Ecosystem services and ecosystem cover types: An investigation of multifunctionality and trade-offs between ecosystem services in the European Union

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Resumé

Mennesker er i høj grad afhængige af uundværlige økosystemtjenester som forsynes af naturen. Behovet for disse tjenester har i de senere år været stigende, mens den europæiske naturtilstand er faldende. Ændringer i arealdækningen har konsekvenser for økosystemernes evne, til fortsat at kunne levere nødvendige tjenester til mennesker. Forholdet mellem økosystemtyper og -tjenester har stor betydning for den fremtidige forvaltning af den europæiske natur. Effektiv identifikation af potentielle trade-offs og synergier mellem tjenester i forskellige naturtyper er afgørende for reguleringer. Dette projekt undersøger netop forskellene i disse tjenester, på tværs af økosystemer i Den Europæiske Union, for at finde en sammenhæng mellem økosystemtjenester og -typer. Undersøgelsen foregik i tre trin: 1) En analyse af fordelingen af økosystemtjenester og korrelationen mellem tjenesterne. 2) Opstilling af en model for sammenhængen mellem økosystemtjenester og arealdækningsprocenten. 3) En sammenligning af standardiserede økosystemtjenester ved forskellige grader af landdækningsdominans. Resultaterne viste, at niveauet af multifunktionalitet mellem økosystemtjenesterne varierede mellem typerne og på tværs af dominansgraden. En høj dækningsprocent af skov og vådområder resulterede i det højeste niveau af multifunktionalitet, mens det for hede og tyndt bevoksede områder forårsagede den laveste multifunktionalitet. Andre økosystemer var i højere grad multifunktionelle ved en lav arealdækning, grundet indflydelsen fra flere økosystemtyper.

Abstract

Human reliance on indispensable ecosystem services is rising while the conditions of the European ecosystems are declining. Land cover changes have important consequences for ecosystems' abilities to continue providing necessary services to people. The relationship between ecosystem types and the provision of ecosystem services is of great importance for the future management of the European nature. Identification of potential trade-offs and synergies are essential for the planning of future regulations. To address these issues, this project investigates the differences in ecosystem service values across different ecosystem types within the European Union, to determining the relationship between ecosystem services and the ecosystem types. A three-step approach was followed: 1) Examination of distribution and correlations between the ecosystem services. 2) Modelling of the relationship between ecosystem services and land cover percentage. 3) Contrasting standardized ecosystem services at different levels of land cover dominance. Results showed that the level of

multifunctionality between ecosystem services varied between ecosystem types and dominance levels. High coverage of forest and wetland ecosystems resulted in the highest level of multifunctionality, while heathland and sparsely vegetated areas had the lowest levels. Other ecosystem types proved more multifunctional at lower land cover percentages, possibly due to the interference of other ecosystem types.

Introduction

Nature is highly important in sustaining life on Earth. Natural processes and beneficial goods supporting human well-being are known as ecosystem services (Millennium Ecosystem Assesments, 2005). These life-supporting ecosystem functions include several benefits and are generally divided into provisioning, regulating, cultural, and supporting ecosystem services (Garland *et al.*, 2020). Provisioning services include the production of foods, biomass, and natural products as examples, while regulating services sustain life through other means such as climate regulation, pollination, flood control and water purification. Cultural ecosystem services include recreational and aesthetic benefits of nature, and the supporting ecosystem functions are necessary for all other services and include primary production, soil properties, nutrient cycling, and photosynthesis (Daily, 1997; Garland *et al.*, 2020; Millennium Ecosystem Assesments, 2005).

Numerous ecosystem services are provided to humankind. Not all are equally valued by society although services are interrelated and dependent on one another (Bennett *et al.*, 2009). Ecosystem functioning is inherently multidimensional, that is a given species composition can provide more than one set of services and goods, and this is the core idea behind the concept of ecosystem multifunctionality. Formally, multifunctionality is the ability of an ecosystem to support and provide multiple ecosystem functions and/or services at once (Byrnes *et al.*, 2014). Multifunctionalities arise because of synergistic interactions within a system, which are usually disrupted by simplifications of ecosystems (Mastrangelo *et al.*, 2014). Ecosystem synergies are defined by Bennett *et al.* (2009) in Mastrangelo *et al.* (2014) as relationships between ecosystem services where both services vary in the same direction due to either direct interactions between the services or as a result of indirect common drivers.

The “Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment” (MAES) was a European Union infinitive focused on reporting the state of ecosystems and the levels of services provided by the ecosystems at the within the EU using 2010 as a baseline year (Maes *et al.*, 2020). MAES describes the interaction between the ecosystem condition and the ecosystem services which is highly relevant for policy makers and for the improvement of the condition of ecosystems (Maes *et al.*, 2020). The assessment is based on an operational framework developed by MAES and includes a conceptual framework for linking ecosystems and ecosystem service. This framework also provides a common methodology for a uniform operational basis across all EU member states for the assessment of ecosystems relative to the baseline values for 2010 (Maes *et al.*, 2020).

