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D4.2 Trade-off/synthesis analyses including spatial co-occurrence of ESS / biodiversity socio-economic

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Trade-off/synthesis analyses including spatial co-occurrence of ESS / biodiversity socio-economic

Deliverable D4.2

31st October 2022

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BESTMAP
Behavioural, Ecological and Socio-economic Tools for Modelling Agricultural Policy

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Preface

This document describes the interrelationships between the ecosystem services, biodiversity and socio-economic outputs modelled in the Work Package 3 (WP3), to identify bundles of co-occurring services. Furthermore, this document presents an analysis of how different types of Agri-Environmental Measures (AEM) drive trade-offs and synergies among different services. The analysis spans two AEM adoption scenarios, one without AEM and one reflecting the current AEM adoption levels, for all five Case Studies (CS) of BESTMAP.

Summary

This document presents the analysis of trade-offs and synergies between ecosystem services (ESS), biodiversity and socio-economic outputs for each case study (CS) in the H2020 project BESTMAP. The deliverable is largely based on the models and model results generated in the Work Package 3 (WP3) of BESTMAP, which are described in detail in the deliverable D3.3 - “Ecosystem Service, biodiversity and socio-economic models for each case study”. Assessing the relationships between ESS, biodiversity and socio-economic outputs is a necessary step to identify ecosystem service bundles (e.g. co-occurring services), and how they may change under different land-management scenarios. Understanding how Agri-Environmental Measures (AEM) drive trade-offs and synergies across ESS, biodiversity and socio-economic outputs is important to optimise the design of future policies. Here, we used the farm as a unit of analysis, and we calculated the provision of ESS, biodiversity and socio-economic output for each farm in the five CS. Each farm was assigned a Farming System Archetype (FSA), based on the farm specialisation and its economic size, as described in the deliverable D3.5 - “Farming System Archetypes for each CS”. Here we present the results of the trade-off analysis and the identified ecosystem service bundles. We discuss CS-specific examples and compare our overall results across CSs. Moreover, we discuss the challenges encountered during this task, and how they affected the timeline towards the task’s completion. Finally, we describe how the results of the bundles and trade-off analysis will contribute to other future activities of BESTMAP, namely the translation of ESS bundles into policy indicators (task 4.3), which will ultimately feed into the policy dashboard (task 6.4).

1. Introduction

Improved provision of ecosystem services (ESS) and conservation of biodiversity in agricultural landscapes are among the main objectives of the European Union’s Common Agricultural Policy (CAP; European Union, 2016). Agri-environmental schemes, ecological focus areas and organic farming - here collectively called Agri-Environmental Measures (AEM) - are the main instruments of the CAP that are developed to address such goals by fostering more sustainable farming practices (Scown et al., 2020). However, designing policy instruments that effectively preserve or enhance several ESS, biodiversity and socio-economic outputs is challenging due to the complex relationships between them and their different and potentially diverging responses to management changes (Dade et al., 2019). Indeed, positive (synergies) or negative (trade-off) relationships between different services can depend on common drivers affecting one or multiple services at the same time (e.g. land use change) or on direct interactions among services (e.g. reliance on the same ecosystem processes; Cord et al., 2017). Synergies between multiple ESS are defined “as the positive response of multiple ES to a change in the driver” (Bennett et al., 2009), and are thus win-win situations; trade-offs are antagonistic situations in which a higher provision of one service involves losses of another one (Cord et al., 2017).

ESS bundles are defined as “sets of services that appear repeatedly together” (Raudsepp-Hearne et al., 2010), and can include both synergies and trade-offs (Spake et al. 2017). The concept of ESS bundles is often used in spatially-explicit frameworks for identifying and mapping ESS associations (Dittrich et al., 2017; Spake et al., 2017). A better understanding of ESS associations is crucial to inform management decisions, so that sustainable levels of all services are maintained across the landscape. Recent research suggested that more effort should be put into identifying drivers of change (such as changes in land-use management), as well as the underlying mechanisms linking such drivers to ESS (Dade et al., 2019). Indeed, suggested policy solutions will likely be more effective if based on an improved understanding of the response of ESS to a given driver of change.

In this document, we analysed which positive and negative relationships exist among ESS, biodiversity and socio-economic outputs measured at the farm-level in the five CS regions of BESTMAP. The analysis was repeated for two scenarios: i. without AEM, and ii. under the current AEM adoption scenario (based on data from the years 2016-2019). We used Principal Component Analysis (PCA) to identify bundles of co-occurring services and to describe their interrelationships. Furthermore, we investigated how these trade-offs and synergies are influenced by increasing proportions of AEM on the total farm area. We analysed and discussed these results for the most prominent farm specialisations within each CS, and we compared the results across CS.

2. Data and methods

2.1. ESS, biodiversity and socio-economic models

The ESS, biodiversity and socio-economic outputs considered in this analysis of trade-offs and synergies are the results of the biophysical modelling task described in deliverable D3.3.

The following model outputs were used as input data for the analysis:

- biodiversity: the biodiversity indicator consists of a relative species richness index which ranges from 0 to 1, and is based on stacked habitat suitability maps of several farmland bird species. A value of 0 indicates unsuitable habitat for all modelled species, whereas a value of 1 indicates that all modelled species are occurring in the given area. The mean value per farm was extracted to run the analysis. In the Serbian CS Bačka, a slightly different indicator was used, consisting of an averaged habitat suitability score across four modelled species, i.e. three farmland bird species and a ground squirrel species;
- nutrient export: the surface nutrient export in kg/ha/year was calculated for each farm from the output of the Nutrient Delivery Ratio model, separately for nitrogen (N) and phosphorus (P);
- standard output: the mean standard output in €/ha was calculated for each farm as one of the outputs of the food and fodder model. For certain crops, the standard output coefficient was not available, hence the farm standard output could not be calculated;
- soil organic carbon (SOC): soil organic carbon in t/ha is the output of the carbon sequestration model. The mean value per farm was used. For one of the CS (i.e. UK), SOC results were not included in the analysis due recent corrections to the model workflow, which still need to be operationalised;
- change in farm viable income (CFVI): the estimated percent change in Farm Net Value Added (FNVA), deriving from the adoption of agri-environmental schemes, for a given year per farm. CFVI is the output of the farm income model. CFVI could only be modelled for those farms which applied AEM in the current AEM adoption scenario; for all other farms, the median across all modelled farms was used. For CS in which the percentage of modelled farms was very low (16% in DE and 6% in ES), the CFVI was

excluded from the bundle analysis. CFVI could not be modelled in RS as Farm Accountancy Data Network (FADN) data are not available for Serbia.

The ESS, biodiversity and socio-economic outputs were modelled for two different policy scenarios, one in which no AEM are applied, and one based on the current AEM adoption according to the Integrated Administration and Control System (IACS) data from the years 2016/2019. BESTMAP focuses on a set of seven AEM groupings: buffer areas/strips, cover crops, land-use conversion to permanent grassland, land-use conversion to forest, maintaining permanent grassland, organic farming and fallow land. Since AEM policies vary across countries, not all AEM groups exist in every CSs, and their uptake and spatial coverage varies largely across CSs. Hence, not all AEM were modelled in all CSs, and this document will present examples based on each CS's specificities.

2.2. Farm classification

The provision of ESS, biodiversity and socio-economic outputs is likely to change considerably from one farm to another, depending on the farm size, farm specialisation and land use (e.g. percent of cropland, grassland, permanent cultures, etc.) and its land management (e.g. applied AEM, conventional or organic farming, etc.). To account for these differences, BESTMAP developed Farming System Archetypes (FSAs), a generalised typology of farming systems that are assumed to have similar response to policy change.

The FSAs are based on two dimensions, the farm specialisation and its economic size. The farm specialisation can be one of 5 possible categories:

- P1 (general cropping),
- P2 (horticulture),
- P3 (permanent crops),
- P4 (grazing livestock and forage), and
- mixed (for farms with no dominance, i.e. at least 66.6% of the farm area of one of the above mentioned types).

The farm economic size is instead categorised in four classes: <2000 €, small, medium and large. The FSAs consist of all possible combinations of the two dimensions, leading to 20 different FSAs. Details on the FSA development and distribution in the BESTMAP CS are described in the deliverable D3.5 - "Farming System Archetypes for each CS". In this document, we used the classification of farms into different farm specialisations and FSAs to select relevant examples of commonly occurring farm types and widely adopted AEM, which can act as drivers of trade-offs and synergies between ESS, biodiversity and socio-economic outputs.

2.3. Statistical analysis

All performed analyses employed the farm as a unit of analysis, as this is also the unit at which land-use management decisions are taken. Thus, the provision of ESS, biodiversity and socio-economic outputs was calculated at the farm level. To identify bundles of ecosystem services we used Principal Component Analysis (PCA). PCA can quantify the main multivariate relationships between ESS, biodiversity and socio-economic outputs to assess whether they co-occur (synergies) in spatial bundles, or if instead the provision of one service is correlated with the reduction of another one (trade-off) (Depellegrin et al., 2016; Marsboom et al., 2018; Spake et al., 2017). The farm-level values of ESS, biodiversity, and socio-economic outputs were scaled (z-normalisation) prior to the analysis, and only the PCA dimensions with an eigenvalue > 1 were retained to characterise the relationships among variables and whether bundles of services could be identified (Turner et al., 2014). The correlation coefficients between ESS, biodiversity and socio-economic outputs and the retained PCA dimensions were used to explain the nature of the identified bundles, if any. To assess whether ESS associations change under different management scenarios, the PCA was performed separately for the two different AEM adoption scenarios, i.e. the no AEM scenario, and scenario reflecting the current AEM adoption levels (based on 2016-2019 data).

To investigate how AEM adoption drives trade-offs and synergies among services, the scaled ESS, biodiversity and socio-economic output values, extracted for each farm, were plotted against the proportion of farm area covered by AEM, separately for each AEM group. The relationships between ESS, biodiversity and socio-economic output provision and the AEM proportion were modelled through smoothing functions. This step allowed us to visualise convergences or divergences in the responses of these services to a given AEM driver. All analyses were performed in R version 4.1.3 (R Core Team, 2022), using the packages *dplyr* (Wickham et al., 2022), *tidyr* (Wickham & Girlich, 2022) and *sf* (Pebesma, 2018) for data wrangling, *factoextra* (Kassambra & Mundt, 2020) and *FactoMineR* (Le, Josse & Husson, 2008) for PCA analysis and biplots, and *ggplot2* (Wickham, 2016), *gridExtra* (Auguie, 2017) and *tmap* (Tennekes, 2018) for the graphics.

3. ESS, biodiversity, socio-economic bundles and analysis of trade-offs and synergies

3.1. Mulde, DE

Small P4 farms are the most abundant FSA type in the Mulde CS, followed by P1 large, P4 <2000EUR, and mixed large. However, in terms of area, large P1 and large mixed farms are the FSA types that cover the vast majority of the CS area. P4 farms instead are more common in the southern, mountainous part of the region. Among the most popular AEM in this CS are the maintaining permanent grassland schemes, buffer areas/strips, and cover crops.

3.1.1. Bundles

The PCA identified two dimensions which together explained 61.7% of the variance in the data (Figure 1). The first dimension represents an ES bundle consisting of a synergy between N and P export in surface water, and a mild positive correlation with biodiversity. The second dimension is highly correlated to the mean standard output per ha, and weakly negatively related to soil organic carbon. P2 and P3 farms form distinguishable clusters in this two-dimensional space, whereas the distributions of mixed, P1 and P4 farms are overlapping. ESS associations and bundles did not significantly change between the two AEM adoption scenarios; the results of the PCA in the scenario without AEM are provided in the Appendix (Figure A1).

