liming grassland delivers many potential advantages, which justify its wider adoption such as reducing soil acidity, increasing grass productivity, reducing fertiliser nitrogen requirement and increasing species richness.

(iii) Soils supporting PG had generally lower bulk density and higher hydraulic conductivity than arable soils, and generated less runoff and soil loss. Differences were less clear-cut in comparison with forests, although PG had higher bulk density and runoff values.

(iv) (An evaluation of threats to recreation and landscape aesthetics described in the literature, showed that the most common threats were land-use and management change processes, followed by social attitude, industrial developments and natural threats. However, recreational activities relating to tourism can also have a negative impact on biodiversity and cultural ES

The third task used expert elicitation to assess the effect of management interventions on the provision of ES by PG. The study clearly identified management options where there are trade-offs between feed provision and non-feed ES (e.g. nitrogen fertiliser use,

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renewal frequency) and management options which supported multiple ecosystem services (e.g. presence of legumes, lime and number of sown species).

The fourth task used expert elicitation to identify contrasts in ES delivery according to PG-type, which mainly reflected production intensity. The PG types summarised in the PG Atlas are able to discriminate between different patterns of ES delivery. which is an import prerequisite for communication to farmers, policy makers and scientists.

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1 Introduction

Permanent grasslands (PG) cover 34% of the European Union's agricultural area (Eurostat, 2020) and are vital for human wellbeing as they contribute to a wide variety of essential ecosystem services (ES) (O'Mara, 2012; Habel et al., 2013; Bengtsson et al., 2019). Thus, any change in their area or the capacity of grassland to provide ecosystem services will have significant societal impacts. For centuries, permanent grasslands have been the basis for livestock production and the main pillar of nutrient cycling on farms all over Europe (Green, 1990; Lemaire et al., 2011; Hejcman et al., 2013). After the Second World War, the goal of self-sufficiency in food production stimulated the improvement and intensification of management of permanent grasslands, or their conversion to temporary grasslands or croplands. In less versatile areas, like mountainous regions or wet lowlands, large areas of PG were abandoned or afforested (Habel et al., 2013; Boch et al., 2020). While statistical data on the loss of permanent grasslands are fragmented, the available figures illustrate the significant loss during the last decades. For example, in the EU-6 countries (Belgium, Netherlands, Luxemburg, France, Former West Germany, Italy), PG losses have been estimated at about 30% between 1967 and 2007 (Huyghe et al., 2014). Regionally, losses have been even higher, as in Upper Normandy, France, where about 50% of the PG area was lost between 1970 and 2000 (Van den Pol-Van Dasselaar et al., 2019). In Eastern Europe, the political transformations at the end of the 1980s triggered large scale abandonment of PG, for example in Slovakia 42% of PG were left unused (Kizeková et al., 2018).

Grass continues to be amongst the cheapest high-quality feed sources for efficient ruminant meat and dairy production (Van den Pol et al., 2018). In addition to the provision of feed, PG sustain a broad range of additional ES, including climate regulation through carbon sequestration (Soussana et al., 2010); cultural values (Hussain et al., 2019); protection against erosion and flooding (Macleod et al., 2013); and pollination of food crops (Klein et al., 2007; Scheper et al., 2013).

Permanent grasslands across Europe are very diverse (Figure 1.1). This is partly driven by inherent factors such as climate and soil, but also by varying intensities of grassland management, resulting in continuous gradients of fertilisation and defoliation (mowing or grazing) intensity (Blüthgen et al., 2012). For European permanent grasslands, there is a restricted understanding of land use and management effects on multifunctionality, which limits the ability to understand and predict the effects of land use change and management intensification on the provisioning of vital grassland ecosystem services.

This report aims to provide an overview of the ES provided by PG. The contribution of land use to ES depends on environmental conditions but also on management and in some circumstances ES will be competing. The report also discusses options for ES delivery and potential trade-offs and synergies of different management options.

The report contains four main sections: The effects of land use and management will be described in the first and second section, based on a systematic literature review and

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associated meta-analyses. The third and fourth sections deal with effects of management and PG type on ES delivery, respectively. These are based on expert elicitation.

Figure 1.1: PG still dominate the agricultural areas in many European regions, especially in places where growth conditions are unfavourable as in mountainous regions (A, Switzerland). Historically, grasslands were relatively nutrient-poor and extensively managed (B, Poland, and C, Germany), but a significant extent of grasslands experienced either intensification of management (D, United Kingdom) or were lost due to conversion to cropland (E, Czech Republic) or abandonment (F, Switzerland). Pictures by V. Klaus (A, C, F), M. Janicka (B), ADAS (D), S. Hejduk (E).

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2 Effects of land use and management on ES delivery from PG (Schils et al., 2022)

This is a summary of Schils et al. (2022). The preliminary findings were reported in deliverable 2.2a.

2.1 Objective

The objective was to address two research questions:

- What are the reported effects of land use change, i.e. the conversion to other land uses such as temporary grassland, cropland or forest, on the delivery of grassland ecosystem services?
- What are the reported effects of intensification and specific management options on the delivery of ecosystem services by permanent grassland?

2.1 Methods

Permanent grassland

The European Union's definition of permanent grassland was used i.e., land used to grow grasses or other herbaceous forage that has not been included in the crop rotation of the holding for a duration of five years or longer (EU, 2004).

Indicators of ecosystem services

A set of indicators was selected that comprised a cross-cutting representation of biodiversity and ecosystem services of permanent grasslands. It is important to acknowledge the multiple roles that biodiversity plays in the delivery of ecosystem services e.g. as a regulator of ecosystem processes, as a service in itself and as a good (Mace *et al.*, 2012). For clarity, biodiversity was considered as one of the ecosystem services.

Search strategy – inclusion criteria

In the fourth quarter of 2019, the Scopus and CAB abstracts databases were searched for grassland studies on 19 indicators of ecosystem services in Europe, published in the English language from 1980 onwards. Scopus and CAB abstracts were used for this systematic review because both databases can effectively perform complex Boolean searches with regards to precision, recall and reproducibility, which is a prerequisite for systematic searching (Gusenbauer and Haddaway, 2020). CAB Abstracts is the leading database on applied life sciences, including crop sciences and grasslands, animal science, environmental science, and recreation/tourism. The multidisciplinary database Scopus is the largest abstract and citation database of peer-reviewed literature in the field of science, technology, medicine, and social sciences.

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Search strings were evaluated and refined in several steps by assessing the relevance of the papers returned, and by checking against key papers in the field. A wide range of search terms were used to cover the diversity of methods used to assess the provision of ecosystem services of permanent grasslands. A search string was developed for the concept “grass”, and combined with the search string for each one of the 19 ecosystem service indicators, using an AND-operator.

The 19 sets of search results were combined into de-duplicated Endnote libraries, one for each ecosystem service. We collected a total of 70,456 papers, varying from 7,181 papers for *water purification* to 16,201 papers for *biodiversity*. These papers, including abstracts, were uploaded to the dedicated systematic review analysis software ‘EPPI reviewer 4 tool’ (http://eppi.ioe.ac.uk/cms/), as six corresponding reviews.

Exclusion criteria

Titles and abstracts were screened in two stages, using the following same set of exclusion criteria:

- Not in the English language.
- Outside the following Natura 2000 biogeographic zones of interest: Alpine, Atlantic, Boreal, Continental, Mediterranean or Pannonian. Biogeographical boundaries are a combination of official delineations used in the Habitats Directive (92/43/EEC) and for the EMERALD Network under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). They are independent of political boundaries of Emerald Network countries or EU Member States (https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3).
- Outside the following countries in Europe: Member states of the EU-28 or Albania, Belarus, Bosnia Herzegovina, Kosovo, Macedonia, Moldova, Montenegro, Norway, Serbia, Switzerland or Ukraine.
- Unit of study was not grassland.
- The outcome was not one of the 19 indicators of interest.
- Papers on urban amenity grasses.
- Reviews.
- Modelling studies.
- Experiments under controlled conditions: laboratories, greenhouses or pots.

Study selection on contrasts

The papers retained after the title and abstract screening contained the body of literature on European experimental studies, published after 1980 and in the English language, and on one or more of the 19 indicators for grassland. From this set of 11,619 papers, papers were selected that contained at least one of eight experimental contrasts in land use (permanent grassland versus cropland, forest or temporary grassland) or

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contrasts in management (sward renewal, legume presence, number of species, defoliation frequency and nitrogen input).

Data extraction

After screening for eligible contrasts, 3,664 studies were retained for full text screening. Retrieved papers were read and either extracted or excluded with reasons. For time management reasons, a stepwise sampling procedure was developed for eligible papers within the ecosystem services *biodiversity* and *provision of animal feed*, which each had more than 1,000 eligible papers Consecutive random samples of 300 papers were taken out of the eligible papers for data extraction until a maximum of 300 extracted papers was reached. Eventually, 510 papers out of the 1,313 papers of the *provision of animal feed* domain were not included in the sample.

Data from valid sampled full text papers were extracted using a data extraction form, developed in MS Excel, which consisted of two sections. The first form (Study) was used to extract data per paper: bibliographical identification, study type, geography, experimental contrasts, and methods for assessment of the relevant indicators. If a paper was excluded at this stage, the reason was recorded in this form as well. The second form (Contrast) was used to extract data on the experimental contrasts. Each paper consisted of at least one contrast and in total the 696 papers contained 1032 eligible experimental contrasts, which were defined as a 'case'. The outcome i.e. no conclusion, favourable, neutral, or unfavourable was registered. The outcome was based on the numerical data and statistical significance in tables, figures, or text, or based on authors' claims in the text. This approach allowed extremely heterogeneous data and metrics across ecosystem service indicators to be combined, which allowed a greater number of studies to be compared for a more comprehensive answer to the research questions. Rather than simply counting which studies had outcomes in a certain direction, sometimes referred to as 'vote-counting' (Stewart, 2010), strict criteria were applied for the inclusion of studies and for the assessment of the direction of change in ecosystem service indicators due to land use contrasts or management interventions.

Data analysis

The outcomes from the data extraction form were tabulated per contrast. For statistical analysis, the outcomes were transformed to numerical values (favourable = 1, neutral = 0, unfavourable = -1). Cases with no conclusion were discarded from the analysis. A one-sample t-test was carried out, with H_0 assuming no effect (outcome = 0). The analysis was carried out with the facilities of SPSS version 25 (SPSS, 2020).

Reviewer bias

Screening and data extraction were carried out by expert teams, consisting of a lead-reviewer and at least one co-reviewer per ecosystem service. The assessment of the lead-reviewer, an expert in the field, was the benchmark against which the co-reviewers' assessments were compared. To align the scoring in screening and extraction,

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intermediate results including arising disputes were discussed and resolved. At least 5% of the papers were double-screened, independently by the lead-reviewer and one or more co-reviewers. We assessed the number and proportion of 'false exclusions', i.e. when the co-reviewer excluded a paper that was included by the lead-reviewer. If the proportion of false exclusions was higher than 10%, we reconciled the issues.

2.2 Results

We considered 70,456 papers, identified for 19 indicators of grassland ES across Europe, published since 1980. After screening, we included 696 papers in the final analysis (1%). While we found papers covering almost all regions of Europe, the majority were found in a broad northwest to southeast range, roughly stretching from the British Isles to Eastern Europe (Figure 2.1). Although most of the papers included in this review were identified in regions where over 40% of the utilised agricultural area (UAA) was covered by permanent grasslands, regions with less than 20% permanent grasslands were also represented. Around two thirds of the extracted papers originated from the Atlantic or Continental biogeographic regions.

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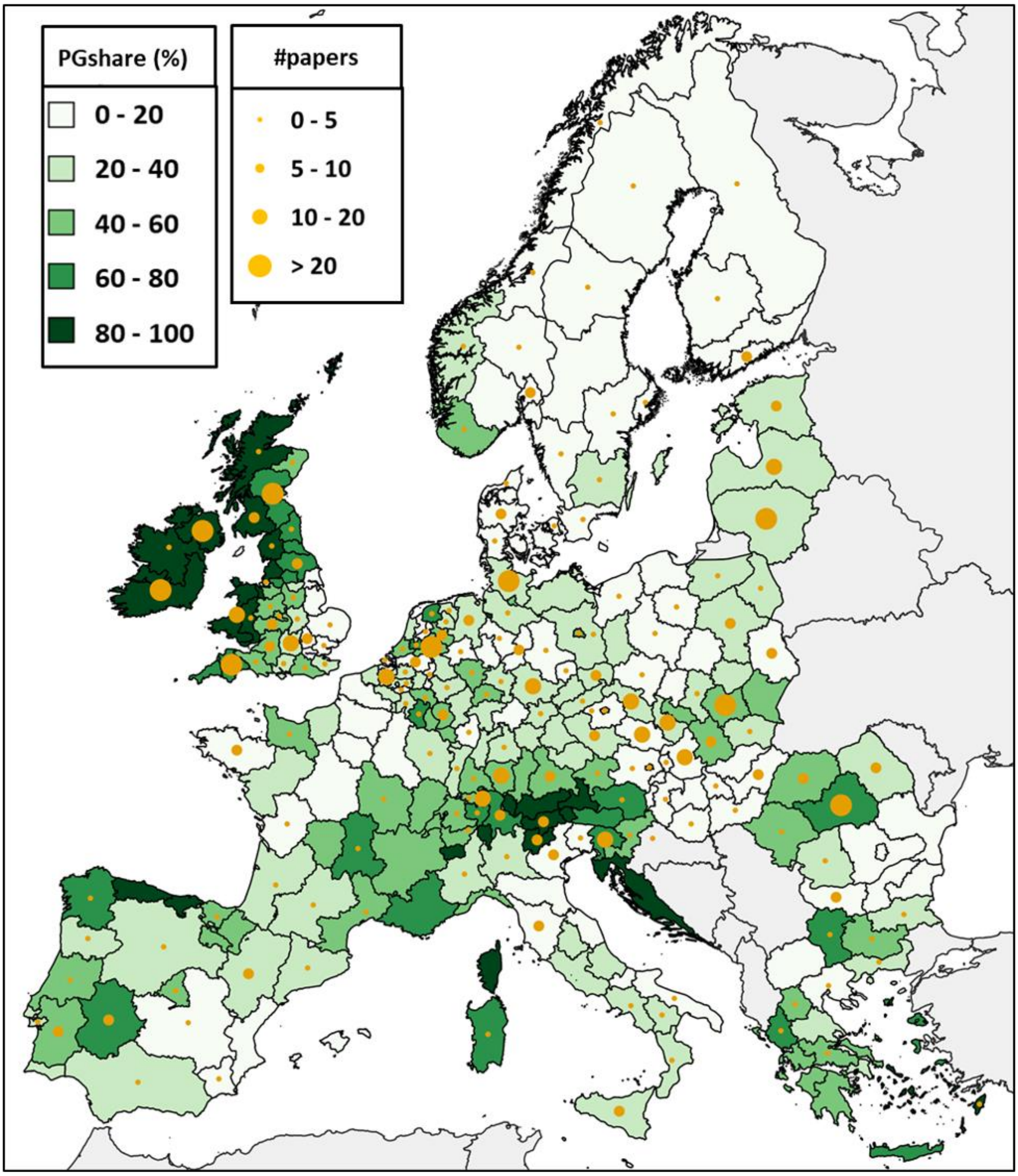

Figure 2.1: Geographical distribution, across NUTS2 regions in Europe, of included papers (#papers), published since 1980, and the share of permanent grassland (PG share) in the total utilised agricultural area (UAA); data from 2016, except Norway and Macedonia from 2013 (Eurostat, 2020); grey areas indicate no data.

The review showed that most studies reported favourable outcomes for permanent grasslands compared to croplands across all ecosystem service indicators, except for forage yield and energy content (Figure 2.2a). Furthermore, the favourable outcomes of all indicators for *climate regulation, water purification, erosion and flood control,* and *cultural values* were supported by at least five cases.

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Only a few studies compared permanent to temporary grasslands, with the outcomes generally supported by less than five cases. There was no consistent evidence, with only seven cases available, of higher grass yields from temporary grasslands compared to permanent grasslands, contrary to the common expectation when converting permanent grasslands into temporary grasslands (Søegaard *et al.*, 2007). Temporary grasslands are, by definition, always part of a rotation with other crops. This implies that the outcomes of the comparison with croplands are also relevant for the assessment of the conversion from permanent to temporary grassland.

When PG were compared to forests, the reported outcomes suggest trade-offs between the studied ecosystem services (Figure 2.2b). There was consistent evidence of studies reporting a better performance of forests regarding all indicators for *erosion and flood control*. In contrast, most studies reported higher levels of *biodiversity* and *cultural values* for permanent grasslands compared to forests, in particular for the indicators 'threatened species' and 'aesthetic value'. The reported outcomes on *climate regulation* and *water purification* did not show a consistent effect. A small majority of cases (9 versus 6) showed higher soil carbon sequestration in forests. However, the assessment did not include the overall ecosystem carbon sequestration of forests which is typically higher than in permanent grasslands due to the long-term build-up of above ground biomass.

There was a lack of studies that compared permanent to temporary grasslands, especially across the whole spectrum of non-feed ecosystem services. These research gaps can be addressed by either long-term plot experiments under controlled conditions or monitoring campaigns at the scale of fields or landscapes, depending on the targeted ecosystem service indicator.

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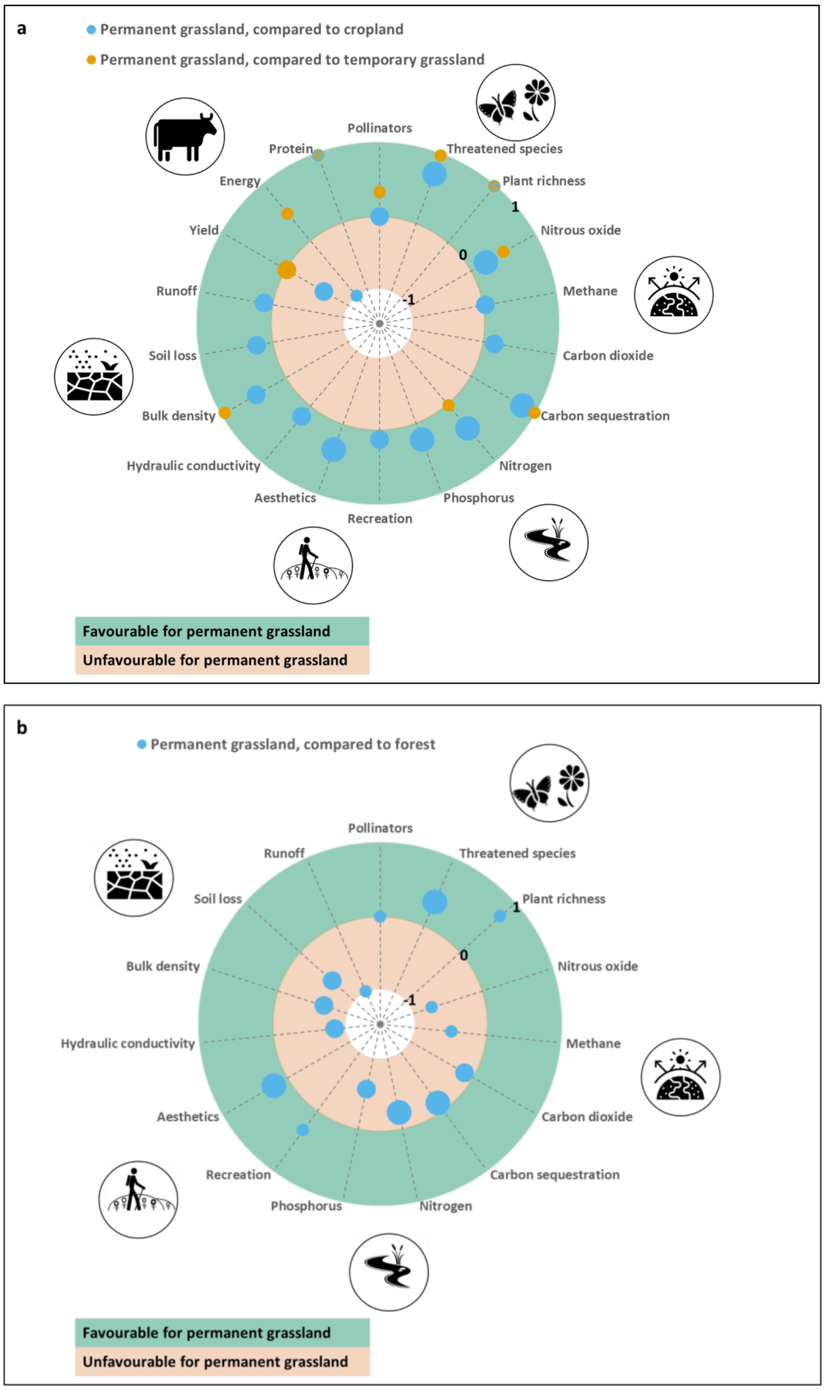

Figure 2.2: Comparison between land use types for indicators of ecosystem services, (a) permanent grassland compared to cropland and temporary grassland, (b) permanent grassland compared to forest. The boundary between the outer and inner shaded zones represents a mean score of 0. The shaded outer zone represents a favourable score for permanent grassland (moving outwards, the mean score increases from 0 to 1), the shaded inner zone represents an unfavourable score (moving inwards, the mean score decreases from 0 to -1). Dot size indicates number of underlying cases (small: <5 cases, medium: 5-9 cases. Large: >9 cases).

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There were consistent trade-offs in the reported outcomes between indicators for feed and non-feed ecosystem services for three types of management options that represent increasing management intensity, i.e. fertiliser nitrogen input, increasing defoliation frequency and grass renewal (Figure 2.3a). Nitrogen input gave significantly unfavourable effects on indicators for *biodiversity, water purification*, and *climate regulation*, but not carbon sequestration. In contrast, there were significantly favourable effects of nitrogen inputs on forage yield and protein content. Yield and quality were oppositely affected by defoliation frequency. Increasing frequency, resulted in significant improvement of forage quality, but a significantly lower forage yield. There were few studies on the effect of defoliation frequency on the non-feed ecosystem services. A limited number of studies investigated *climate regulation (7)* and *water purification (6)* but no cases for *erosion and flood control* or *cultural values* were identified. However, the overall negative effects of increasing defoliation frequency on all indicators of *biodiversity* and on nitrogen losses to water were supported by at least five cases. Finally, sward renewal showed significant favourable effects on forage yield, but no consistent effect on forage quality, across 30 cases reporting energy content and 28 cases reporting protein content. In contrast, grassland renewal was shown to significantly increased nitrous oxide emissions and nitrogen losses to water. It is remarkable that only 40% of the studies stated the sward age at renewal. Of these, the dominant sward age at renewal (70% of studies that stated sward age) was between 5 and 25 years, while only 10% were younger than 5 years and 20% older than 25 years.

In addition to the above interventions that relate to management intensity, sward botanical diversity was studied as a separate category of management options, and was not considered as a dimension of intensity. The reported outcomes of increased number of species in the sward showed mainly favourable effects on the indicators for *biodiversity, cultural values* and *water purification* and mixed effects on *provision of animal feed*. An increased number of species significantly increased the number of pollinators and threatened species. There were less than five cases reporting *cultural values* and *water purification*, but they consistently reported a favourable effect of number of species in the sward. An increased number of species significantly increased yield, but decreased the energy content, and showed no consistent effect on protein content.

Papers comparing swards with and without legumes, with similar nitrogen fertiliser inputs, reported significant favourable effects of legumes on yield and protein content, whereas energy content was not affected. Papers investigating non-feed ecosystem services of legume presence were relatively underrepresented. A consistent favourable effect of legumes, based on eight cases, was reported for the abundance of pollinators. The papers on nitrogen losses to water showed a small unfavourable effect of the presence of legumes.

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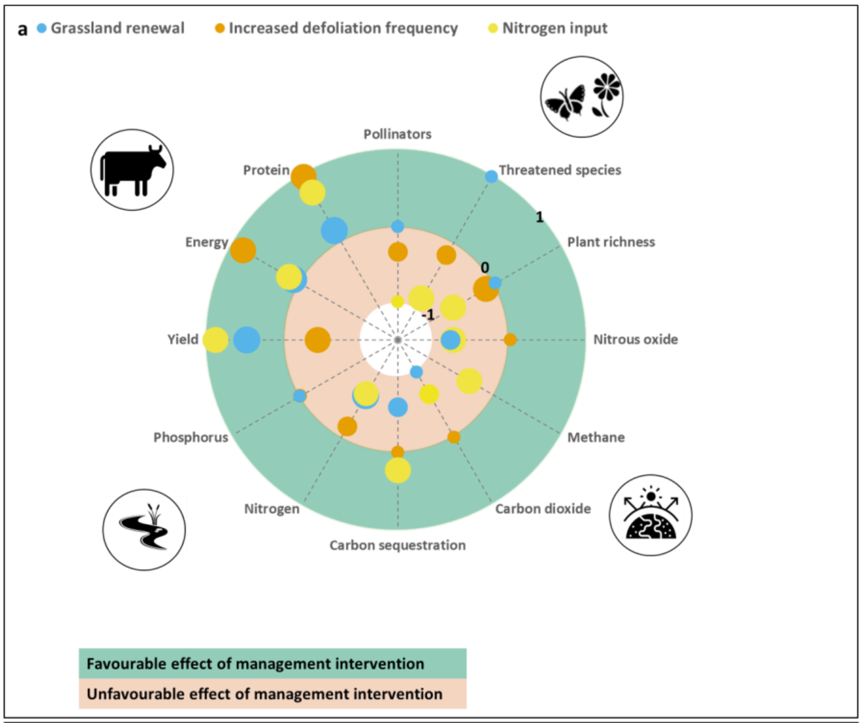

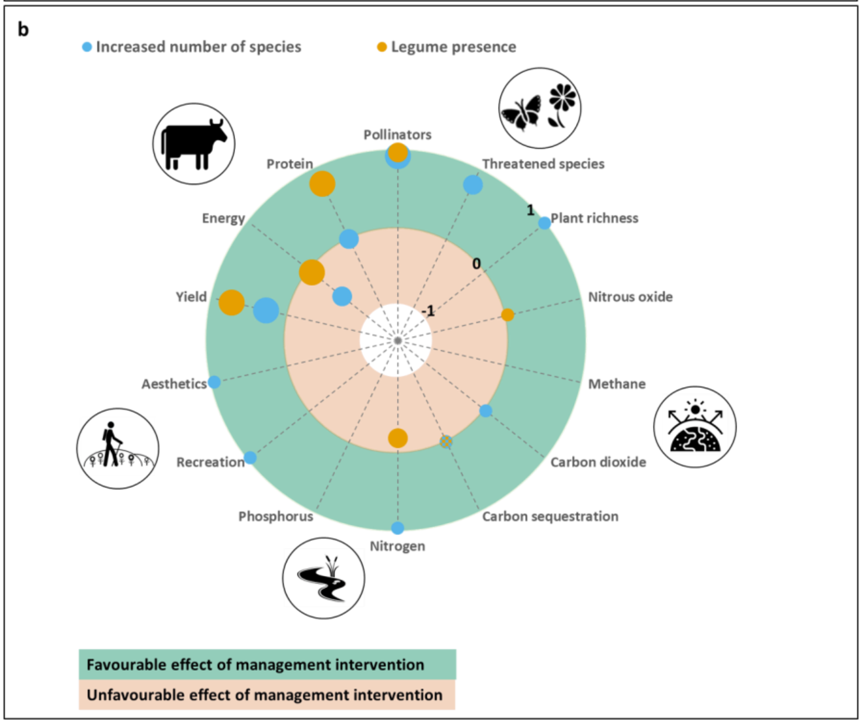

Figure 2.3: Effects of management options on indicators for ecosystem services; (a) management interventions related to intensification, (b) management interventions related to species in the sward. The boundary of the outer and inner shaded zones represents a mean score of 0. The shaded outer zone represents a favourable score (moving outwards, the mean score increases from 0 to 1), the shaded inner zone represents an unfavourable score (moving inwards, the mean score decreased from 0 to -1). Dot size indicates number of underlying cases (small: <5 cases, medium: 5-9 cases. Large: >9 cases).