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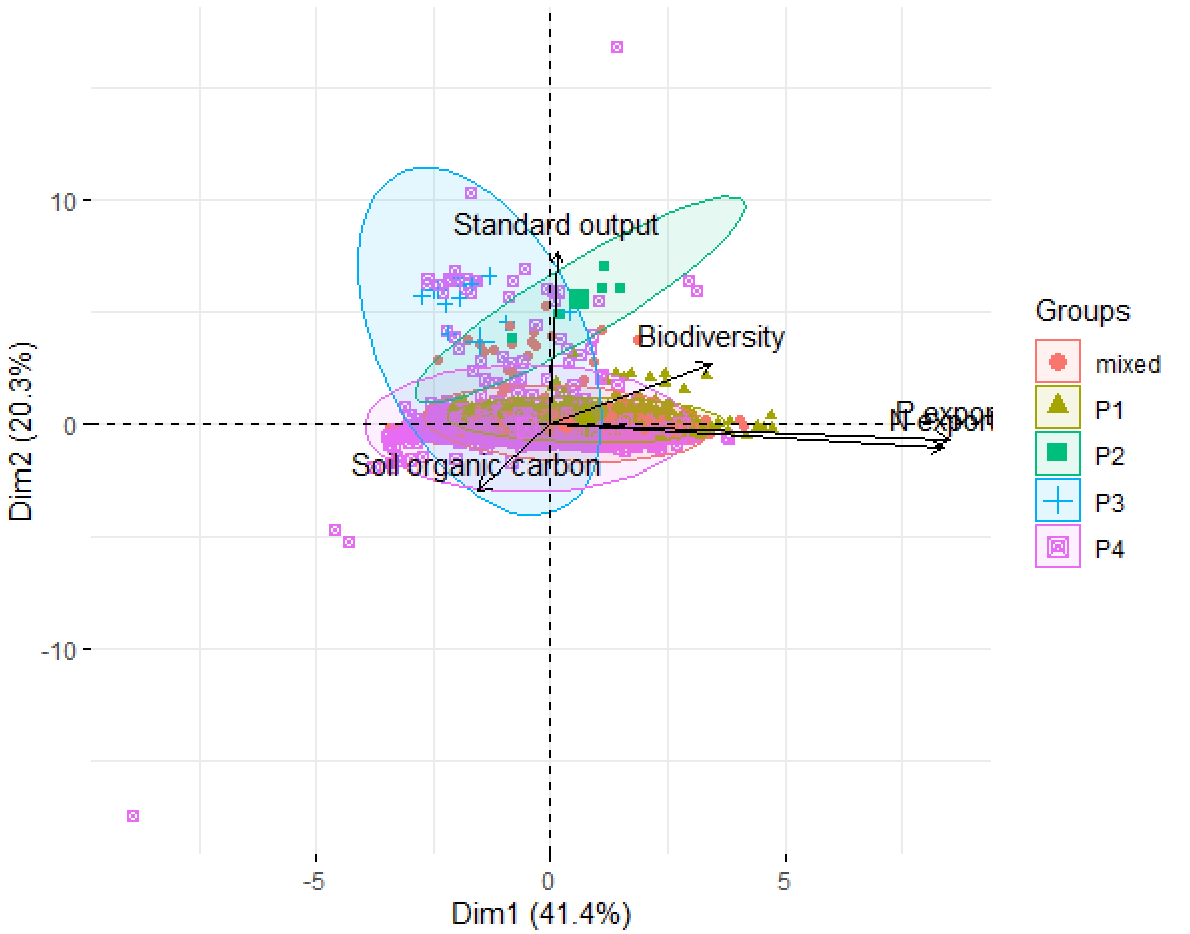

Figure 1: PCA biplot of ESS and biodiversity in the Mulde, DE. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

Plotting the two PCA dimensions in space provides a visual representation of the identified bundles (Figure 2); high values for dimension 1 relate to farms with high N and P export in the water, whereas dimension 2 identifies farms with high mean standard output. The spatial mapping of ESS bundles, shown here as an example, will be further developed in deliverable D4.3 - “Translating bundles into policy indicators”.

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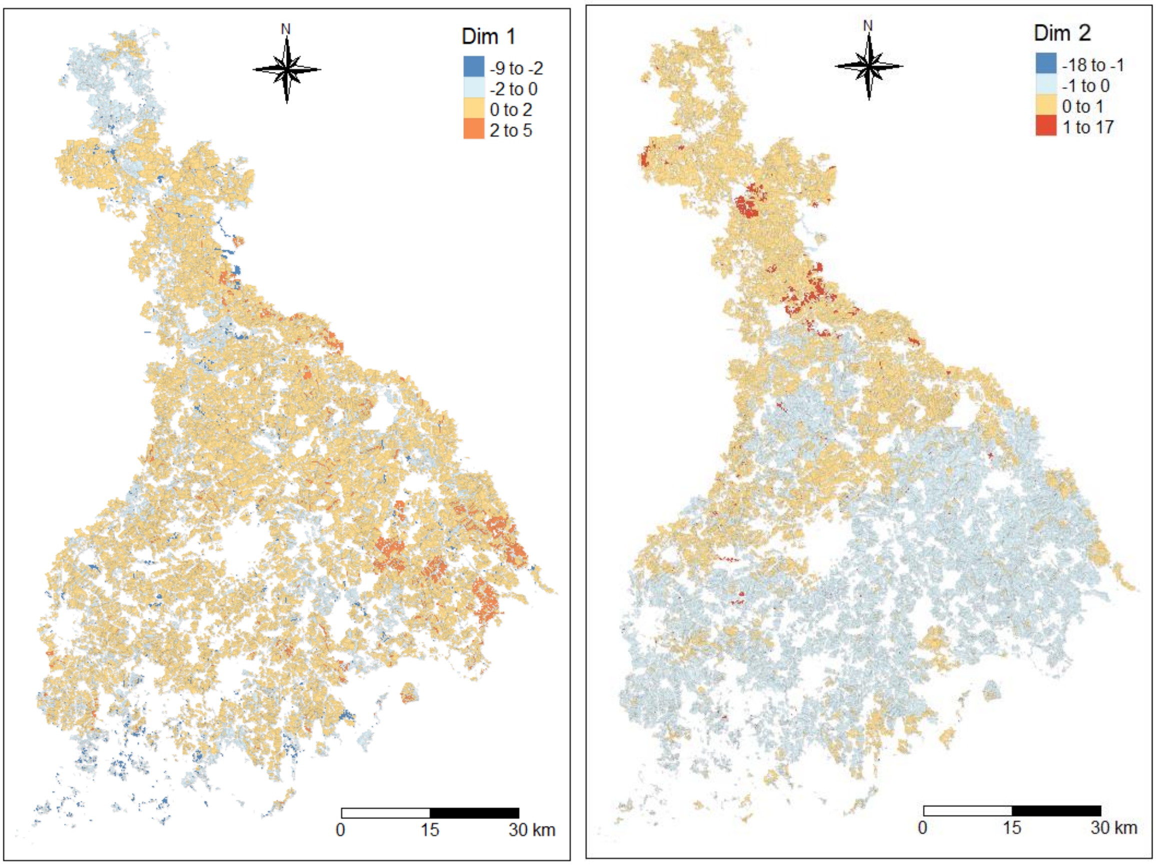

Figure 2: Maps of the two PCA dimensions, plotted per farm in the Mulde CS. Dimension 1 (Dim 1) represents a bundle of N and P export in surface waters, whereas dimension 2 (dim 2) is highly correlated with standard output.

3.1.2. AEM as drivers of trade-offs and synergies

When plotting the changes in provision of ESS and biodiversity along an increasing proportion of farm area under maintaining permanent grassland measures, we found a stark decrease in nutrient export in surface water, and a moderate increase in soil organic carbon (SOC) in both mixed and P4 farms (Figure 3). Biodiversity and standard output showed more complex responses, with hump-shaped curves in the P4 farms. This is not surprising as the biodiversity indicator, based on stacked habitat suitability maps of several farmland bird species, can have low values in extensively-managed biodiversity-friendly farms if they are embedded in unsuitable habitat for the modelled species. The increase in standard output for P4 farms with high proportions of extensive grassland is unexpected, but is related to a few small farms with orchard meadows, categorised as grassland farms but for which the standard output includes also the incomes from fruit production.

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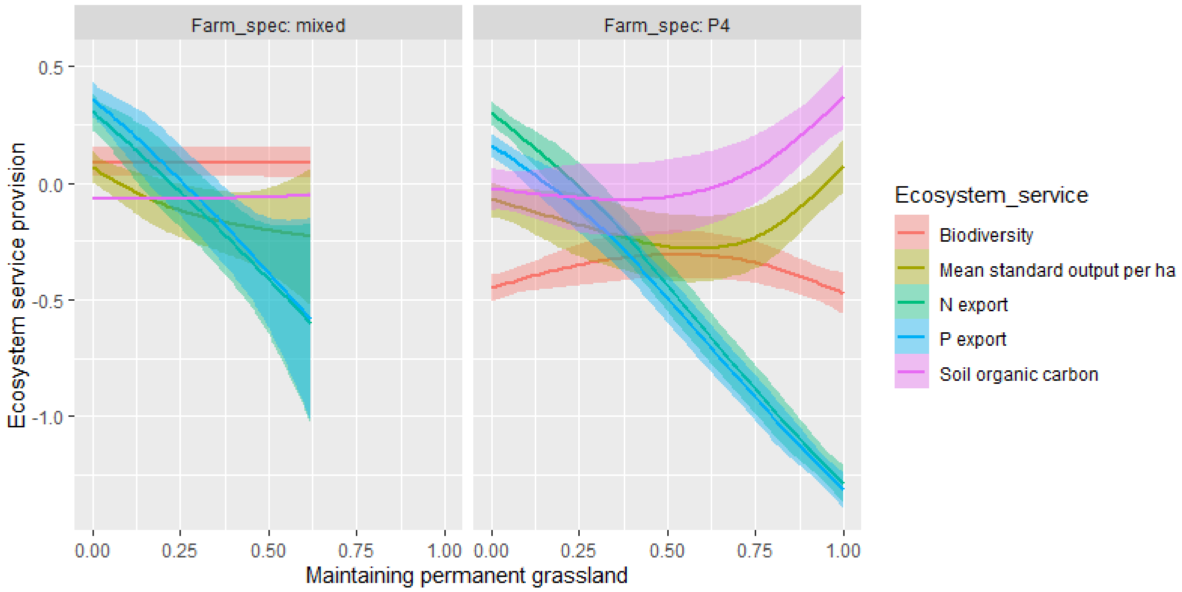

Figure 3: ESS and biodiversity provision relative to the proportion of farm area under maintaining permanent grassland practices. The two plots show trade-offs and synergies for mixed (left) and P4 (right) farms, respectively.

Buffer areas and vegetation strips, popular among mixed and P1 farms in the Mulde, improved water quality by reducing nutrient export in water, but they also reduced the standard output by subtracting field area from production (Figure 4).

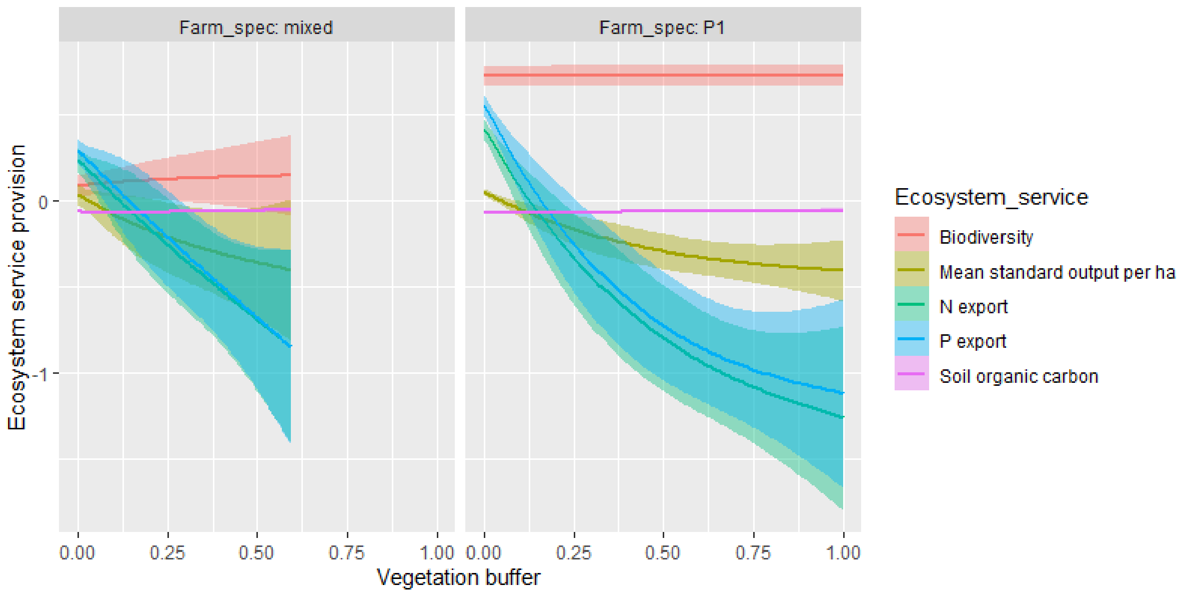

Figure 4: ESS and biodiversity provision relative to the proportion of farm area with a vegetation buffer. The two plots show trade-offs and synergies for mixed (left) and P1 (right) farms, respectively.