The findings suggest that a low or reduced management intensity of permanent grasslands can improve the balance between the environmental impact of ruminants and the utilisation of herbage. In regions like Eastern Europe where intensification is still ongoing in some areas, the main aim should be to identify options to support management that enables securing the current level of all ecosystem services and avoid drastic intensification. In regions with predominantly intensive grasslands, simply reducing management intensity will not lead to an immediate recovery of all ecosystem services as extensification is not the exact inverse of intensification. While, for instance, greenhouse gas emissions would decrease relatively fast, the response of biodiversity will be rather slow, and might require active measures of ecological restoration. Besides technical innovations, effective restoration requires integrated socio-economic solutions including recognition of grasslands in global policy and enhancing knowledge transfer and data sharing on restoration experiences.

Prioritising non-feed ecosystem services comes at a cost of the *provision of animal feed*. While this trade-off is clear for reducing nitrogen inputs, other management interventions show mixed or even synergistic outcomes and thus should be implemented more frequently. For instance, the review found that a higher number of species in the sward was favourable for *biodiversity* and *provision of animal feed*, albeit with predominantly lower herbage energy content. Introduction of multiple species in species-poor swards, including legumes, will however require some form of sward renewal, which itself can have unfavourable effects on *climate regulation* and *water purification.* Grassland renewal should thus only be carried out infrequently, with as little soil disturbance as is manageable and when conditions are favourable to maximise the probability of successful establishment. The proposed shift from feed to non-feed ecosystem services will result in reduced stocking rate and thus lower milk or meat production per hectare with potential negative effects on farm income,. However, increasing the number of species in the sward for example, can also have positive effects on magnitude and stability of economic revenues, in particular for risk-averse farmers (Binder *et al.*, 2018; Schaub *et al.*, 2020).

2.3 Conclusions

This extensive systematic review of the literature on permanent grasslands across Europe, found that preventing the conversion of permanent grassland to cropland or temporary grassland secures the provision of multiple ecosystem services. In addition, the review found that intensification of existing permanent grasslands threatens multifunctionality. These findings are important for the future of permanent grasslands in view of the impact of our food system, and especially ruminant livestock, on environmental change.

The review showed that, in general, lower management intensity allows for a higher multifunctionality, although prioritising non-feed ecosystem services comes at a cost for the provision of animal feed. It is important to emphasise that there is no simple general blueprint for the implementation of a reduced management intensity. Extensification is more than just reducing inputs and may require some kind of ecological restoration including the supply of affordable seed mixtures for diverse grasslands. Moreover, multifunctionality is likely to be optimised differently depending on the local context. For example, an optimal configuration on a farm in the Italian Alps might not work for farms on the west coast of Ireland. The potential for change may be limited as many farmers are locked in to production-orientated systems, influenced by persistently low prices for milk and meat and in some cases high land rental charges.

Over recent decades, the permanent grassland area suffered significant losses. The outcomes of our review suggest that, in spite of recent apparent changes in dietary preferences, the protection of permanent grasslands in Europe has to be prioritised to prevent further losses and thus the provision of multiple ecosystem services. However, whilst there is a need to reduce ruminant livestock's impact on climate change, an increase in support for low to medium-intensity management on existing permanent grasslands to deliver a combined approach of protection and extensification will help secure multiple benefits from Europe's permanent grasslands.

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3 Effects of land use and management on ES delivery from PG (meta-analyses)

The systematic review described in the previous chapter collected many data that were suitable for further in-depth meta-analyses. This is a summary of four papers that were published using the systematic review data (Figure 3.1).

		Recreation & Aesthetics	Water quality	Biodiversity	Climate regulation	Erosion & flood control	Animal feed
Francksen et al., 2022	Nitrogen			√			
Abdalla et al., 2022	Lime				√		√
Milazzo et al., 2023	Land use					√	
Pellaton et al., 2022	Threats	√					

Figure 3.1: Overview of topic and ecosystem services addressed in the four meta-analyses that were carried out in the second stage of task 2.3 in WP2.

3.1 Effect of nitrogen on plant richness (Francksen et al., 2022)

Objectives

To explore the relationship between a common form of agricultural intensification (use of nitrogen fertiliser) and a key measure of grassland biodiversity (plant species richness) using a meta-analysis of control vs. treatment effects from experimental studies conducted on European permanent grasslands.

To examine the shape and strength of the relationship between nitrogen fertiliser application rates and changes in plant diversity, whilst accounting for a range of other relevant factors.

Methods

A total of 345 scientific research articles were reviewed, which formed a subset of the >70 k articles systematically reviewed by Schils et al. (2022). From this body of research, strict inclusion criteria were applied when selecting data for the meta-analysis: i.e. (i) study includes a control (no nitrogen addition) and a treatment (nitrogen addition); (ii) the study measured changes in plant species richness in both control and treatment conditions; and (iii) the study reported basic statistical data (mean, standard deviation and number of replicates (n)), or these could be calculated from the information provided. This process led to the inclusion of 14 independent studies reporting results

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from field experiments conducted in European permanent grasslands, from which 34 effect sizes were included in the meta-analysis.

The mean difference in plant species richness between control and each treatment level in each study was used as the effect size in the analysis, which allowed for ease of interpretation in the results presented. Studies that only provided other metrics of plant diversity in this meta-analysis (e.g., Simpson's or Shannon's Diversity Indices) were not included owing to the low number of studies using these metrics that had extractable data or data that could be readily standardised. Where means and standard deviations were given in graphical form, values were extracted using open source, web-based application Web Plot Digitizer. If the study reported more than one value for the same experiment at multiple time points, the data for the final time point was used.

Defoliation rates (i.e., number of cuts or grazing episodes per year) were recorded for each contrast in nitrogen application rate. Contrasts where defoliation levels differed between control and nitrogen addition treatment were excluded. This ensured that within each control vs. treatment contrast, the defoliation rate was constant, although for some studies it differed between contrasts when more than one contrast could be extracted. This approach reduced any confounding effect of defoliation and helped to isolate the effect of nitrogen application on plant diversity. Plant species richness was also recorded on control (i.e. zero N) treatments for all eligible contrasts, to give the 'baseline species richness'. The plot size was also considered (since diversity can be expected to increase with plot size) along with the time between nitrogen application and the recording of richness values, and whether the nitrogen was applied as 'nitrogen only' or as 'nitrogen + other nutrients' (referred to as 'fertilizer type').

Eligible data were anlaysed using a three-level mixed-effects meta-analysis model. These models are more equipped to handle clustered effect sizes than more traditional methods used in meta-analyses. Models were fitted using the 'rma.mv' function in the package 'metafor' in R using restricted maximum likelihood (REML) procedures to explore the effect of nitrogen fertilisation rate on differences in mean plant species richness between control and treatment plots. Models were generated using 'study' as a random effect to address potential non-independence without compromising sample size. Model heterogeneity was compared both within studies (level 2) and between studies (level 3) using the 'var.comp' function within the 'dmetar' package.

Each effect size (mean difference in plant species richness between control and nitrogen addition treatment) extracted from eligible studies was associated with a nitrogen application rate, as well as with a number of additional variables, each of which were justified based on prior knowledge of their possible effect on plant richness. These included: baseline species richness, defoliations per year, plot size, fertilisation type, and years of nitrogen application. Additionally, an interaction term between nitrogen application rate and defoliation rate was included, with nitrogen application rate added as both a linear and non-linear term to assess the importance of non-linear effects. A

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full model with each of these variables included as moderators was built after checking for any strong and/or significant correlations between variables.

Results

Meta-analysis revealed a mean change of plant species richness between zero-nitrogen controls and all treatment levels of −2.75 species (95% CI: −5.02––0.47). The mean treatment level for all 34 interventions was 136 kg N ha^{-1} yr^{-1} (range: 12.5–600). There was a high degree of inconsistency in the effect, with 22 out of 34 contrasts (65%) showing a negative effect of nitrogen application on plant species richness, and 12 showing a positive effect. Furthermore, confidence intervals overlapped across studies for most effects (Figure 3.2).

Conclusions

Meta-analysis of 34 control-treatment effects from 14 studies conducted across nine European countries revealed a negative linear relationship between nitrogen application rate and change in plant species richness, equivalent to approximately 1.5 species/m^2 lost for every 100 kg ha^{-1} yr^{-1} of nitrogen added. Nitrogen application induced reductions in plant species richness were greater when defoliation rates were lower. There was some evidence that grasslands with a higher baseline plant diversity lost more species when nitrogen fertilizer was applied compared to more species poor grasslands, although uncertainty was high. Due to the diverse grassland types included in the analysis, the variability in fertiliser-driven changes in plant diversity was high. Several remaining limitations were identified, including uncertainty about non-linear effects, which could aid efforts to optimise the trade-off of between plant diversity and increasing grassland yields.

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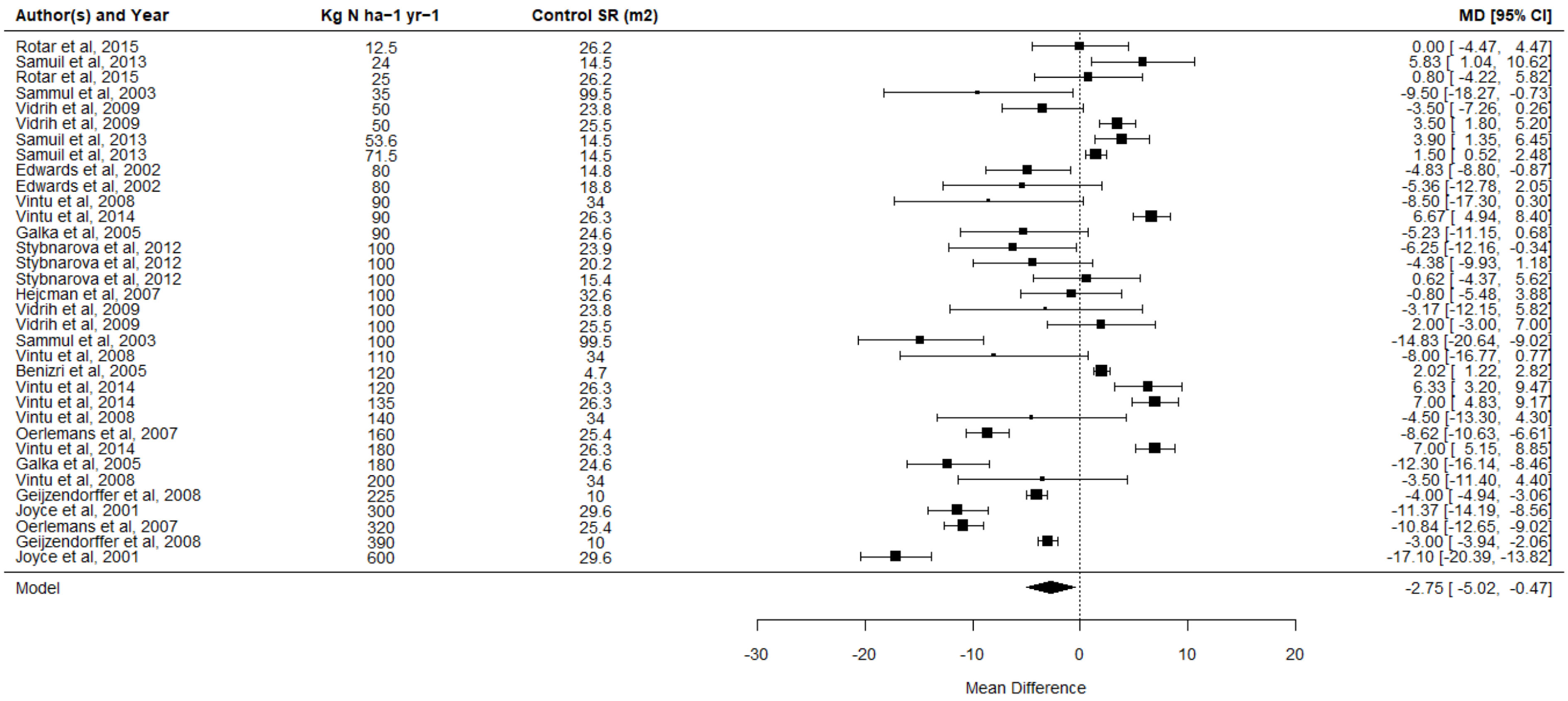

Figure 3.2: The effects of nitrogen (N) application on the mean difference (MD) in plant species richness for 34 effect sizes in 14 studies conducted on European permanent grasslands included in a meta-analysis. A mean difference of zero would indicate no change in species richness, whereas negative values indicate the number of species lost and positive values the number of species gained between zero N controls and N addition treatment. Error bars show 95% confidence intervals (Cis), and MD and 95% CIs are given in the right column for each effect and for the overall model. Nitrogen application rates and control species richness (SR) values are shown for each effect. Effects are ordered in ascending order of nitrogen application rate.

3.2 Effect of liming on soil pH, greenhouse gas (GHG) emissions and grass yield (Abdalla et al., 2022)

Objective

To use the globally available literature to assess the impacts of liming grasslands on soil pH, biomass production and net GHG emissions.

Methods

This review is part of a more extensive reviewing process for European permanent grasslands (Schils et al., 2022). All papers published globally between 1980 and 2021 were collected using the keywords: grassland, lime, nitrous oxide (N_2O), carbon dioxide (CO_2), methane (CH_4), soil organic carbon (SOC) and net greenhouse gas (GHG) emissions. Only 57 papers with studies carried out across 88 sites covering different countries and climatic zones were found suitable for this review. Thirty-three papers on soil pH and grass production, and 24 papers on SOC or GHG emissions were identified. This shows that data on the impacts of liming grasslands on GHG emissions are very scarce in the literature. The quantitative analysis was confined to data on soil pH and grass biomass production, while the papers on SOC (15 studies) and GHG emissions (N_2O (4 studies); CH_4 (2 studies) and CO_2 (5 studies) were only reviewed and summarized. Most of the studies were short-term liming experiments of 2–4 years, though some were long-term studies (>10 years).

The data was explored, analysed, and visualised using R version 4.1.0. In addition to linear mixed-effects modelling, the response ratio (RR) of liming on the grass dry matter production between treatment and control was used to confirm the results. Linear regression models were used to show relationships between the changes in soil pH and clay, silt and sand contents in the soil.

Results

The response ratio analysis (±95% confidence intervals) showed (Figure 3.3) that in the MC climate, the increase in grass dry matter production of 20.8% due to liming was significantly higher and the increase of 14.6% in the MW climate was higher but not significantly different from the control. Whilst temperature can increase grass productivity, it may also increase plant decomposition and microbial response to other perturbations (e.g. liming). The increase in grass dry matter production due to liming for both monoculture (17.4%) and multi-species (17.7%) grass were both significantly higher compared to the control ($p < 0.05$). The response ratio analysis showed that significantly higher biomass production of 34.4% could be achieved by liming grasslands grown on medium soil, and of 42.1% by applying N fertiliser annually ranging from 100 to 200 kg N ha^{-1}. However, although the increases in grass dry matter production due to liming for other soil types/applied amounts of N fertiliser were higher, no significant differences were observed.

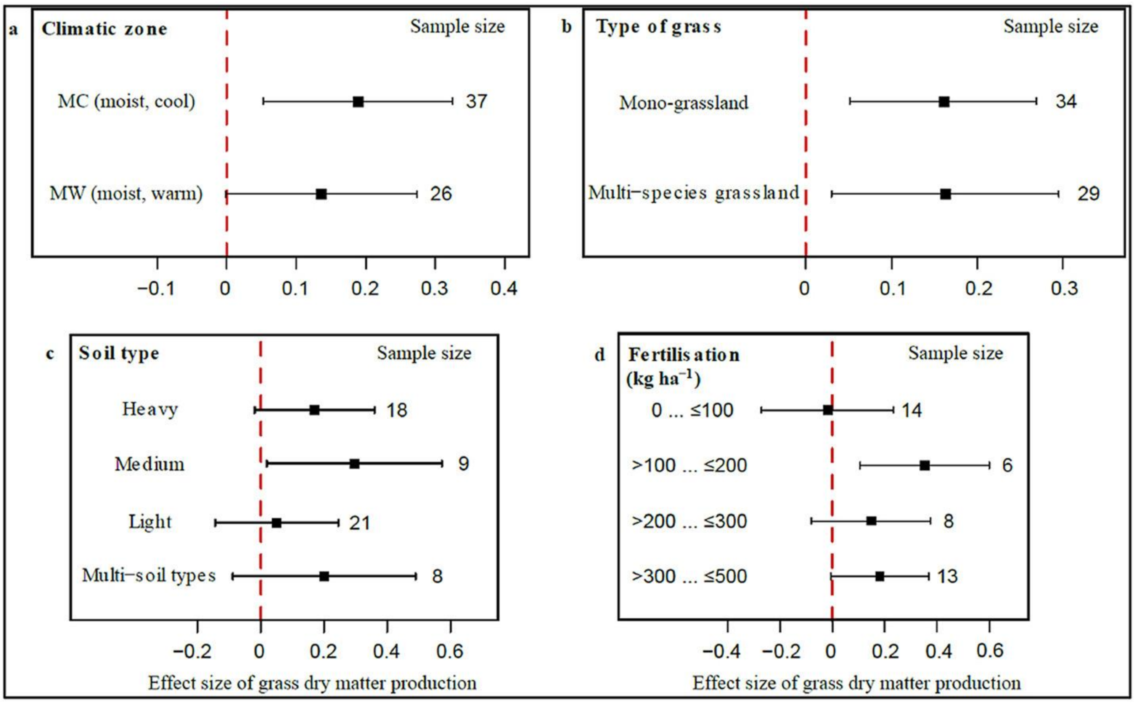

Figure 3.3: Responses of grass dry matter production to liming in the different climatic zones (a), number of species (b), soil types (c) and amounts of fertilisation (d). Effect size stands for the response ratio between treatment and control. Bars represent the 95% confidence intervals. The number of observations of each variable is noted beside the bar. Response ratio ±95% confidence intervals do not overlap 0 means $p < 0.05$.

Conclusions

All of the studies examined showed that liming either reduced or had no effects on the emissions of two potent greenhouse gases (N_2O and CH_4). Though liming of grasslands can increase net CO_2 emissions, the impact on total net GHG emission was minimal due to the higher global warming potential, over a 100-year period, of N_2O and CH_4 compared to that of CO_2. Liming grassland delivers many potential advantages, which justify its wider adoption. It significantly ameliorates soil acidity, increases grass productivity, reduces fertiliser requirement and increases species richness. To realise the maximum benefit of liming grassland, acidic soils should be moderately limed within the context of specific climates, soils and management.

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3.2 The role of grassland for erosion and flood mitigation in Europe (Milazzo et al., 2023)

Objective

To present a comprehensive overview of soil erosion and flooding issues that affect European permanent grassland by performing:

i. A quantitative meta-analysis of the soil erosion and flooding mitigation role of permanent grassland; and
ii. A qualitative evaluation of additional erosion and flooding-related processes that threat permanent grassland in Europe.

Methods

The role of permanent grassland in erosion and flood mitigation was quantified and compared with arable land and forest land by performing a meta-analysis that focussed on four indicators: (i) bulk density, (ii) hydraulic conductivity, (iii) runoff and (iv) soil loss. In 2019, a systematic literature search was performed to identify studies reporting on the effect of grasslands on soil erosion and flooding (Schils et al., 2022). At the end of the screening process, only 24 scientific papers were included in the meta-analysis.

The extracted data were analysed using the logarithm response ratio weighted meta-analysis approach. For every single entry, the effect of land use on the selected contrast was assessed as the natural logarithm response ratio (LnRR) of the mean of the contrasting land uses.

Results

There were no overall significant differences in bulk density between PG and arable land (random error - RE [95%CI] = 1.17[−0.07; 0.40], n = 9) (Figure 3.4). Also, there was no overall significant differences in hydraulic conductivity (RE [95%CI=−0.01[−0.61;0.59] n = 5), although the majority of estimates (60%) were negative for arable land. The estimated average response rate based on RE of runoff was positive (i.e. unfavourable) for arable land, although it was not significantly different from zero (RE [95%CI=0.30 [−0.43; 1.02] n = 6). This assessment suggests that soil loss is higher on arable land than on permanent grassland, although it is also not significant (RE [95%CI=1.73 [−0.09; 3.56] n = 7).

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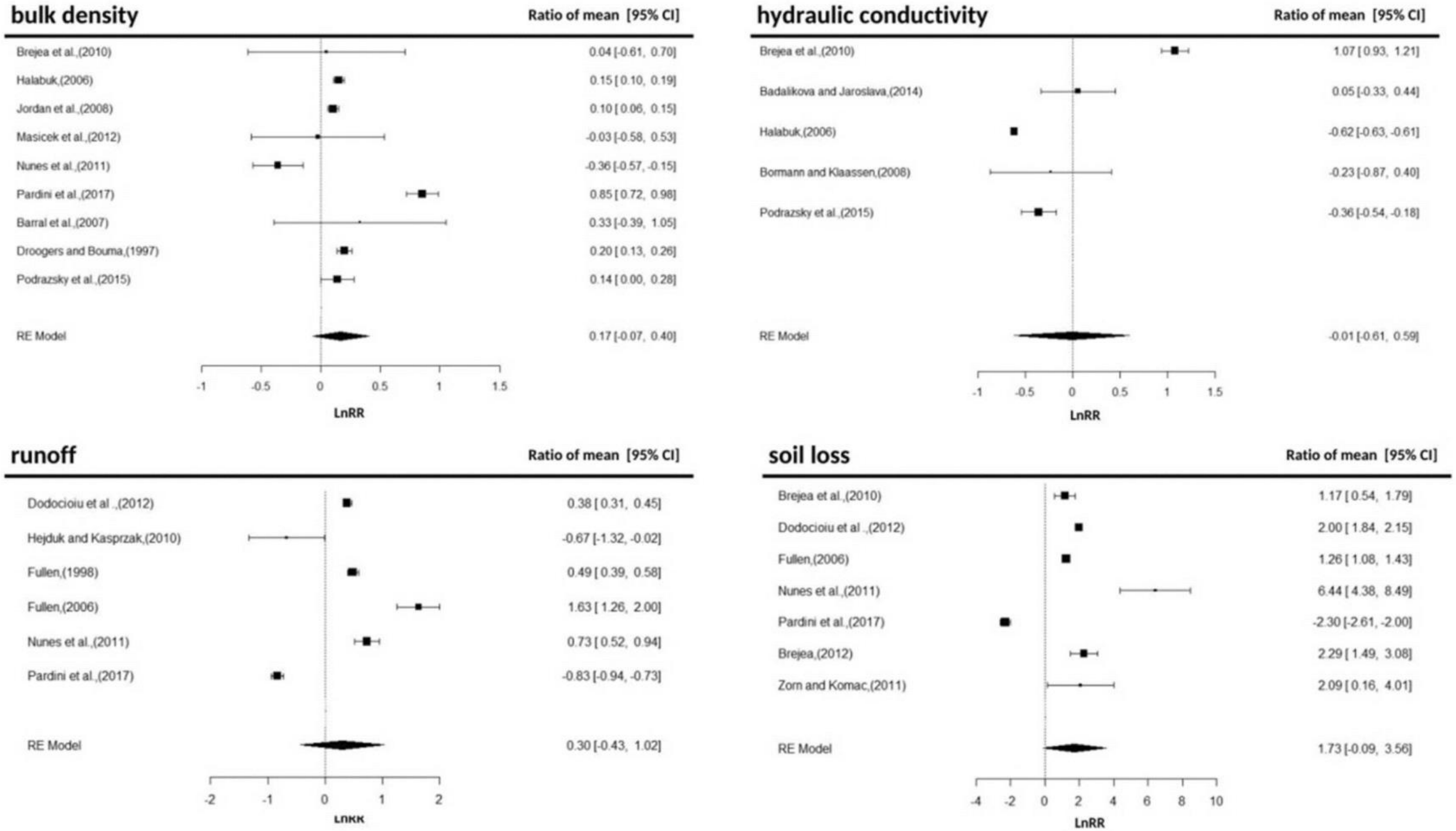

Figure 3.4: Fig. 1. Weighted mean effect (log response ratio, LnRR) and 95% confidence interval of permanent grassland (PG) vs. arable land on bulk density, hydraulic conductivity, runoff, and soil loss. A LnRR> 0 indicates a higher value of the indicator under arable land, while LnRR< 0 indicates a lower value under arable land, compared to PG. Effects are significant (P ≤ 0.05) where confidence intervals do not intercept 0.

Conclusions

The results show that permanent grassland soils had generally lower bulk density and higher hydraulic conductivity than arable soils, and generated less runoff and soil loss. Soil bulk density and hydraulic conductivity were similar on grassland and forest soils although permanent grassland had higher bulk density and runoff values. Secondly, a qualitative, in-depth review was performed to identify knowledge gaps related to the characteristics, importance and driving factors behind relevant soil erosion processes affecting grasslands in the EU. This identified six processes with appreciable knowledge gaps: trampling-induced erosion, gullying, piping, landslides, snowmelt erosion, and avalanche erosion. Additionally, three processes were identified that promote runoff generation and soil erosion: compaction, hydrophobicity and wildfires.