3.2. South Moravia, CZ

Large P1 farms are the most abundant in South Moravia, and they also cover the largest share of the CS area. Nonetheless, the CS also comprises many P3 farms, while P4 farms are abundant in the hilly regions in the south-east of the CS. The share of organic and integrated farms has been rising in recent years, and this AEM is popular especially among the P3 and

P4 farms. Among the five CS of BESTMAP, South Moravia provides a good example of the AEM land use conversion from arable to grassland, which is relatively popular in this CS. For some of the field parcels in this CS, no crop or yield information was available, so that the total standard output per farm could not be calculated. Farms affected by this problem were filtered out of the dataset, leaving 662 out of 1103 farms.

3.2.1. Bundles

Three PCA dimensions had eigenvalue > 1, and together explained 76.6% of the variance in the data. Dimension 1 represents a synergistic association of standard output and N and P exports (Figure 5). The second dimension was highly related to CFVI and, more mildly, to biodiversity, which was instead highly correlated to the third PCA dimension. P1 and P4 farms can be distinguished in both biplots, with P1 farms generally showing higher standard output and nutrient export levels, and P4 farms having higher soil organic carbon content. The PCA for the scenario without AEM did not include CFVI, as this output can only be estimated for farms applying AEM. Here, only the first two PCA dimensions were retained (all other ones had eigenvalue <1), and they identified similar interrelationships between ESS, though standard output was less related to nutrient export than in the current AEM scenario (Figure A2).

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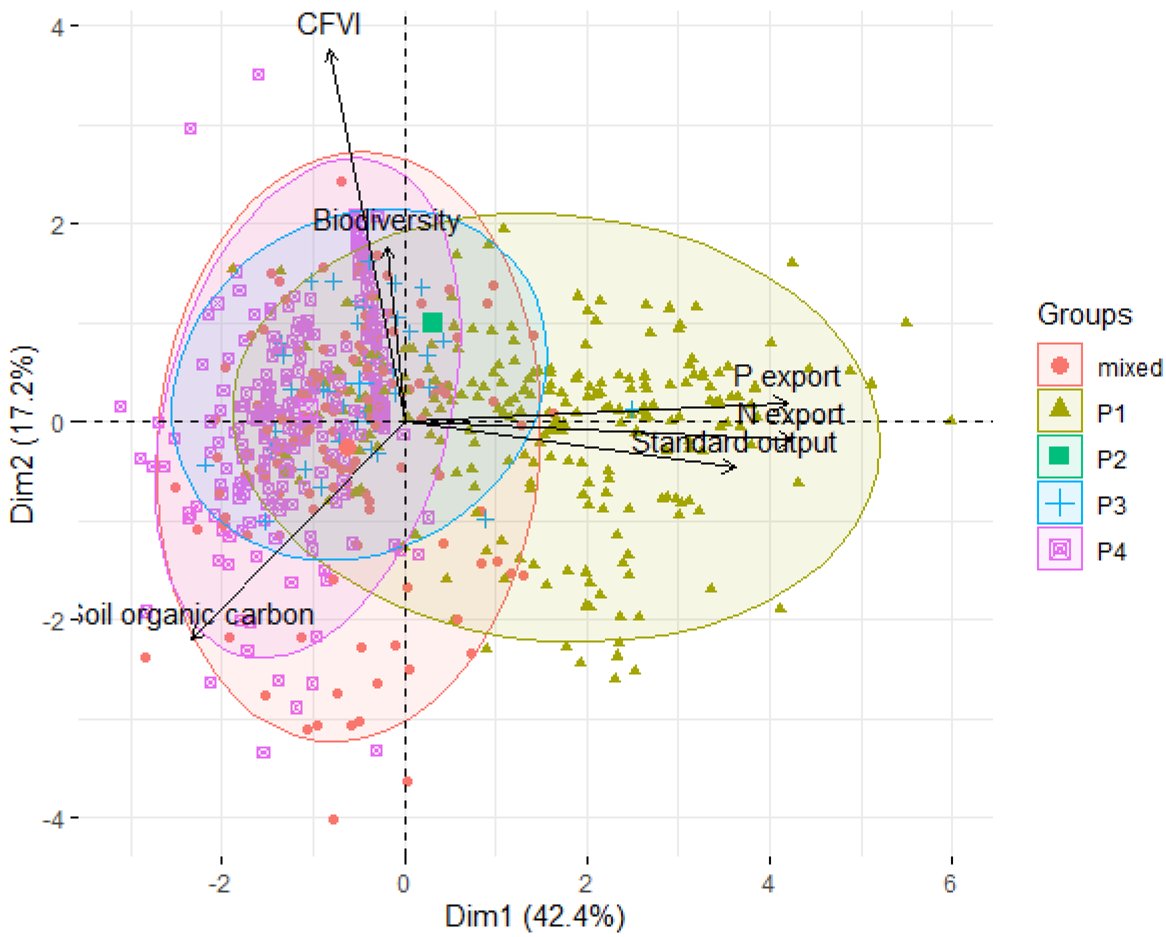

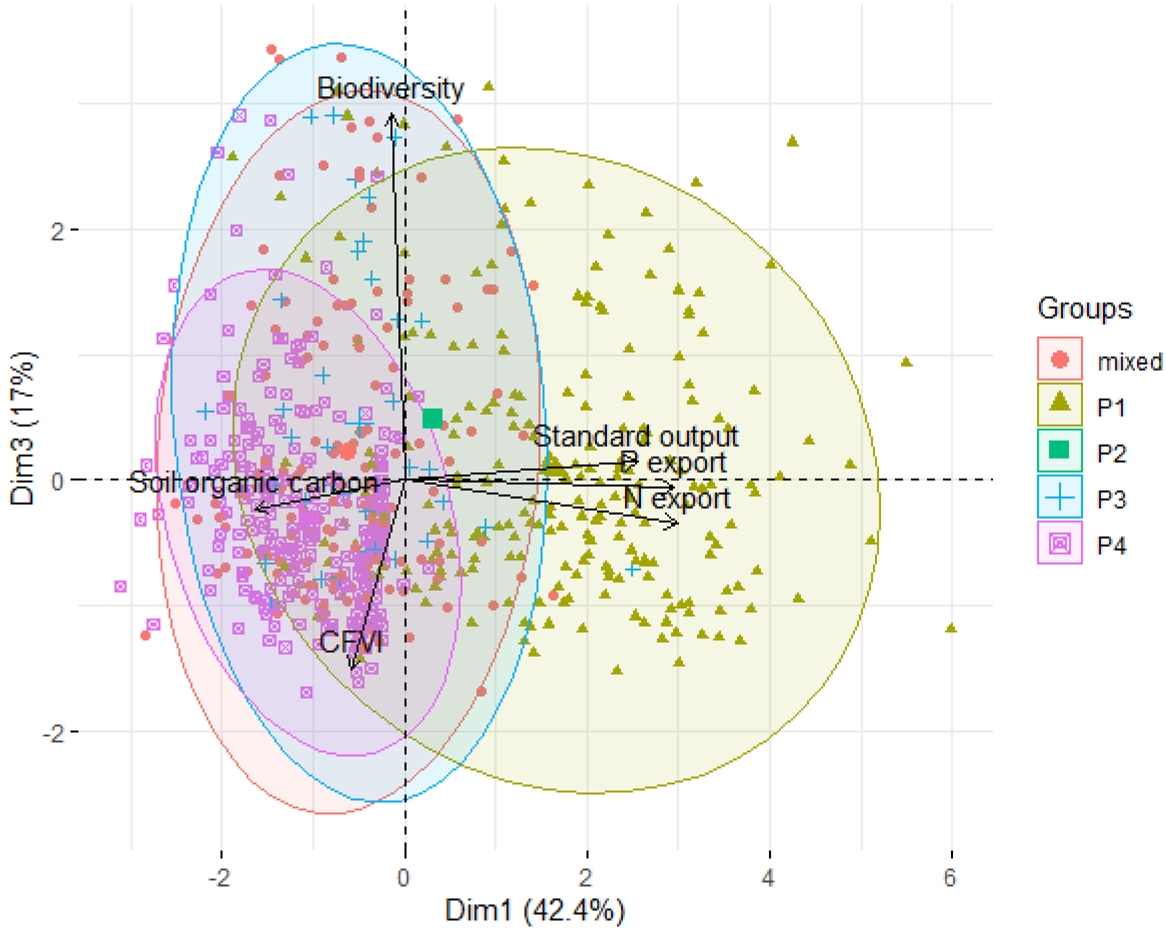

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Figure 5: PCA biplots of ESS, biodiversity and CFVI in South Moravia, CZ. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

3.2.2. AEM as drivers of trade-offs and synergies

The proportion of AEM conversion to grassland on the total farm area was positively related with the biodiversity indicator and to soil organic carbon, both in mixed and P1 farms, whereas a reduction in nutrient export as well as in standard output in water was noticeable only in P1 farms (Figure 6).

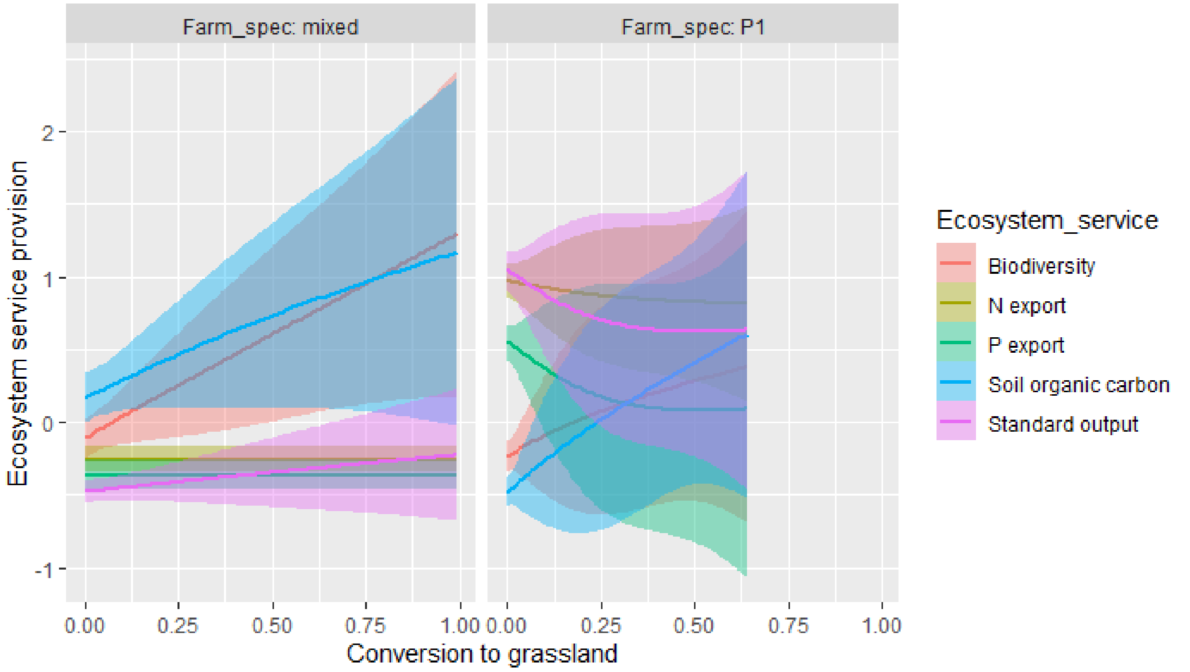

Figure 6: ESS and biodiversity provision relative to the proportion of farm area converted from arable to grassland. The two panels show trade-offs and synergies for mixed (left) and P1 (right) farms, respectively.

Organic and integrated management showed positive effects on biodiversity levels, but a negative effect on standard output in all farm specialisations (Figure 7). N export decreased with increasing area under organic farming, whereas P export showed a slight increase in mixed and P3 farms. Soil organic carbon content increased under organic farming management in all farm types.