3.2 Cultural ecosystem services (CES) in European grasslands: A systematic review of threats (Pellaton et al., 2022)

Objective

To evaluate what threats to recreation and landscape aesthetics have been described in the literature, what consequences they may have and what solutions have been suggested for their mitigation.

Methods

As part of the systematic review in the first phase the Scopus and CAB abstract databases were searched in November 2019 for grassland CES in Europe (for a detailed description of the search, selection method and extraction, see Schils et al. 2022). From the initial set, 71 papers were selected that contained at least one of the following aspects: threats to CES and permanent grasslands, threats to grasslands from CES, solutions to prevent or reverse threats. The selected papers contained 77 studies, with four papers including two or more studies from different countries, which were analysed separately. The elicited data included bibliographical information, country and region of the study, spatial scale (i.e. country, regional, landscape or plot scale), grassland type, threat type, underlying causes and consequences and suggested solutions.

The selected 77 studies were analysed qualitatively. A substantial part of the data analysis was the identification and classification of threats and their respective underlying causes and consequences Furthermore, solutions that had been suggested to prevent or mitigate negative effects were analysed. Data were summarised, classified and compared in two main categories: first, threats to CES, namely factors that negatively impact the CES of permanent grasslands, and second, threats from CES, namely negative impacts of CES on the ecosystem and its other ecosystem services.

IPBES (2018) distinguishes institutional, demographic, economic, scientific and cultural indirect drivers (i.e. underlying factors), to which the climatic driver was added as it has an indirect impact on touristic activities. Additionally, the economic driver was split into socio-economic, institutional and purely economic factors, as they were considered distinct categories. The socio-economic driver contains economic factors where the social environment is in close interaction with the economic processes. For the "Threats from CES" analysis, the demand for recreation was introduced as an additional underlying factor. For the direct threats, a large category not captured by either classification system was social attitudes. These include the disapproval of nature conservation measures, indifference towards the development of recreational services and the lack of appreciation for existing cultural values. Furthermore, both the absence and overwhelming presence of infrastructure are potential direct threats to the livelihoods of rural areas, although for different reasons. Consequences and suggested solutions were classified in broad categories to cover the variety of mentioned threats. We developed them post-hoc, as no classification existed that proposed such categories. The categories of the suggested solutions were created based on those in the underlying causes to reflect whether they were of socio-economic, institutional, infrastructural, demographic or of other nature.

During the evaluation process, the number of underlying causes, threats, consequences and solutions was counted within each of the 77 studies. Consequently, the same category may appear several times for a single study if mentioned in a different context or if related to another threat category.

Results

The various aspects of CES degradation were summarized as direct threats, consequences and suggested solutions mentioned in the extracted studies (Figure 3.5).

Based on the IPBES classification, seven types of underlying causes were mentioned in the reviewed studies of which socio-economic factors had the highest frequency (39 cases). The second-most frequent underlying cause (27 cases) was institutional aspects, including strict regulations controlling recreational activities and other related regulations (e.g. privatisation, urban development) that do not support CES.

A total of 95 direct threats provided an insight into the diversity of threats affecting the function and CES of European grasslands. Based on the IUCN-CMP direct threat classification, four major groups of direct threats could be distinguished. The largest group was land-use and land management changes with 71 cases, distinguishing four land-use change and two land management change categories. Land abandonment was mostly associated with spontaneous shrub and tree growth (27 out of 29 cases), an increase in homogeneous landscapes and a declining number of grazing animals and shepherds. The second-largest group of threats was related to social attitude (12 cases), a category with no equivalent in biodiversity science.

The reported consequences of these threats could be divided into two major groups: First, the reduced appeal of grasslands for recreation, and second, the decreased aesthetic value because of a homogenous landscape. Many threats affected recreation and aesthetics simultaneously. The loss of landscape aesthetics was the more dominant

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consequence with 81 cases, followed by reduced recreational appeal in 49 cases, restricted recreational activities in eight cases and hampered tourism development in four cases.

Socio-economic solutions were by far the most widely suggested solution type (46 cases) and covered a wide range of mitigation measures for the development of rural areas. The solutions encompassed financial support from governments (e.g. agri-environmental payment), the stimulation of employment in rural areas, farm income diversification (e.g. the promotion of local food and products), improved market access, but also conservation measures and the development of sustainable rural tourism.

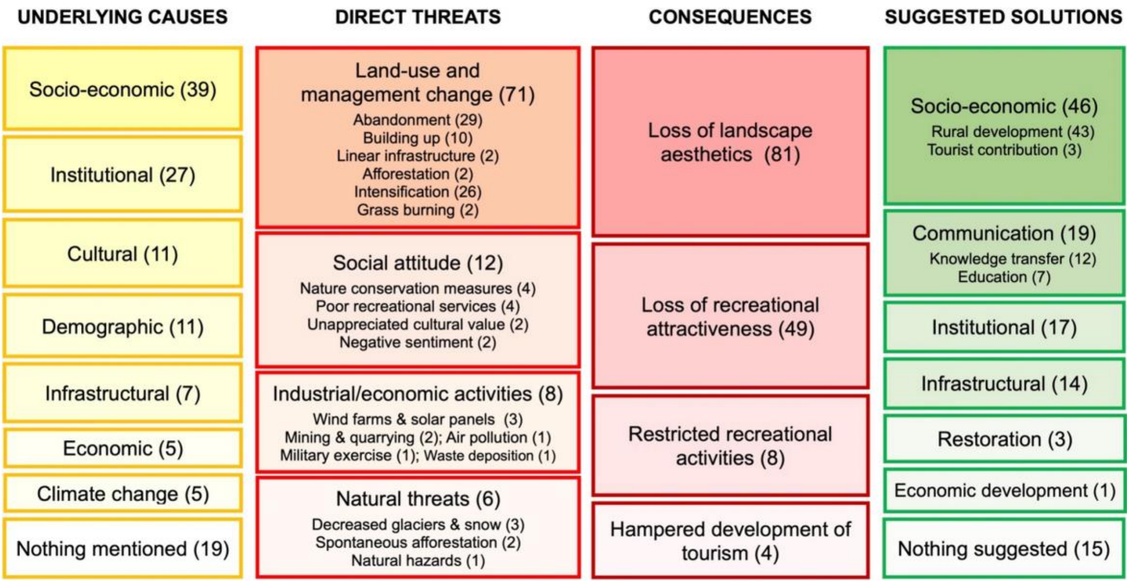

Figure 3.5: Threats to cultural ecosystem services in permanent grasslands based on the conceptual framework (Fig. 1). The number of studies involved is noted in parentheses. Note that a study can contribute to more than one box in a column if several aspects were mentioned.

An overall 37 reviewed studies (in 36 papers) reported threats caused by CES. The most frequently mentioned underlying cause for threats to permanent grassland CES was the demand for recreation (36 out of 37 selected studies). The second-most frequently mentioned underlying cause was economic factors (8 cases). All were related to tourism becoming more economically profitable than agriculture. Based on the IUCN-CMP direct threat classification (IUCN-CMP, 2019), seven main threat categories could be distinguished. The most abundant threats were disturbances and pressures by tourism (29 cases), where four subcategories were differentiated, namely (1) general disturbances on ecosystems and people (e.g. high traffic frequency, diverse activities at the same place, etc.); (2) hiking and related trampling effects; (3) skiing, with similar effects like hiking, together with the disturbance of bird species in the surrounding areas; and (4) recreational vehicles for activities such as motorised sports (e.g.

snowmobiling) or biking, where the physical impact was the main disturbance, together with noise and air pollution and impacts on wildlife. The second threat category was the development of tourist facilities (i.e. tourist infrastructure such as roads and ski lifts; 12 cases), followed by the building of accommodation for tourists (e.g. summer houses, hotels, mountain cabins), as a specific type of urban development competing with grasslands (7 cases). The most frequent consequences were land degradation processes (37 cases), such as reduced aboveground biomass, vegetation cover, species frequency and composition. Furthermore, land degradation was connected to soil erosion and compaction, soil nutrient changes and sometimes even the total disappearance of grasslands due to buildings or recreational activities. Biodiversity loss was the second-most mentioned consequence (24 cases), often co-occurring with land degradation. The regulation of tourism and economic development were suggested most often, using institutional and economic tools to avoid the overuse of the ecosystem (20 cases). Several reviewed studies suggested limiting visitors or implementing a frequentation management plan in sensitive areas or according to season to prevent negative impacts of human trampling. Alternatively, it was suggested to concentrate tourists on a few areas rather than let them spread or to monitor the negative effects with sensitive indicator species. The second-most frequently mentioned solutions were the regulation of urban development through land-use planning, conflict management and collaborations, among others (10 cases).

Conclusions

The most common threats were land-use and land management change processes, followed by social attitude, industrial developments and natural threats. However, recreational activities negatively impacted the ecosystem, biodiversity and CES, most frequently in the form of various touristic activities. Suggested solutions were most commonly socio-economic and institutional measures to enhance rural communities, as well as improving communication with relevant stakeholders. CES play a crucial role in reconnecting people with nature, and their consequent acknowledgement and incorporation into future ecosystem service frameworks and agri-environmental policy developments are key elements in supporting future sustainable grassland management.

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4 Effects of management on ES delivery from PG (expert elicitation)

4.1 Objectives

To assess the effect of management interventions on ES delivery from PG across Europe.

4.2 Methods

A two-step expert elicitation Delphi-type process (Crime and Wright, 2006) was carried out using 19 grassland academics from 11 countries representing the Atlantic (7), Alpine (3), Continental (5) and Mediterranean (4) biogeographic regions. The experts were presented with a set of questions (Table 4.1) to rate the effect of management options on a specific ES indicator. The questions were answered separately for each of 19 ES indicators for biodiversity (pollinators, threatened species, soil biodiversity, plant diversity), climate regulation (nitrous oxide, methane-soil, methane-enteric, carbon sequestration), water quality (nitrate, phosphate, pesticide), erosion and flood control (bulk density, runoff, soil loss), recreation & aesthetics (recreation, aesthetics) and animal feed (DM yield, energy content, protein content). A five-point scoring scale from very unfavourable to very favourable was used (Table 4.2), which was transformed to a five-point scale from -2 to +2. Furthermore participants were asked to indicate their confidence in their answers: viz. very high (>90%), high (65-90%), medium (35-65%), low (10-35%) or very low (<10%). For each ES indicator, the responses to the questions were used to calculate a preliminary score for each management option. The outcomes of all first-round scores were discussed with all participants. In the second round, experts had the opportunity to adjust their first-round scores. Finally, the scores for the ES indicators were weighted and aggregated to scores for each of the six main ES.

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Table 4.1: Set of questions to assess the effect of management.

Nr	Contrast	Question
1	Nitrogen	How do you rate the effect of **increasing nitrogen input** for the indicator?
2	Phosphate	How do you rate the effect of **increasing phosphate input** for the indicator?
3	Lime	How do you rate the effect of **increasing lime input** for the indicator?
4	Manure type	How do you rate the effect of **solid manures, compared to liquid manures**, for the indicator?
5	Defoliation system	How do you rate the effect of **grazing, compared to cutting**, for the indicator?
6	Grazing system	How do you rate the effect of rotational grazing, compared to continuous grazing, for the indicator?
7	Cutting system	How do you rate the effect of **increasing cutting frequency** for the indicator?
8	Sown species	How do you rate the effect of **increasing the number of sown species** for the indicator?
9	Legumes	How do you rate the effect of the **presence of legumes** for the indicator?
10	Renewal frequency	How do you rate the effect of **increasing the renovation frequency** for the indicator?
11	Renewal method	How do you rate the effect of sward renewal with ploughing, compared to direct drilling methods, for the indicator?
12	Animal type	How do you rate the effect of **grazing with cattle, compared to sheep & goats**, for the indicator?
13	Stocking rate	How do you rate the effect of **increasing the stocking rate** for the indicator?
14	Irrigation	How do you rate the effect of **increasing the irrigation amount** for the indicator?
15	Water table	How do you rate the effect of **increasing the water table** for the indicator?

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Table 4.2: Overview of indicators per ecosystem service

Service	Indicator	Unit	Increase is ...	Decrease is ...
Biodiversity	Pollinators	Diversity	Favourable	Unfavourable
	Threatened species	Diversity	Favourable	Unfavourable
	Plant diversity	Diversity	Favourable	Unfavourable
	Soil biodiversity	Diversity	Favourable	Unfavourable
Climate regulation	Nitrous oxide emission	kg/ha	Unfavourable	Favourable
	Methane-soil emission	kg/ha	Unfavourable	Favourable
	Methane-enteric emission	kg/ha	Unfavourable	Favourable
	Carbon sequestration	kg/ha	Favourable	Unfavourable
Water quality	Nitrate losses	kg/ha	Unfavourable	Favourable
	Phosphate losses	kg/ha	Unfavourable	Favourable
	Pesticide use	kg/ha	Unfavourable	Favourable
Soil	Bulk density	kg/l	Unfavourable	Favourable
	Soil loss	kg/ha	Unfavourable	Favourable
	Runoff	kg/ha	Unfavourable	Favourable
Recreation & Aesthetics	Recreation	Presence	Favourable	Unfavourable
	Aesthetics	Presence	Favourable	Unfavourable
Feed provision	Dry matter yield	kg/ha	Favourable	Unfavourable
	Energy content	MJ/kg	Favourable	Unfavourable
	Protein content	g/kg	Favourable	Unfavourable

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4.3 Results

The average number of responses per ES indicator was 11, which varied from 10 for CH_4-emission to 13 for plant richness. For the different combination of management option and ES indicators, there was considerable variation in agreement between experts. Figure 4.1 shows six examples of individual scores of the 19 experts. High, nearly unanimous, agreement in the direction of the score and the confidence was observed for the effect of nitrogen fertiliser on DM yield. On the other end of the scale, a high variation was found in effect direction and confidence for the effect of nitrogen on soil biodiversity, which may be related to the underlying different types, e.g. bacteria, fungi and earthworms. A unanimous lack of effect was scored for the effect of animal type on aesthetics. Similar effect directions but with different confidences were observed for effects of nitrogen fertiliser applications on plant richness and pollinators, or the effect of stocking rate on nitrate losses.