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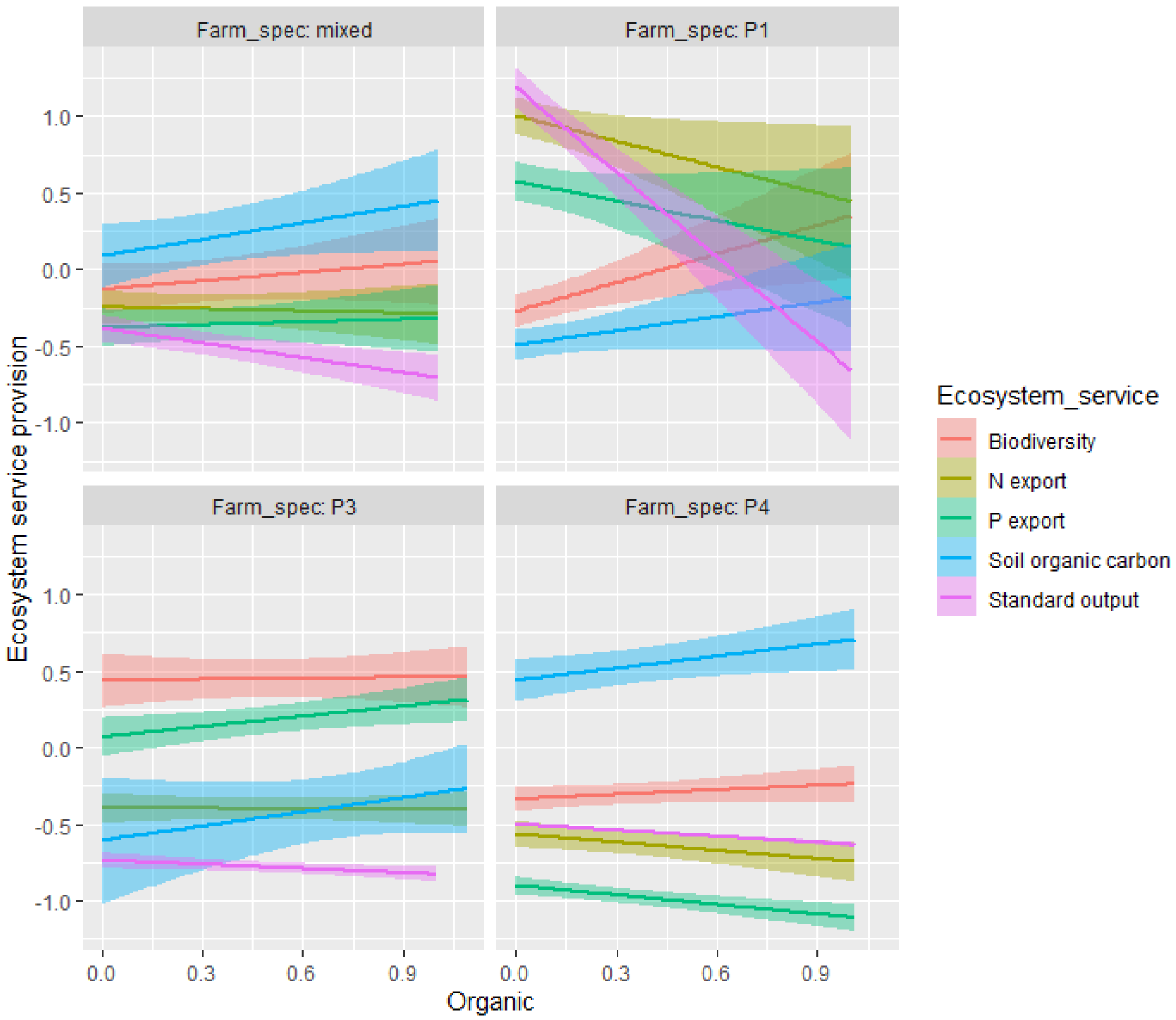

Figure 7: ESS and biodiversity provision relative to the proportion of organic farm area. The four plots show trade-offs and synergies for mixed (top left), P1 (top right), P3 (bottom left) and P4 (bottom right) farms.

3.3. Catalonia, ES

Catalonia is the largest and most diverse among the five CS of BESTMAP. The extent of the CS encompasses different climatic zones and high topographic variations. P3 farms are more common in the southern parts of Catalonia, whereas P1 farms cover large areas of the centre and the eastern tip of the region. P4 farms are instead most common in the northern parts of the CS, in the more mountainous regions of the Pyrenees.

3.3.1. Bundles

The PCA on the farm-level ESS and biodiversity values in Catalonia identified two dimensions that collectively explain 63.8% of the variance in the data (Figure 8).The first dimension represents a bundle of N and P export in water, whereas the second dimension bundles together three different services: co-occurrence of biodiversity and standard output, which together are negatively related to soil organic carbon. Different farm specialisations are partly distinguishable in this two-dimensional space, with P4 farms having generally higher values of SOC, and P3 farms showing higher levels of standard output and biodiversity. The analysis run on the scenario without AEM revealed similar associations between services, though

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additionally a third dimension was retained to explain 20.5% of the variation (Appendix: Figure A3).

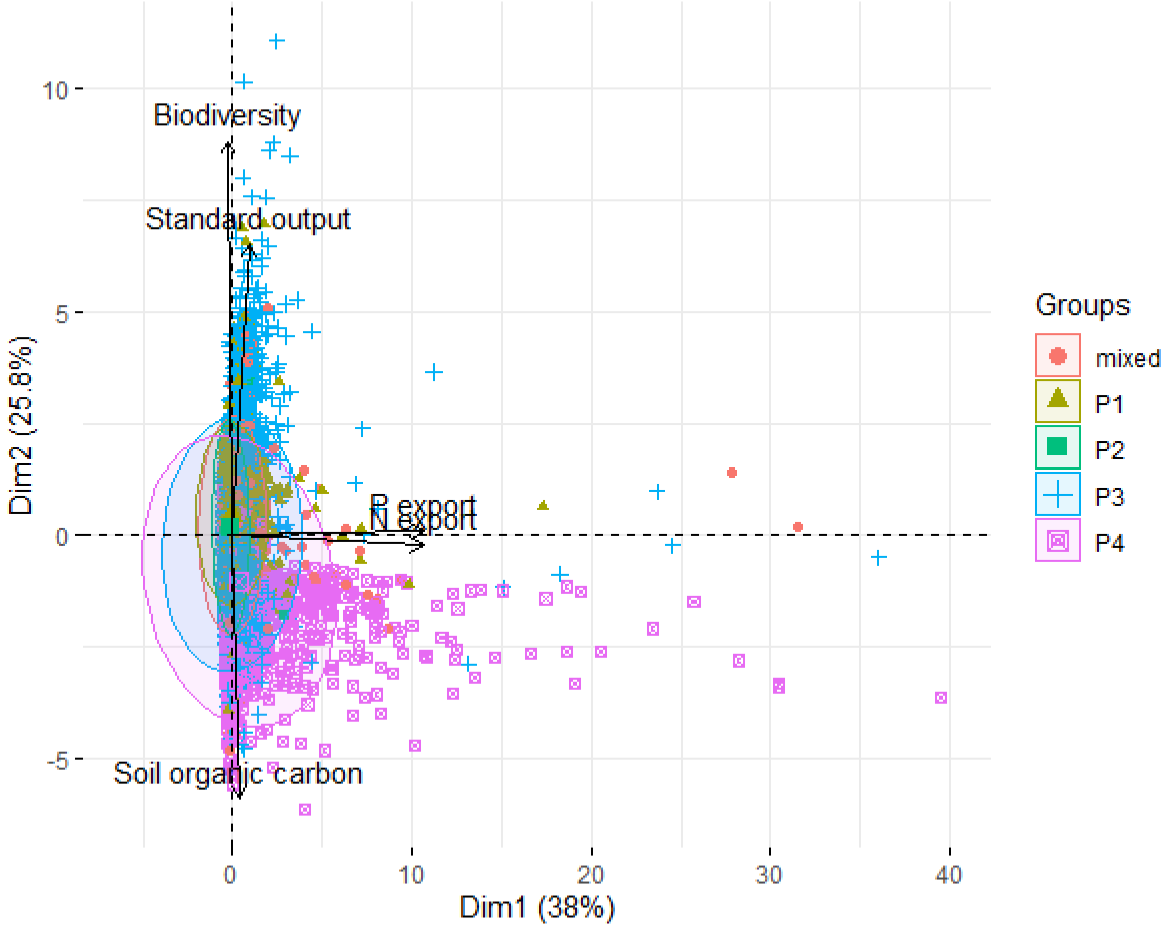

Figure 8: PCA biplot of ESS and biodiversity in Catalonia, ES. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

3.3.2. AEM as drivers of trade-offs and synergies

The proportion of fallow land, a crucial habitat for the maintenance of farmland biodiversity, has significantly decreased in Spain in the last decades, especially since the obligation to maintain 10% of the land as fallow was ended in 2008 (Traba & Morales, 2019). Our analysis showed that a potential increase in the area of fallow land per farm had considerable positive effects on the biodiversity indicator in Catalonia, while the standard output was reduced as a consequence of the reduction of area available for cropping (Figure 9). The soil organic carbon content also related negatively to fallow land proportions: the carbon model developed in BESTMAP does not take into account effects of fallow land on SOC, and the negative trend in our data may be explained by the fact that field parcels that already have low fertility are used as fallows.

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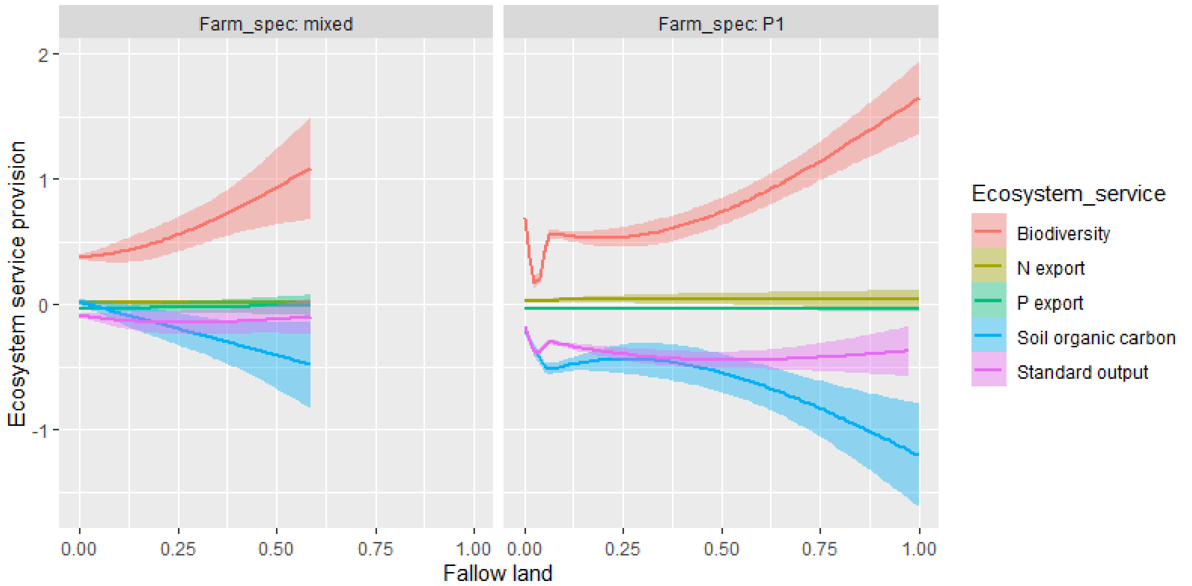

Figure 9: ESS and biodiversity provision relative to the proportion of fallow land. The two plots show trade-offs and synergies for mixed (left), P1 (right) farms.

CFVI could be estimated only for the farms in the NUTS regions ES511, ES512, ES513 (but not ES514) which applied AEM in the current adoption scenario. Therefore, CFVI was not included in the PCA analysis, but such data remains very interesting especially in a heterogeneous region like the Catalan one. For the modelled farms, the correlation between percent change in farm viable income following AES adoption and the standard output per ha of the farms revealed a trade-off, indicating upon visual inspection that farms with comparatively lower monetary output/ha receive the highest support proportionately from the AES subsidies (Figure 10). This is true especially for small P4 farms, although naturally a degree of caution should be exercised when interpreting very small values (e.g. < €1000) and percent change.

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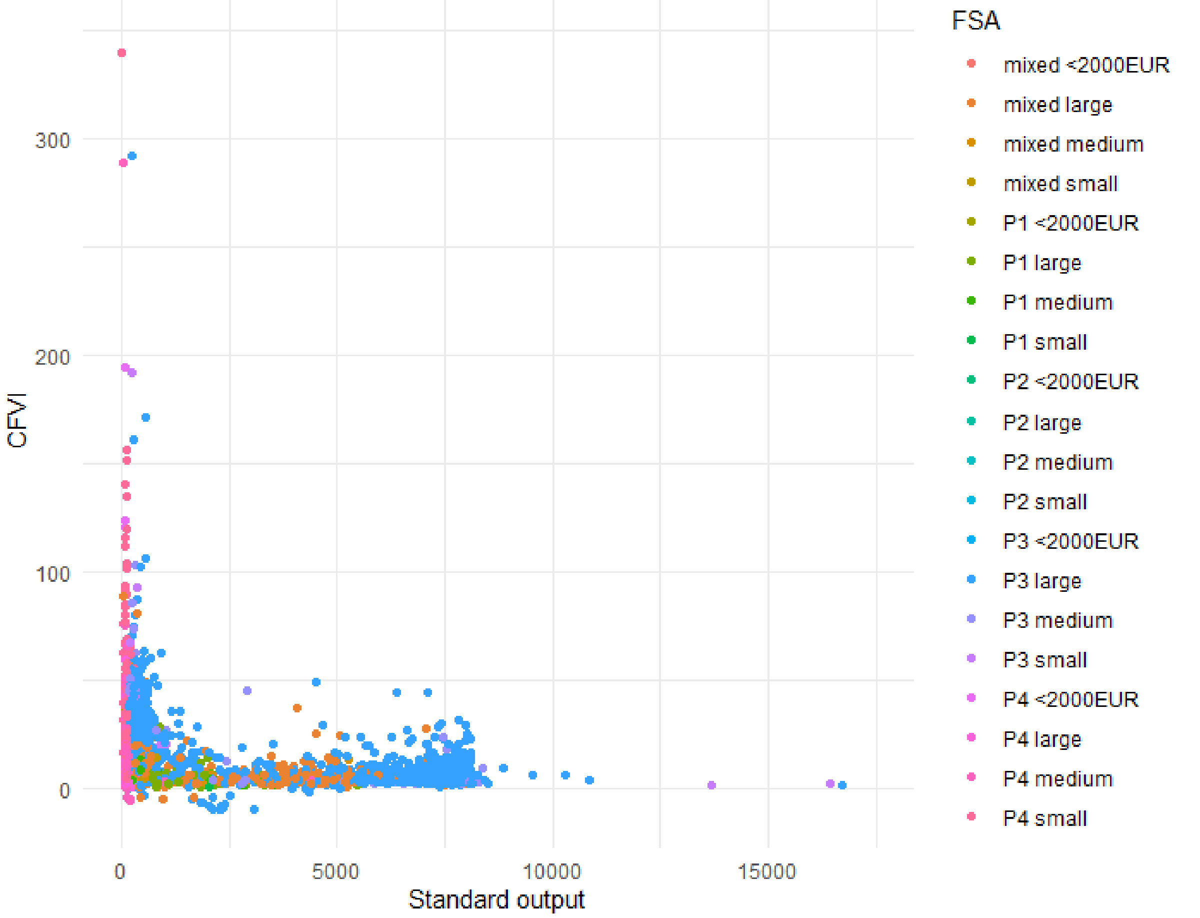

Figure 10: estimated percent change in farm viable income relative to the standard output per ha in Catalonia, ES. Single farms are colour-coded depending on their FSA type.

3.4. Humber, UK

Large P1 farms are the most prevalent FSA type in the Humber, both in terms of numbers and covered area. Consequently, AEM designed for arable land, like vegetation buffers, cover crops, and fallow land, are frequent in this CS.

3.4.1. Bundles

Also in the Humber, most of the variation (63.1%) in ESS, biodiversity and CFVI could be explained by the first two PCA dimensions (Figure 11). The first dimension is strongly related to N and P export levels, whereas the second one represents a trade-off between CFVI and biodiversity, and to a lesser extent with standard output. The vast majority of farms are clustered in the same two-dimensional space, with some outliers on both axes. The PCA performed on data reflecting the scenario without AEM (which did not include CFVI) identified the same ESS bundles, though with different orientations respective to the two PCA dimensions (Figure A4).

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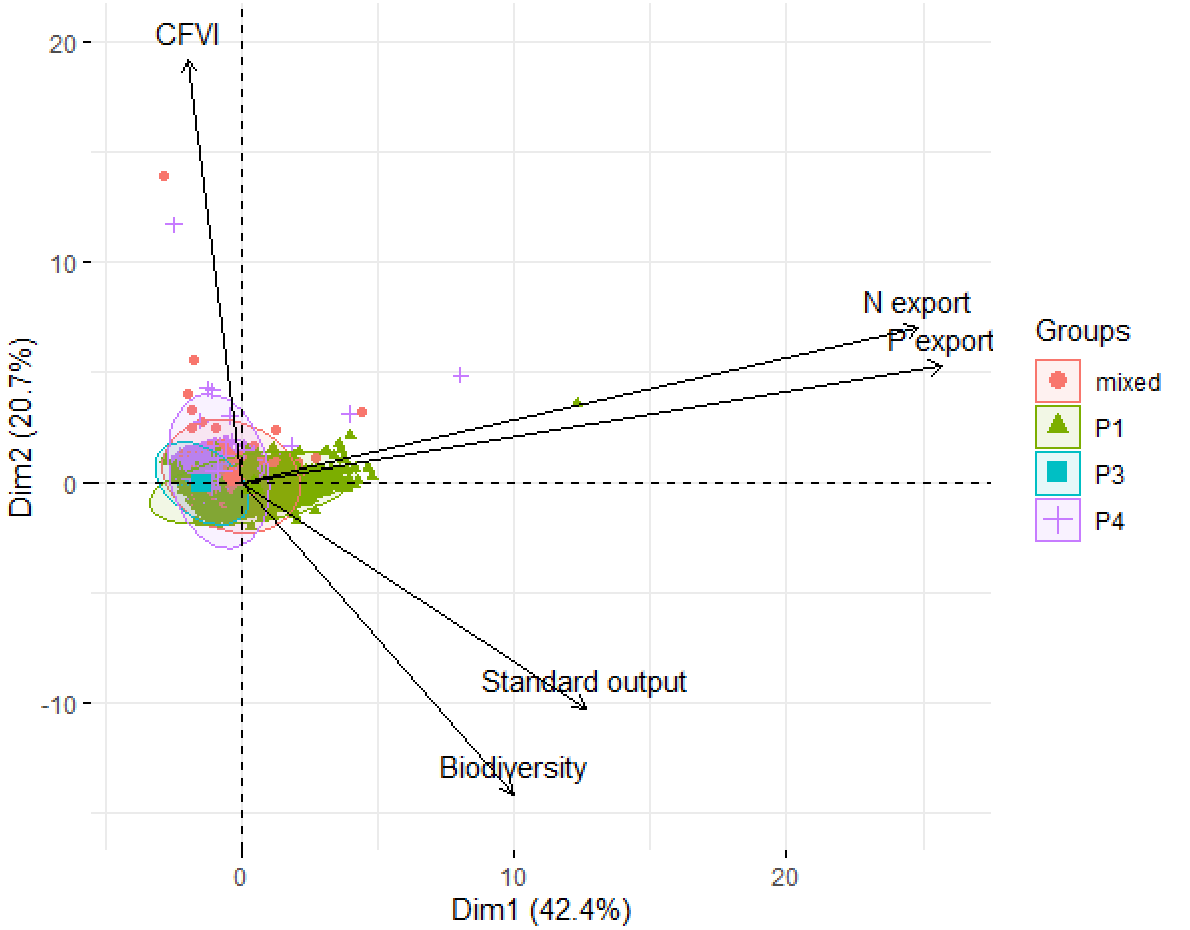

Figure 11: PCA biplot of ESS, biodiversity and CFVI in the Humber, UK. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

3.4.2. AEM as drivers of trade-offs and synergies

Synergies in the co-occurrence of standard output, biodiversity and CFVI were apparent along the gradient of cover crops' cover (Figure 12). Nutrient export in waters was instead reduced by cover crops. The wide confidence intervals though suggest that there is high variation in all modelled services among farms applying cover crops.

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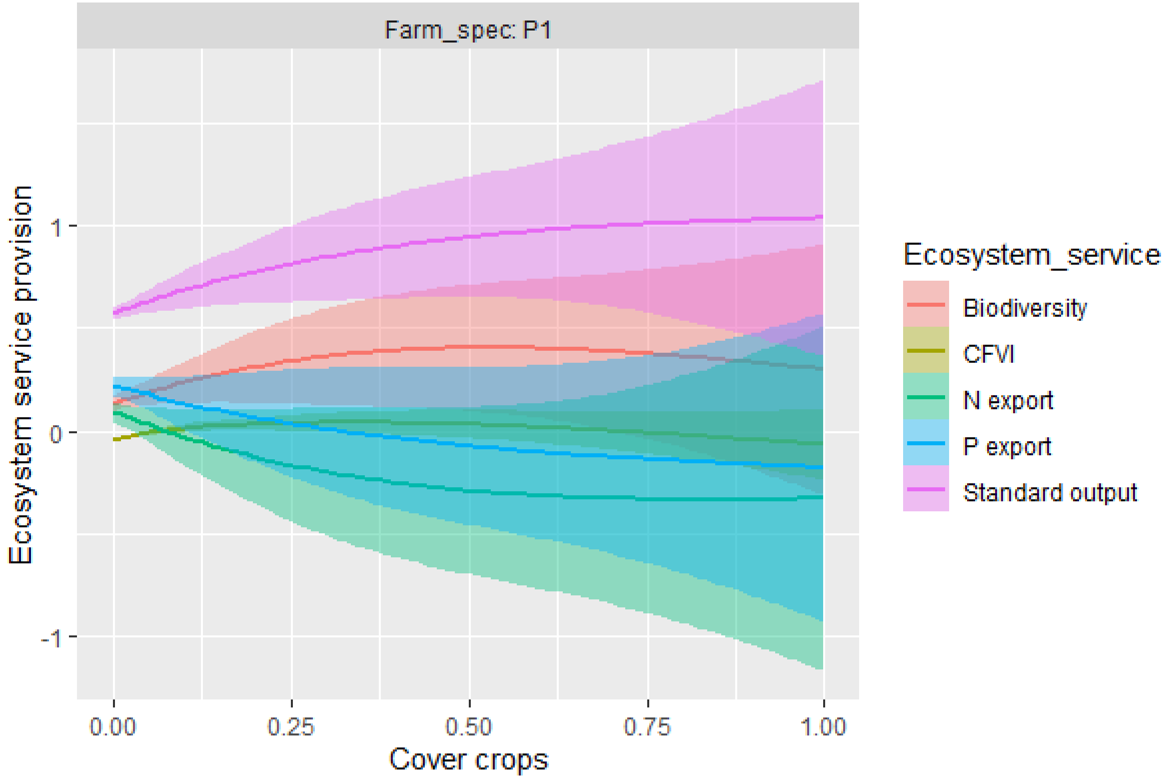

Figure 12: ESS, biodiversity and CFVI provision relative to the proportion of cover crops. Trade-offs and synergies are shown for P1 farms.

The proportions of vegetation buffers affected CFVI most substantially in the mixed farms of the Humber region, and nutrient leakage was reduced by increasing cover of vegetation buffers (Figure 13). Smoothing curves for biodiversity and standard output showed high uncertainty (i.e. large confidence intervals).

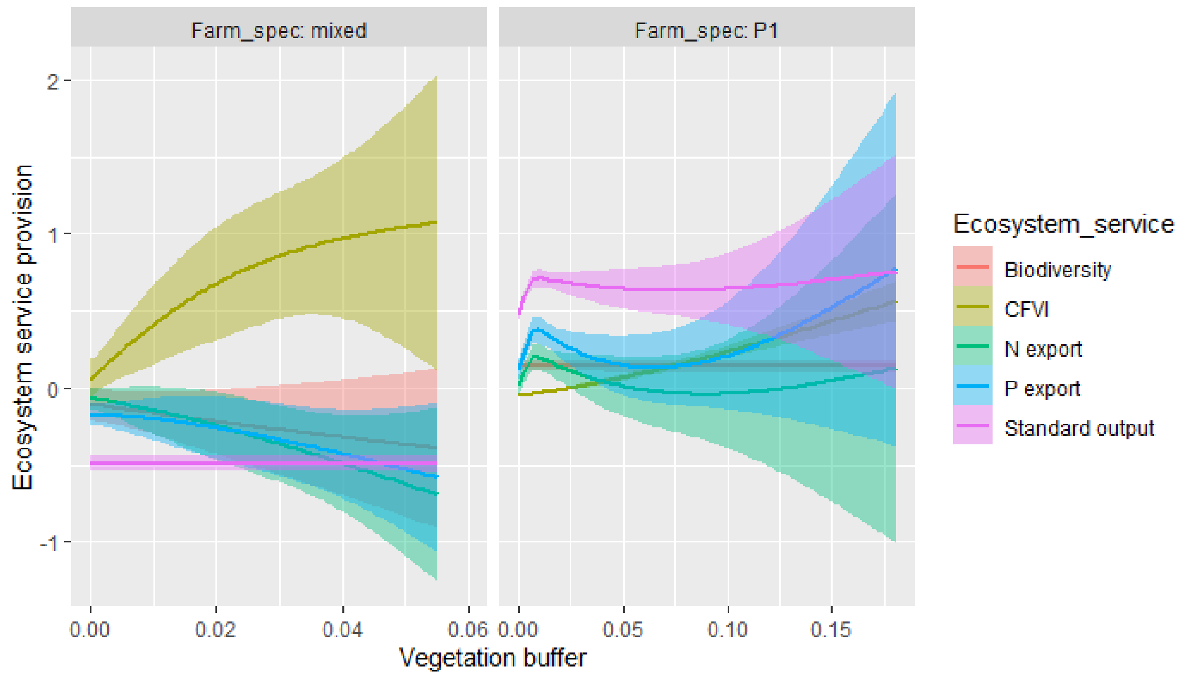

Figure 13: ESS, biodiversity and CFVI provision relative to the proportion of vegetation buffers. The two plots show trade-offs and synergies for mixed (left) and P1 (right) farms.