The average effects for all question-indicator combinations are presented in Figure 4.2. Although it is obvious that there is a lot of variation in effect sizes and directions, it was possible to identify some management options with mainly favourable scores (green) across the whole indicator spectrum. These included the use of lime, the use of solid FYM, rotational grazing, increasing the number of sown species and the presence of legumes. Increasing the stocking rate had mainly unfavourable (red) effects.

Within a specific ES, the average scores of the individual ES indicators generally showed high correlations. The only exception was climate regulation, where carbon sequestration was less correlated to the other indicators. For communication purposes, the average aggregated scores per ES (Figures 4.3 to 4.6) are presented. The management options are grouped into nutrient management, grazing and cutting management, sward management, and water management.

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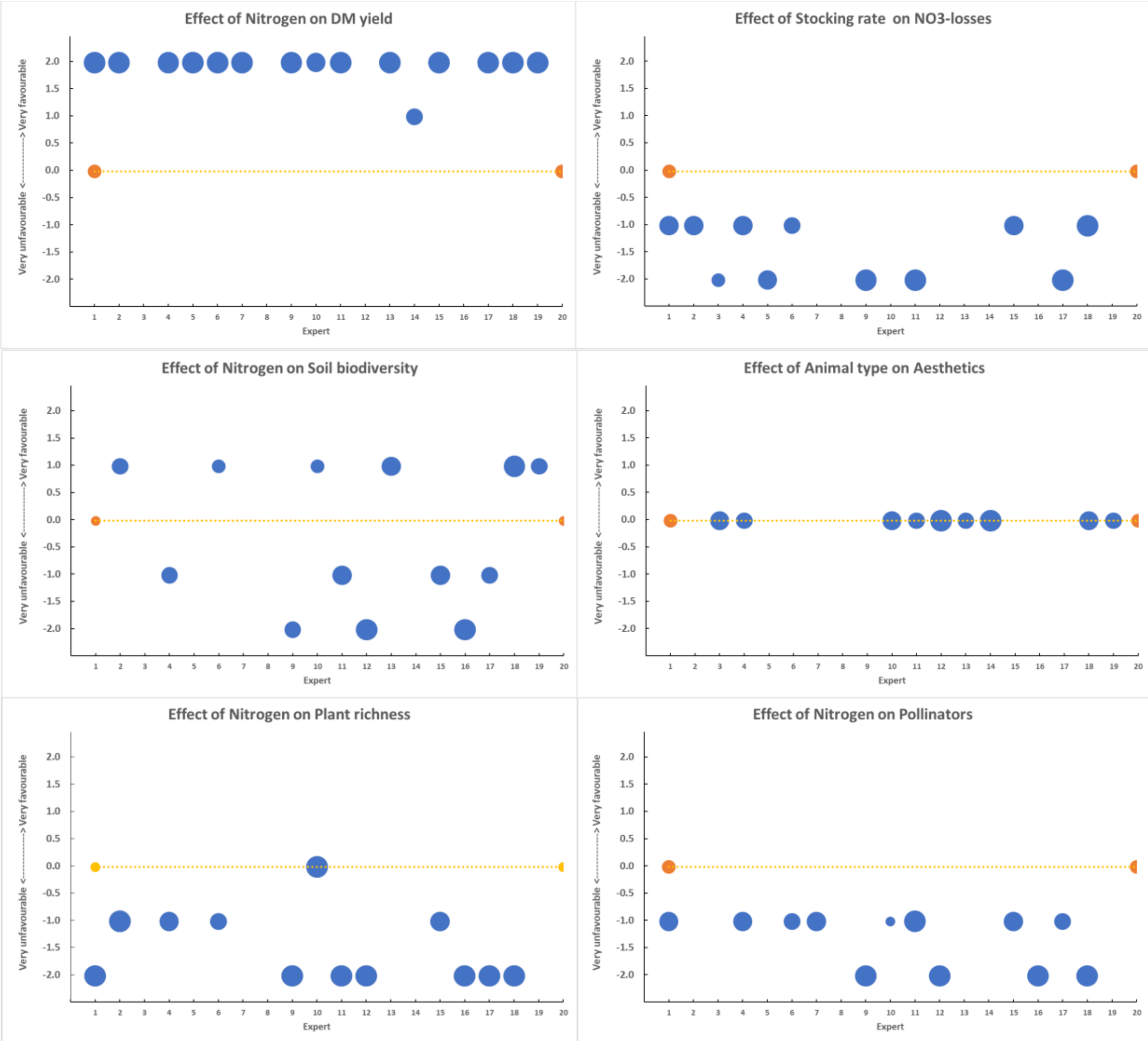

Figure 4.1: Individual scores of experts for six combinations of management intervention and ES indicator. Increasing marker size indicates increasing confidence.

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Figure 4.2: Complete overview of average scores for all combinations of management and ES indicators.

	Biodiversity				Climate				Culture		Erosion			Feed			Water		
	Plant richness	Pollinators	Soil biodiversity	Threathened species	C sequestration	CH4-enteric emission	CH4-soil emission	N2O emission	Aesthetics	Recreation	Bulk density	Run off	Soil loss	DM yield	Energy content	Protein content	NO3-losses	P losses	Pesticide use
Increasing nitrogen input	-1.5	-1.2	-0.3	-1.5	0.8	0.3	0.0	-1.8	-0.6	-0.5	0.3	-0.1	0.3	1.9	0.9	1.9	-1.6	0.3	-0.3
Increasing phosphate input	-0.6	-0.3	-0.1	-0.9	0.9	0.2	0.0	0.3	-0.5	-0.2	0.2	0.3	0.5	1.3	0.9	1.1	0.6	-1.4	-0.1
Increasing lime input	0.9	0.9	1.1	0.1	0.7	0.0	0.4	0.4	0.2	0.1	0.6	0.6	0.6	1.2	0.9	1.0	0.3	0.5	0.1
Solid manures, compared to liquid manures	0.8	0.8	0.5	0.6	0.9	-0.3	0.5	0.6	0.3	0.3	0.8	0.7	0.4	-0.2	0.1	-0.1	0.5	0.4	0.1
Grazing, compared to cutting	0.4	0.4	0.8	0.7	0.2	0.2	0.0	-0.7	1.1	0.5	0.0	0.1	0.0	-0.6	0.3	0.4	-0.9	-0.7	0.1
Rotational grazing, compared to continuous grazing	0.6	0.7	0.4	0.4	0.5	0.1	0.1	0.0	0.3	0.4	0.4	0.2	0.2	0.9	0.6	0.6	0.3	-0.1	0.0
Increasing cutting frequency	-1.2	-1.4	-0.8	-1.4	-0.6	0.8	-0.2	0.0	-0.6	0.0	-0.8	-0.3	-0.3	0.1	1.2	1.3	0.2	0.3	0.4
Increasing the number of sown species	1.2	1.3	1.2	0.6	0.6	0.4	0.0	0.4	1.1	1.0	0.8	0.3	0.4	0.7	0.6	0.8	0.5	0.3	0.8
Presence of legumes	1.1	1.3	1.3	0.4	0.8	0.3	0.1	0.8	0.9	0.7	0.7	0.5	0.3	0.9	0.9	1.8	0.3	0.4	0.8
Increasing the renovation frequency	-1.0	-0.8	-1.1	-1.4	-0.8	0.7	-0.1	-1.5	-0.7	-0.5	0.3	-0.8	-0.8	1.0	0.9	0.7	-1.0	-0.4	-0.6
Sward renewal with ploughing, compared to direct drilling methods	-0.6	-0.6	-0.8	-1.2	-1.3	0.2	-0.1	-1.4	-1.0	-0.8	0.8	0.2	-0.7	0.2	0.2	0.3	-1.1	-0.1	0.0
Grazing with cattle, compared to sheep & goats	0.3	0.6	0.1	0.1	0.1	0.0	-0.1	-0.6	0.0	0.0	-0.7	-0.5	-0.5	0.0	0.2	-0.2	-0.4	-0.1	-0.1
Increasing the stocking rate	-0.9	-0.9	-0.5	-1.0	-0.3	-0.7	-0.4	-1.5	-0.7	-0.8	-0.8	-0.6	-0.7	0.2	0.1	0.2	-1.5	-0.7	-0.1
Increasing the irrigation amount	0.3	0.2	0.3	0.0	1.0	0.1	-0.6	-0.4	0.5	0.3	-0.3	-0.2	-0.1	1.6	1.4	0.6	-0.1	0.4	0.1
Increasing the water table	0.5	0.5	0.3	0.7	1.1	0.0	-0.8	-0.1	0.7	0.5	-0.5	-0.3	-0.3	0.5	0.7	0.0	0.0	0.1	0.3

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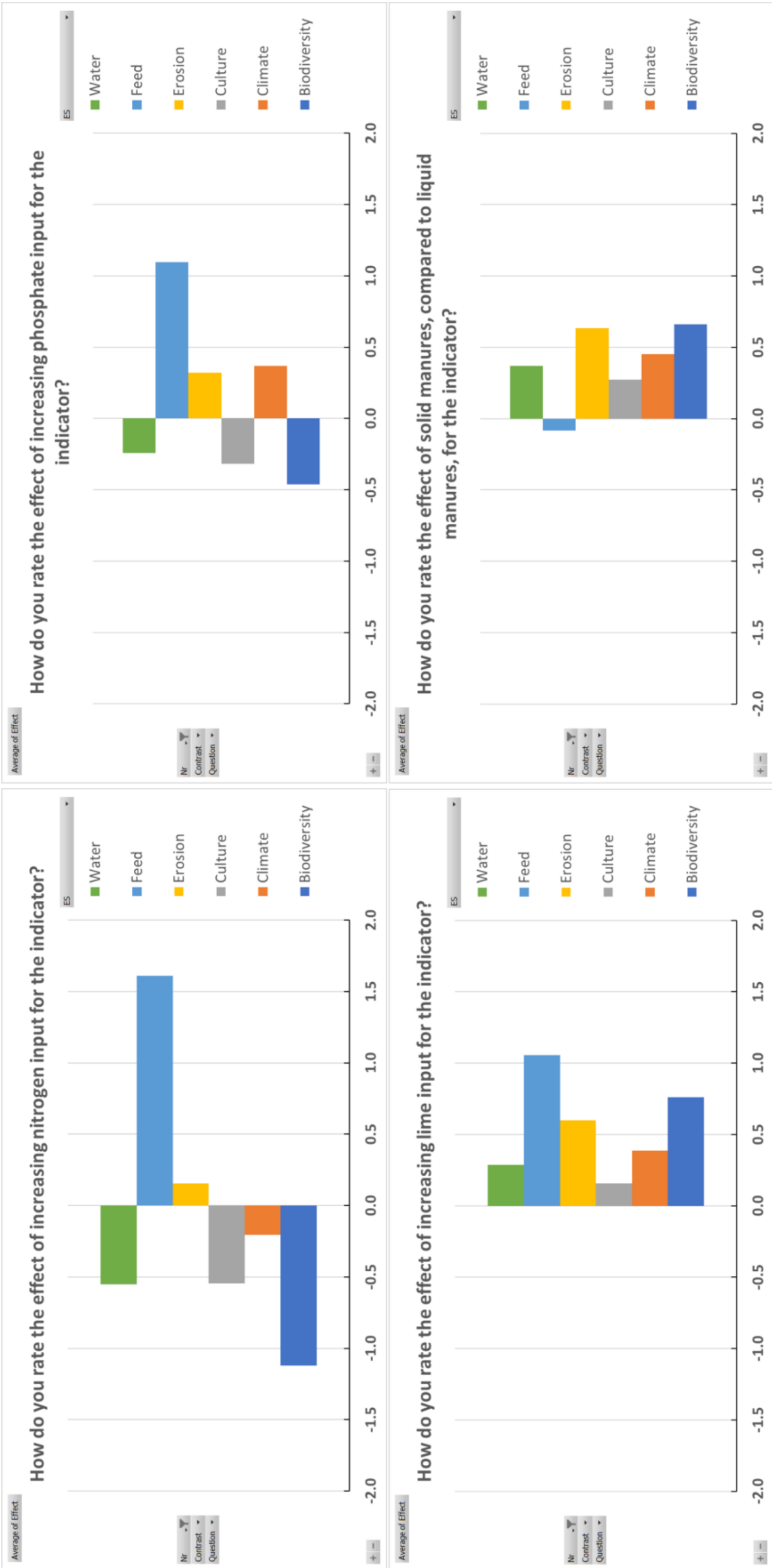
Figure 4.3: Effect of nutrient management on ES delivery.