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3.5. Bačka, RS

P1 farms are the most abundant also in the Bačka CS. Besides general cropping, permanent cultures (P3) is the second most common farm specialisation in the region, followed by livestock farms (P4). This CS is peculiar in that, since Serbia is not part of the European Union, AEM do not exist. “Surrogate” AEM, based on similar management strategies, were compiled for this CS (see D3.3 for details).

3.5.1. Bundles

The PCA revealed a co-occurrence of N and P export, forming the first PCA dimension, and a trade-off between biodiversity and standard output, which bundle together to form the second PCA dimension (Figure 14). Mixed farms appeared to be the most variable ones along the two dimensions. Associations between ESS and biodiversity did not change in the scenario without AEM, and the PCA results are provided in the Appendix (Figure A5).

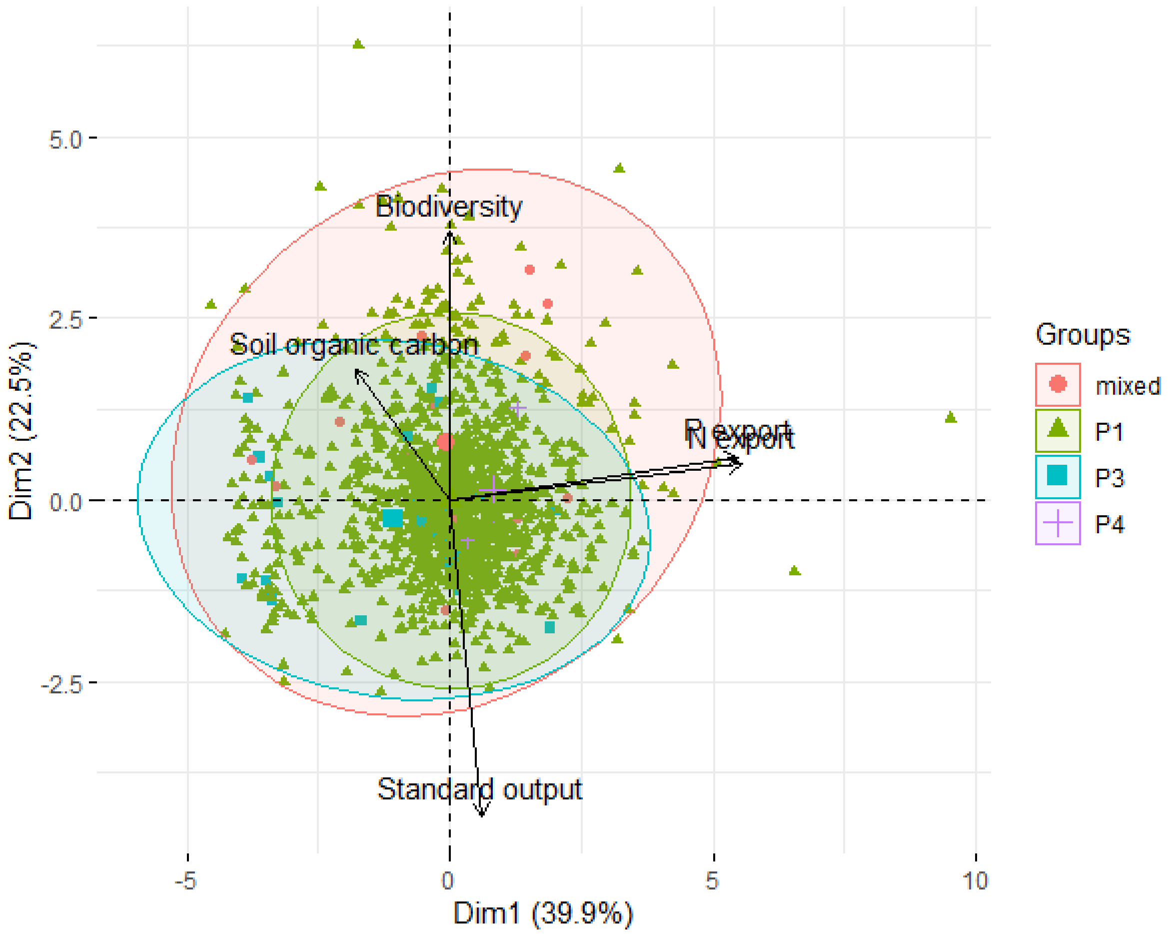

Figure 14: PCA biplot of ESS and biodiversity in Bačka, RS. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

3.5.2. AEM as drivers of trade-offs and synergies

Maintaining permanent grassland AEM had positive effects on biodiversity and soil organic carbon content in the Bačka farms, but it also decreased the standard output (Figure 15). The farms applying this AEM are categorised as P1 farms in our FSA classification, despite having, in certain cases, high proportions of grassland cover. This is likely due to inconsistencies between Agrosens data (see deliverable D3.5 for details), used for the development of the FSA, and the available land-use and surrogate AEM data.

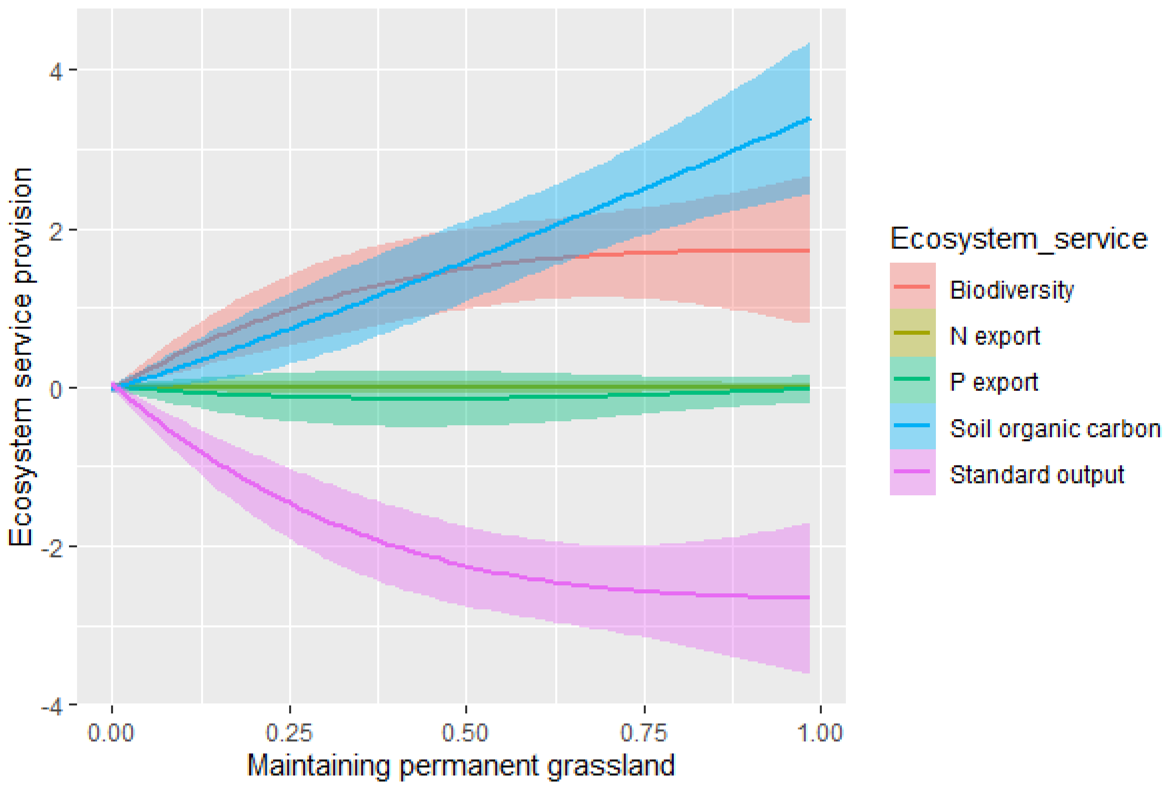

Figure 15: ESS and biodiversity provision relative to the proportion of maintaining permanent grassland AEM.

Organic farming showed very positive outcomes in terms of biodiversity, and mild negative effects on soil organic carbon and standard outputs (Figure 16); but the great variance among farms adds uncertainty to the interpretation of the results.

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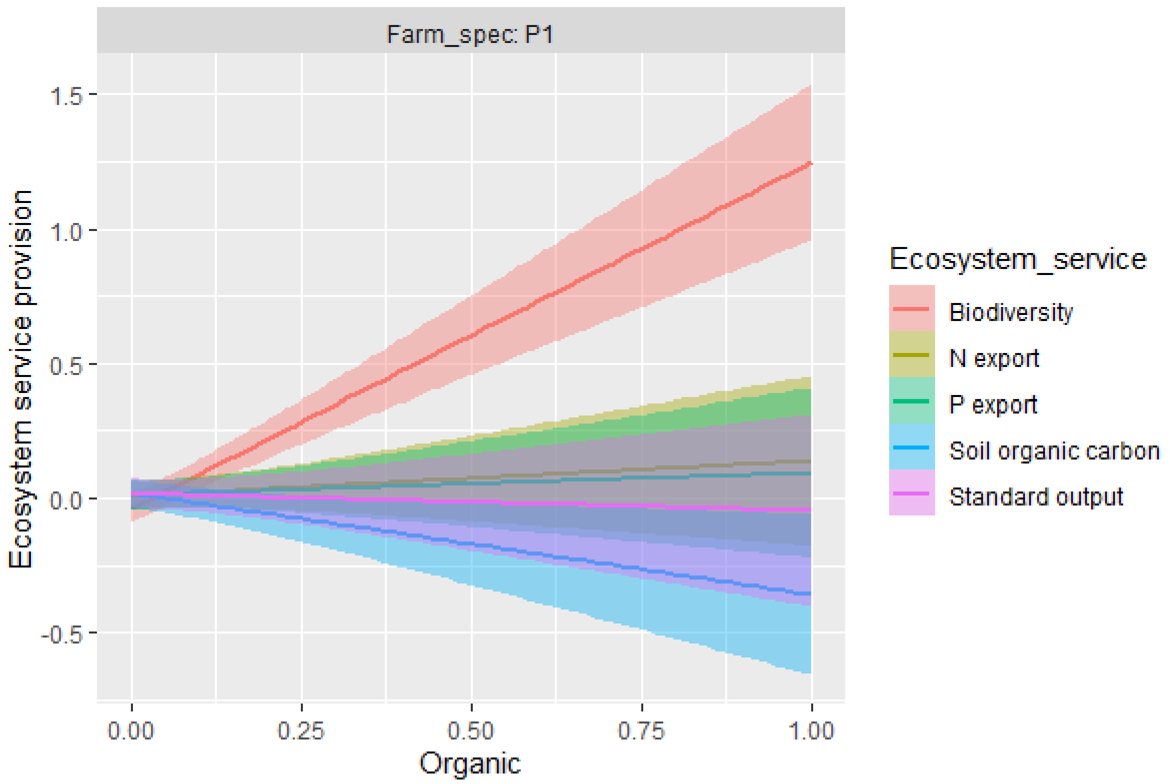

Figure 16: ESS and biodiversity provision relative to the proportion of area under organic farming. Trade-offs and synergies are shown for P1 farms.

4. Discussion

The PCA analysis used to identify bundles of co-occurring services revealed that most variation in the data could be explained by the first two PCA dimensions in all CS except for CZ. In all CS, the largest variance in the data (e.g. along the first dimension) was explained by nutrient export levels in the water. Indeed, N and P exports were always highly correlated to each other and to the first PCA dimension. The second PCA dimension usually reflected variations in standard output (in DE, ES and RS), biodiversity (in ES and RS), or CFVI (CZ). Biodiversity and standard output showed synergistic associations in UK and ES, but were instead negatively related in RS. These diametrically opposite relationships may be due to different factors: firstly, the biodiversity indicator was built on a different set of species in each CS. This implies that different numbers of cropland- and grassland-dependent species were modelled in each CS, which can skew the indicator towards certain types of habitats and farm specialisations. Second, the large differences in FSA distributions in the different CS affect the range of standard output values, which in some CS are driven by high standard output values for P3 farms (e.g. ES and DE). Permanent cultures can indeed provide valuable habitats for farmland biodiversity (Katayama et al., 2019), while also being more profitable than other crop types. Interestingly, standard output and nutrient export were found to be highly correlated only in CZ, while the two services had orthogonal relations in all other CS. The association of soil organic carbon to other services was more variable across CSs, and is likely to be largely influenced by other factors (e.g. soil properties) and processes (Lehmann et al., 2020), which may influence the other modelled services to a lesser extent. The estimated percent change in farm viable income (CFVI) appeared to be more consistent in farms with a lower standard output per ha (Figures 5, 10 and 11). The associations between different services did not change significantly between the scenario without AEM, and the one reflecting the current AEM adoption levels: we can thus assume that changes in management, as exemplified between the two modelled scenarios, do not disrupt the identified ESS bundles,

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but rather influence their occurrence and spatial patterns; though more consistent changes in AEM adoption (e.g. 2- or 10-fold increases in area under AEM) may well produce very different results.

For each CS, we analysed how different AEM groups drive trade-offs and synergies between ESS, biodiversity and socio-economic outputs. Overall, increasing proportions of AEM on the total farm area translated into reductions in nutrient leakage in water, improvements in biodiversity levels and soil organic carbon, and reductions in standard output, in line with previous research (MacDonald et al., 2007; Whittingham, 2011). These results are not unexpected, as the reduction in land-use intensity deriving from participation in AEM has the ultimate objective of preserving sustainable levels of biodiversity and ecosystem services, while ensuring sustainable yield levels (European Union, 2016). However, our results also describe some exceptions: standard output was sometimes increasing with increasing AEM proportions (Figures 3, 6, 12 and 13), and biodiversity (Figure 13) and soil organic carbon (Figures 9 and 16) showed decreasing trends respective to different AEM groups which should instead maintain or even improve the provision of such services. The sometimes broad confidence interval of these modelled trends reflects the great variation in ESS provision across farms with similar AEM levels. This variation is likely linked to other crucial environmental (e.g. climate, topography, land cover in the farm's surroundings) and management (e.g. fertiliser and pesticide input, tillage regime) factors not considered in our trade-off analysis. Furthermore, different AEM are designed to address specific environmental objectives (e.g. reducing water pollution, preserving biodiversity), and not all of them aim at preserving multiple services simultaneously (Batáry et al., 2015). Overall, the common trade-off between sustainable farming and productivity is reflected in our data, and the estimated CFVI suggests that AEM subsidies translate into positive estimated changes in farm viable income only in farms with an already (comparatively) low productivity (e.g. Figure 10). As highly productive farms, like large P1 farms which are the most abundant FSA type in the majority of our CS, manage significant shares of farmland in the five CS, a better targeting of AEM towards these types of farms should be a focal point for policy makers.

4.1. Obstacles and challenges

Assessing trade-offs and synergies between ESS, biodiversity and socio-economic outputs across different European regions is a challenging task, which requires collection, filtering and harmonisation of large amounts of data deriving from different sources. We described the obstacles encountered in accessing and sharing sensible datasets needed for the modelling task in D3.3; these obstacles affected and delayed the completion of this analysis too, as the ESS, biodiversity and socio-economic models were the sources of the data used in this document. Combining outputs from different models also implied the use of data from different years: for example, the socio-economic model is based on FADN data from 2017, whereas the majority of the ESS and biodiversity models used the most recent available IACS data (e.g. 2018 or 2019). Similarly, the FSAs were developed based on 2018 IACS data in Catalonia, while most models were trained on 2019 data. These small inconsistencies are unlikely to have big impacts on our results, but may explain some discrepancies in our analyses. The development of the carbon sequestration model has been subject to delays due to difficulties to find adequate data for model calibration. The recent improvements to the model could not be operationalised in all CS in time for the inclusion of the results in this deliverable. All updated ESS and biodiversity model results will be made available in the UFZ GeoNetwork (https://geonetwork.ufz.de) and all newly developed codes will be stored and accessible in the UFZ GitLab (https://git.ufz.de/) at the end of the project, along with the current versions of the model factsheets describing model inputs and outputs.

5. Outlook

The outputs of this task set the groundwork for task 4.3 - “Translating bundles into policy indicators”. Indeed, while the ESS, biodiversity and socio-economic output models were developed such that they could provide a spatially-explicit output that could be easily linked to already existing policy indicators, ESS bundles can be useful in summarising and visualising information on the co-occurrence of multiple services. In this document, we provided a spatial example (Figure 2) of how PCA dimensions can be mapped as proxies for the ESS bundles that strongly correlate to them. Further clustering of PCA dimensions is sometimes applied to classify spatial units (e.g. farms) with similar levels of ESS provision (Spake et al., 2017). Nonetheless, combined indicators based on multiple dimensions (or aggregating information from different services) are sometimes difficult to interpret (Marsboom et al., 2018), and thus require caution when used for providing recommendations to decision-makers. These ideas will be further developed in the deliverable D4.3 - “Mapping of ESS/biodiversity/socioeconomic bundles into policy indicators”. The developed indicators will be uploaded into the policy dashboard which is being developed as part of task 6.4 - “Implementation of a virtual laboratory”.

6. Acknowledgements

We thank all data providers for the data used in the modelling tasks and in the FSA classification; these are listed in the deliverables D3.3 and D3.5, respectively.

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8. Appendix

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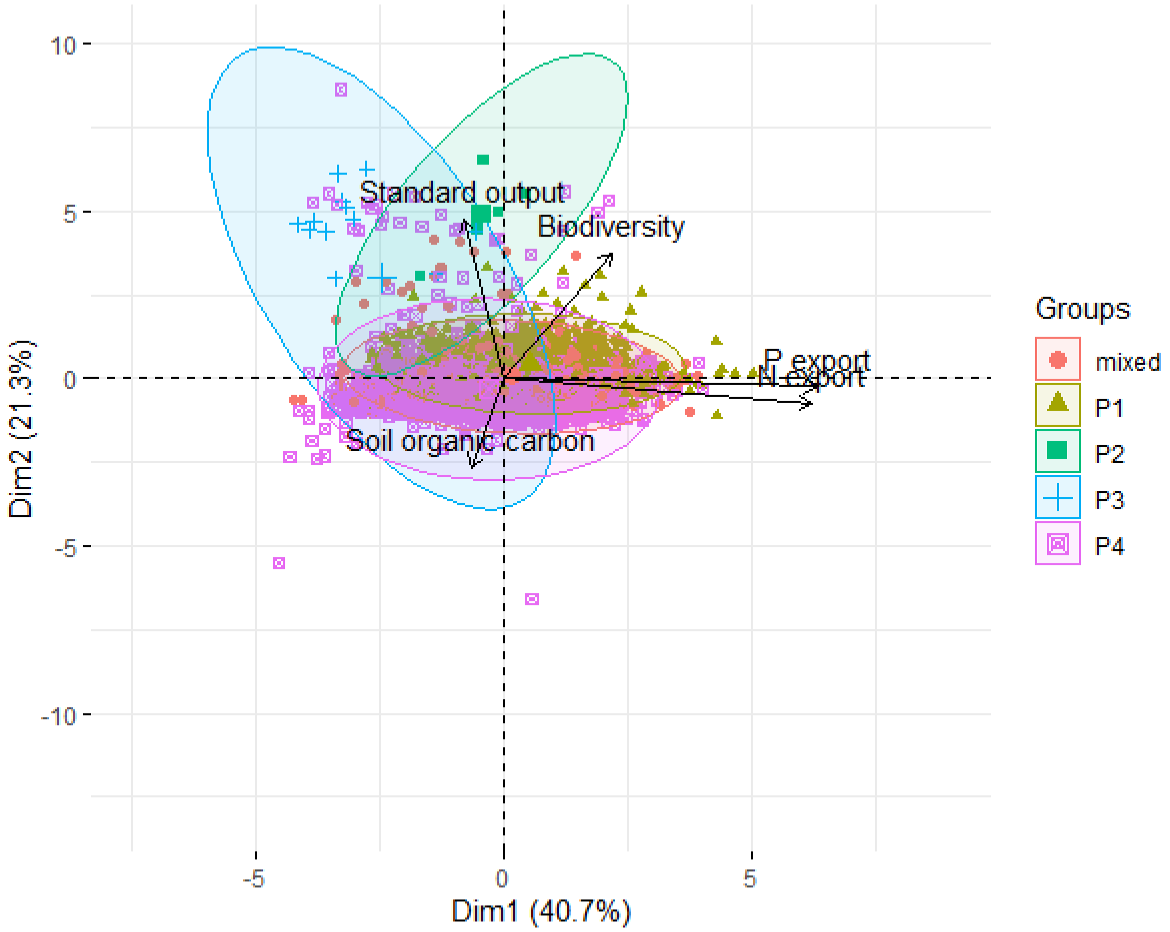

Figure A1: PCA biplot of ESS and biodiversity in the Mulde, DE, under the no AEM scenario. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

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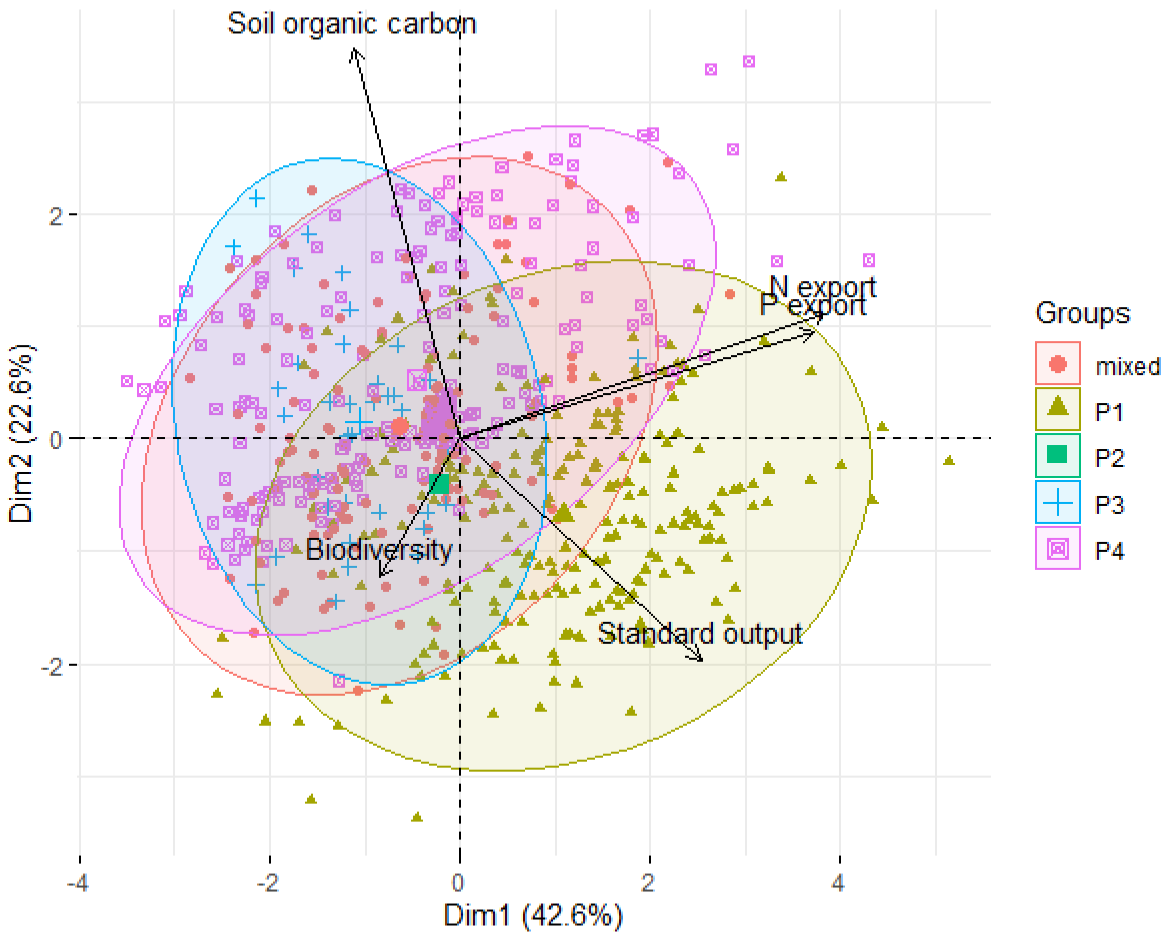