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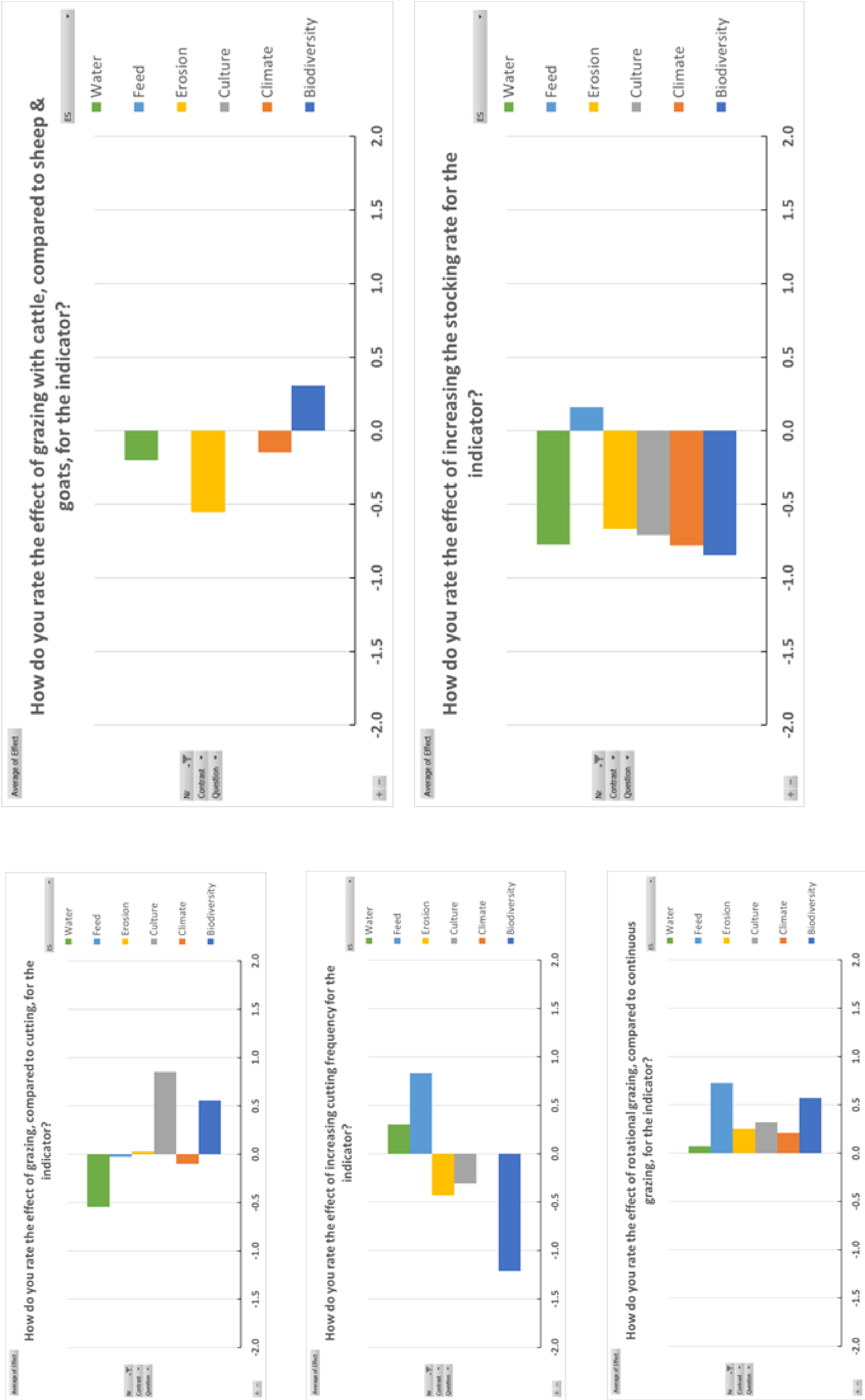
SUPER-G
SUSTAINABLE PERMANENT GRASSLAND

Figure 4.4: Effect of grazing and cutting management on ES delivery.



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SUPER-G
SUSTAINABLE PERMANENT GRASSLAND

Figure 4.5: Effect of sward management on ES delivery.

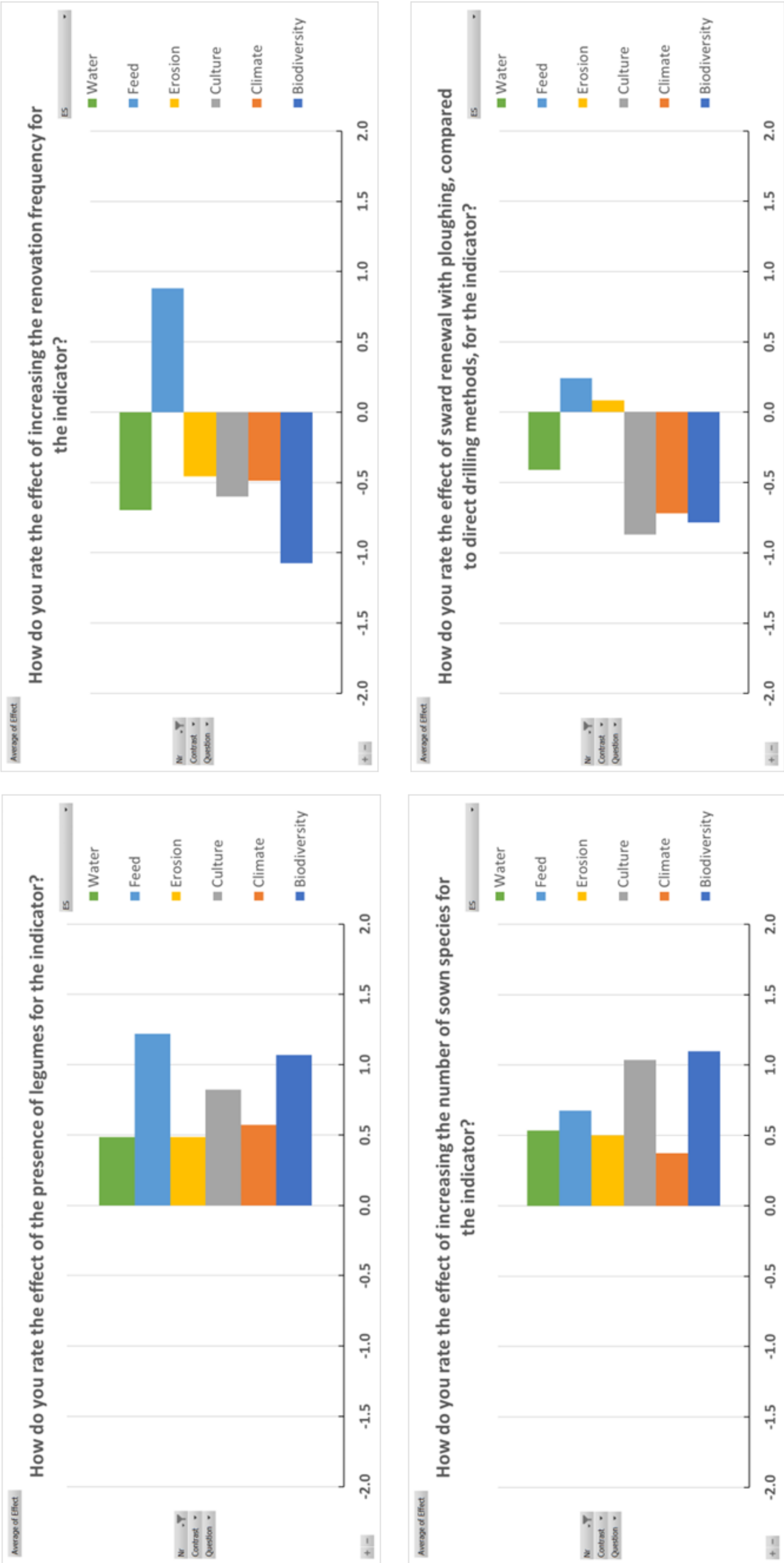

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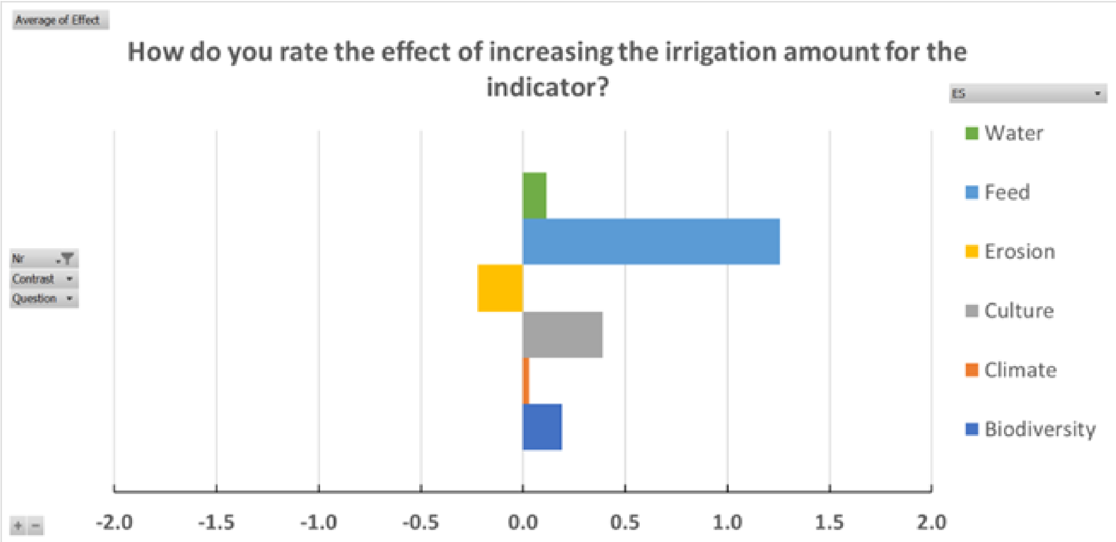
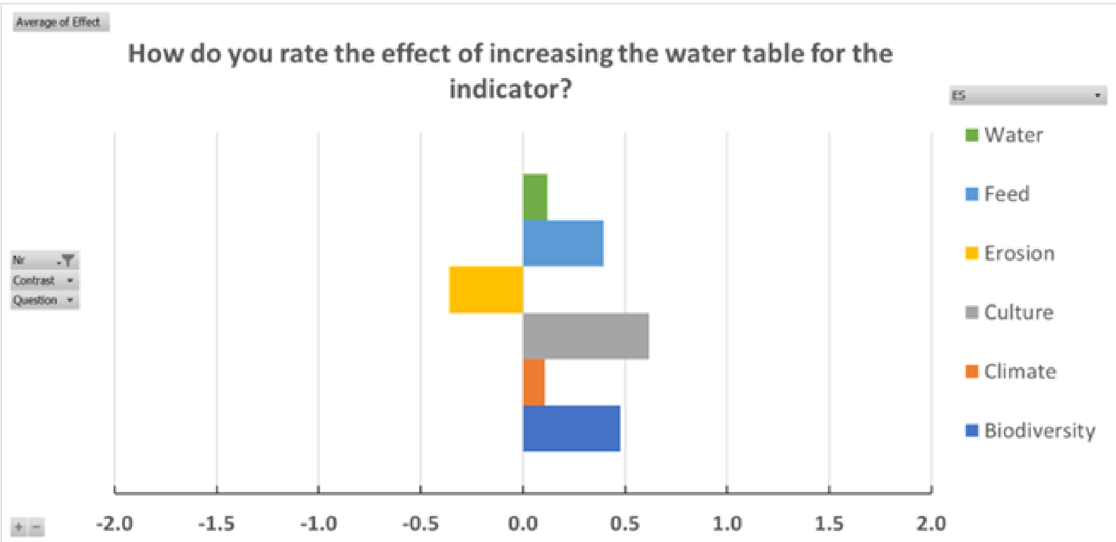
Figure 4.6: Effect of water management on ES delivery.





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4.4 Conclusions

An expert elicitation was used to assess the effect of management interventions on the provision of ES by PG. The results are summarized in Figure 4.7 where the provision of non-feed ecosystem services is plotted against the provision of animal feed. This figure clearly identifies management options where there is a trade-off between feed provision and non-feed ecosystem services (e.g. nitrogen fertiliser application, renewal frequency) and management options that support multiple ecosystem services (e.g. presence of legumes, lime and number of sown species).

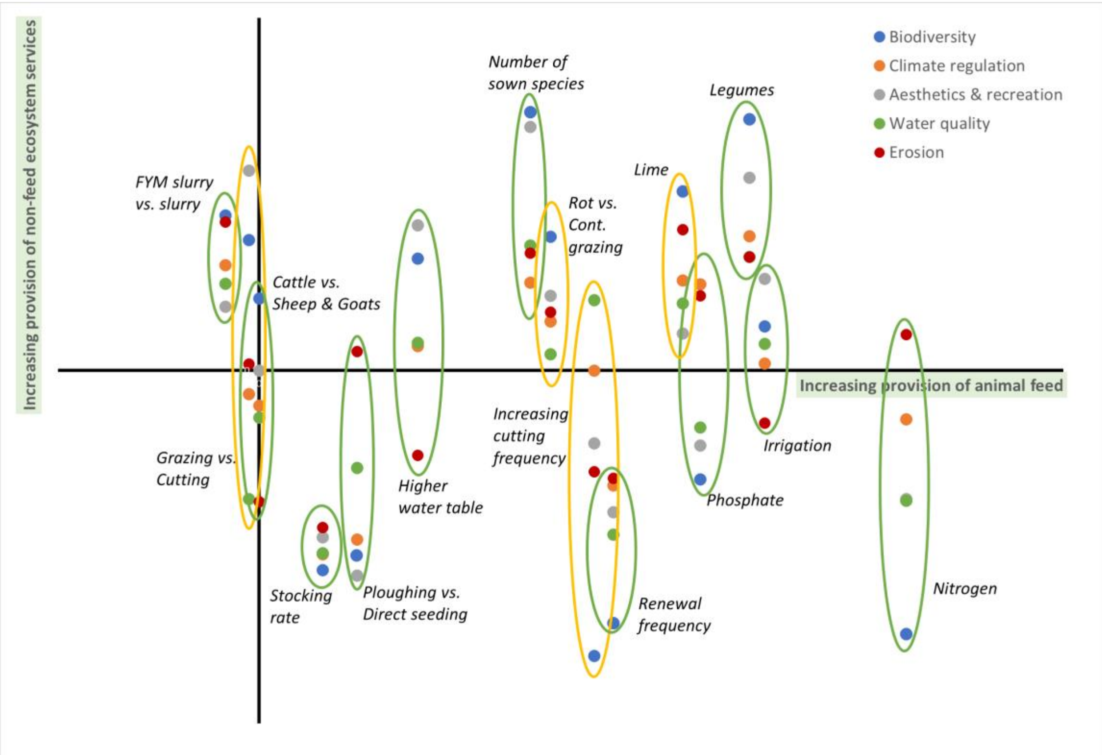

Figure 4.7: Overall summary of management effects. The horizontal axis shows the effect on the provision of feed, while the provision of the non-feed services is plotted against the vertical axis.