Figure A2: PCA biplot of ESS and biodiversity in South Moravia, CZ, under the no AEM scenario. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

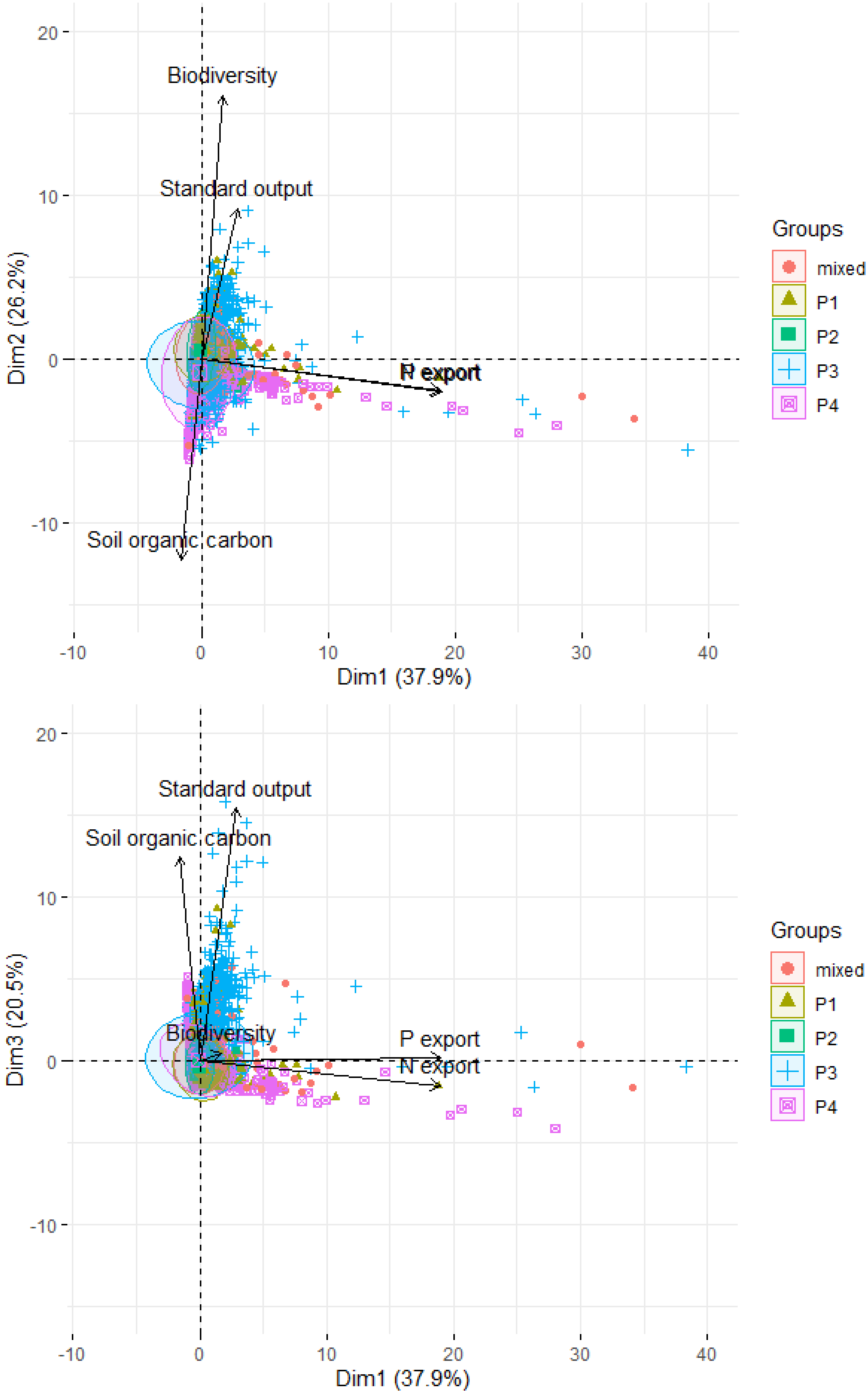
Biodiversity
Standard output
P export
N export
Soil organic carbon
Dim2 (26.2%)
Dim1 (37.9%)
Groups
mixed
P1
P2
P3
P4
Standard output
Soil organic carbon
Biodiversity
P export
N export
Dim3 (20.5%)
Dim1 (37.9%)
Groups
mixed
P1
P2
P3
P4

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Figure A3: PCA biplots of ESS and biodiversity in Catalonia, ES, under the no AEM scenario. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

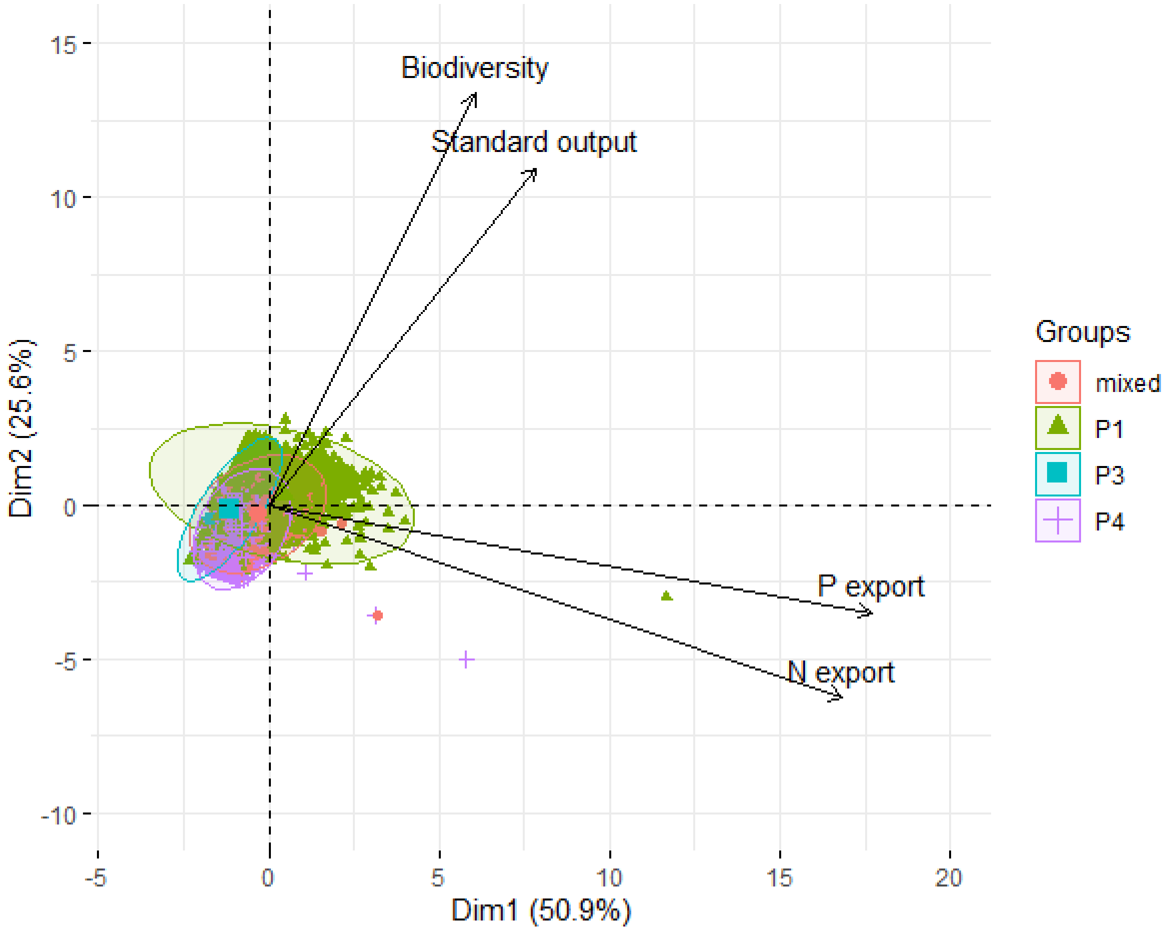

Figure A4: PCA biplot of ESS and biodiversity in the Humber, UK, under the no AEM scenario. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.

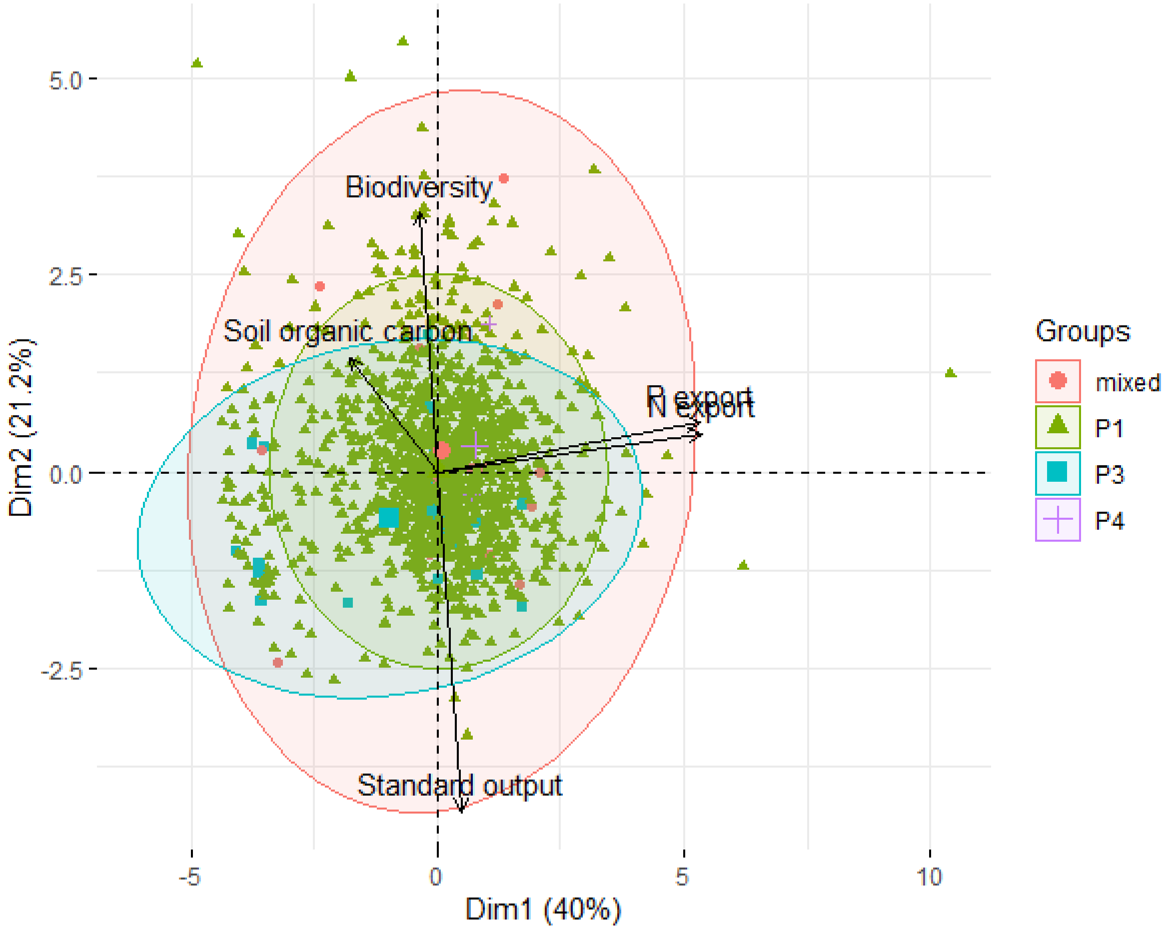

Figure A5: PCA biplot of ESS and biodiversity in Bačka, RS, under the no AEM scenario. The single farms are shown as points, colour-coded according to their farm specialisation. Ellipses are drawn around each farm specialisation group.