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5 Effects of PG type on ES delivery (expert elicitation)

The level of ES provision varies significantly between different PG types across Europe, which can be an obstacle for effective knowledge transfer and policy making. Identifying PG types across Europe that are similar in terms of ES delivery would improve communication between stakeholders and contribute to effective policy making. Previously, a PG typology was developed that consists of 18 PG types based on its management, i.e. defoliation, fertilization and renewal, and other factors such as climatic restrictions or the presence of woody plants (Tonn et al., 2020). It is applicable at field and regional scales and is cross-referenced with existing classification schemes such as the EUNIS and Natura 2000 habitats classes. The typology forms the basis of a PG Atlas which comprises maps, portraits and illustrative cases for each of the 18 PG types. The PG portraits present the explanation of a PG type and include a dedicated section on its ES delivery.

5.1 Objectives

To assess ES delivery from PG types across Europe.

5.2 Methods

A two-step expert elicitation Delphi-type process was carried out (Crime and Wright, 2006) with 25 grassland academics from 13 countries representing the Atlantic (9), Alpine (3), Boreal (2), Continental (7) and Mediterranean (4) biogeographic regions. The experts were presented with a set of questions (Table 5.1) to rate the effect of eight relevant factors, which distinguish PG-types from one another, on a specific ES indicator. The eight distinguishing factors were: presence of management, presence of succession, presence of woody plants, type of woody plants, renewal frequency, management intensity, presence of climatic limitations and defoliation type. The questions were answered separately for each of 19 ES indicators for biodiversity (pollinators, threatened species, soil biodiversity, plant diversity), climate regulation (nitrous oxide, methane-soil, methane-enteric, carbon sequestration), water quality (nitrate, phosphate, pesticide), erosion and flood control (bulk density, runoff, soil loss), recreation & aesthetics (recreation, aesthetics) and animal feed (DM yield, energy content, protein content) (see also Table 4.2). A five-point scoring scale from very unfavourable to very favourable was used, which was transformed to a five-point scale from -2 to +2. For each ES indicator, the responses to the eight questions were used to calculate a preliminary score for each PG-type on a scale from 1 to 10. It is important to note the potential for interactions between the effects of the distinguishing factors, which may make adjustments of scores necessary. Therefore, the experts were allowed to check the preliminary score and revise it into a final score. The outcomes of all first-round scores were discussed with all participants. In the second round, experts had the opportunity to adjust their first-round scores. Finally, the scores for the ES indicators were weighted and aggregated to scores for each of the six main ES.

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Table 5.1: Set of questions to assess the preliminary score.

Contrast	Question
Management	How do you rate the presence of management for the indicator?
Succession	Within unmanaged grasslands, how do you rate grassland succession, compared to Non-grassland succession?
Woody plants	How do you rate the presence of woody plants for the indicator?
Woody plant type	Within woody grasslands, how do you rate the presence of trees for the indicator, compared to shrubs
Renewal frequency	Within managed grasslands, how do you rate frequent renewal for the indicator, compared to infrequent renewal?
Intensity	Within managed grasslands, how do you rate increasing intensity for the indicator?
Pot. productivity	Within managed grasslands, how do you rate increasing potential productivity for the indicator?
Defoliation	Within managed grasslands, how do you rate grazing for the indicator, compared to cutting?

5.3 Results

The average number of responses per ES indicator was 15, but with considerable variation. In general, the indicators on biodiversity and animal feed had higher returns than the indicators on erosion and flood control, climate regulation and water quality. The most scored indicator was plant diversity, with 20 out of a maximum of 25 experts returning scores. At the other end of the scale methane emission from soil returned only 9 scores.

For the different ES indicators, there was also considerable variation in agreement between experts. In general, agreement was relatively high for the indicators on animal feed and water quality, whereas agreement was relatively low for the indicators on climate regulation. The highest agreement was for DM yield and the lowest agreement was for methane emissions from soil and carbon sequestration.

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Figure 5.1: Individual scores of experts for carbon sequestration and dry matter yield.

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Within a specific ES, the average scores of the individual ES indicators generally showed high correlations. The only exception was climate regulation, where carbon sequestration was less correlated to the other indicators. Consequently, the average aggregated scores per ES are presented.

The outcomes of the expert elicitation identified five comparable groups of PG types (Figure 5.2). Within each of the five groups, the ES delivery showed a consistent pattern. The frequently renewed and high-intensity PG scored very high on the provision of animal feed at the cost of other ES (Figure 1a). Within this group, frequent renewal amplified the contrast between animal feed and other ES, while the defoliation type (cutting vs. grazing) had mixed effects. For the medium- (Figure 1b) and low-intensity PG (Figure 1c), the pattern was more balanced, with relatively lower scores for animal feed, and higher scores for other ES. Within the medium and low intensity groups, the effect of climate limitations was mixed and rather small. Effects of defoliation type were also less pronounced compared to the frequently renewed and high intensity group. The group of woody PG types (Figure 1d) had an almost similar pattern as the low intensity PG, but are presented separately for clarity. Within this group, a higher intensity amplified the contrast between provision of animal feed and other ES. The difference between PG with trees or shrubs was quite limited, except for the higher value for aesthetics & recreation for PG with trees compared to PG with shrubs. The unmanaged PG types (Figure 1e) show the highest contrast, with almost no provision of animal feed and near-maximal scores for erosion & flood control, water quality and climate regulation. The contribution to biodiversity and aesthetics & recreation was similar or even lower than the low intensity PG types or woody PG types.

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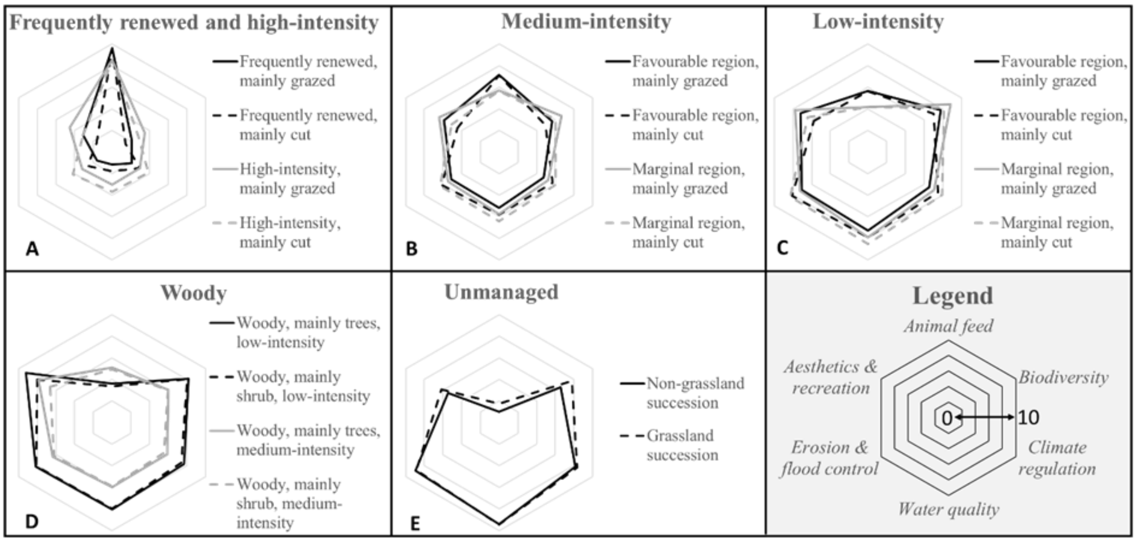

Figure 5.2: Average scores for the provision of ES for five comparable groups of PG types. The higher the score on a scale of 1 to 10, the higher the contribution to animal feed, biodiversity, climate regulation, water quality, erosion & flood control or aesthetics & recreation. Within each group, two to four different PG types are presented with varying contrasts in renewal frequency, intensity, defoliation type, woody type and presence of succession.

The results of these expert elicitations are used as an estimate of ES-delivery in the PG portraits (Figure 5.3). All portraits can be viewed at https://www.super-g.eu/pg-portraits/.

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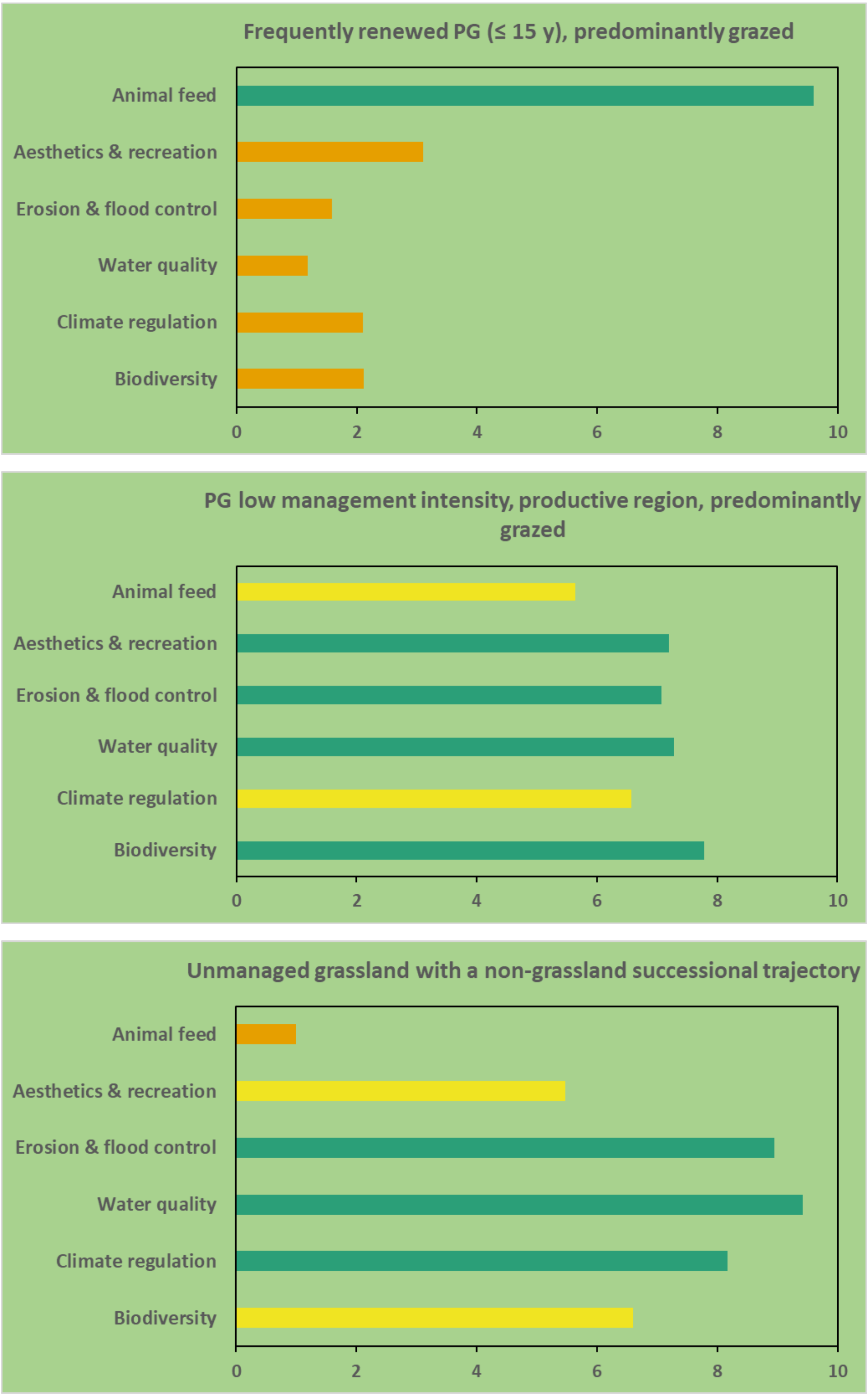

Figure 5.3: Examples of the ES-delivery of three contrasting PG types.

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5.4 Conclusions

The expert elicitation, identified clear contrasts in ES delivery by PG-type, mainly relating to livestock intensity. The PG types in the PG Atlas were able to discriminate between different patterns of ES delivery which is an important prerequisite for communication to farmers, policy makers and scientists.

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