MAES reports seven terrestrial ecosystem types calculated based on the CORINE land cover data (CLC) (Büttner, 2014) which also constituted a reference dataset for the assessment. The report evaluated six ecosystem services: Crop provision, timber provision, carbon sequestration, crop pollination, flood control, and nature-based recreation (Maes *et al.*, 2020). The results from MAES shows an increase in the reliance on ecosystem services between 2000 and 2012, although the conditions of European nature providing such services have been declining (Maes *et al.*, 2020). As human needs such as consumption demands leading to intensification of land use continue to increase, we could see significant and unexpected consequences for ecosystems' abilities to continue providing indispensable services to people (Allan *et al.*, 2015; Jiang *et al.*, 2013).

Increased ecosystem homogeneity and intensification of land use can provoke a reduction of biodiversity (Foley *et al.*, 2005; Stein *et al.*, 2014; Tuanmu & Jetz, 2015) which in turn result in a decrease in multifunctionality of ecosystem services (Fitter *et al.*, 2010; Van der Plas *et al.*, 2016). The current intense land use practices that sustain human needs, such and food production and timber resources, may have the potential to support short-term demands for these goods, although hindering the provision of many other ecosystem services on a long-term basis (Foley *et al.*, 2005). In response to this challenge, radical changes in the way land is used, as proposed by the EU Biodiversity Strategy for 2030 (European Commission Directorate-General for Environment, 2021) can provide a way to ensure the provision of vital ecosystem services.

Multifunctionality, synergies, and trade-offs between ecosystem services are caused by complex interactions of natural cycles and dynamics across multiple different scales (Daily, 1997; Hauck *et al.*, 2013; Willemen *et al.*, 2012), and the supply of services varies across Europe following climatic and topographic gradients (Hölting *et al.*, 2019). The level of multifunctionalities is dependent on the spatial scales at which it is analyzed, and the consideration of scale has important implications for management and decision-making (Hölting *et al.*, 2019).

The expected changes in land use in Europe over the next decade will most likely influence the capacity of different ecosystem types to provide the required services. The first step to devise clear solution is understand how different land uses can provide different ecosystem services. Therefore, a profound understanding of the ecosystem service interactions, and factors affecting the multifunctionality of an ecosystem is key for management of European ecosystems and the well-being of its citizens. Identification and localization of potential trade-offs and synergies are essential for the planning of future rules and regulations concerning conservation strategies, and for ensuring the continued capacity of ecosystems to provide services for mankind. The aim of this project is to investigate the differences in ecosystem service provisions across different ecosystem types within the

European Union. The study also aims to contrast selected ecosystem services within a certain land cover type for the assessment of potential synergies and trade-offs between the services and the implications this may have for future land cover changes. For this, I used spatial data sets from MAES and CLC to generate maps of the distribution of regulating, provisioning, and cultural services across Europe, and investigated its correlations with the land cover of different ecosystem types. The goal is to assess the value of nature conservation in the sense of ecosystem benefits and discuss multifunctionality within and between different land cover types.

Materials and methods

Geospatial datasets

Data for the five ecosystem services used in this project come from the "Mapping and Assessment of Ecosystems and their Services" (Maes *et al.*, 2020). The datasets are available to download from the European Commission, Joint Research Centre (JRC) database (https://data.jrc.ec.europa.eu/collection/maes). The five ecosystem services evaluated include two provisioning services (crop and timber provision), two regulating services (crop pollination and carbon sequestration), and one cultural service (nature-based recreation). Only the actual flow of the ecosystem services was used for mapping and all calculations. The actual flow is the use of ecosystem services and is quantified based on the ecosystem service potential and demand (Maes *et al.*, 2020). The units and definitions of the ecosystem services are in accordance with the data descriptions, MAES (Maes *et al.*, 2020) and Vallecillo *et al.* (2019) as presented in Table 1.

The MAES datasets have 1 km^2 resolution and covers the geographical range of the EU-28 territory (European Union including the UK) and the EU marine regions (Maes *et al.*, 2020). I focused on the year 2012 as the reference year due to the availability of the MAES and CLC data. Before mapping or performing any calculations, the crop pollination raster was transformed to get the units in tonnes of crop per km^2 instead of kg per km^2 by dividing by 1000.

The CORINE Land Cover (CLC) data set from 2012 is used as reference for the land cover type distribution across the European Union (Büttner, 2014). The CLC 2012 raster was reclassified into seven terrestrial land covers: Agricultural croplands, artificial ecosystems, forest, grassland, sparsely vegetated land, heathland, and inland wetlands. The reclassification was done to match the CLC land cover types and the MAES ecosystem types (Maes *et al.*, 2020). In this project the term "Ecosystem type" refer to a physical system or geographic region with its own distinct characteristics and environment in which specific assets will bring about certain ecological properties based on the ecosystem definitions proposed by (Tsujimoto *et al.*, 2018) and division of the different MAES ecosystem types (Maes *et al.*, 2020).

Table 1. *Ecosystem service units and descriptions (Maes et al., 2020; Vallecillo et al., 2019).*

	Units	Definition of the actual flow	Description of methods
Provisioning			
Crop provision	Tonnes of crop per ha in 2012	The share of the total cultivated crop yield derived exclusively from the ecosystem contribution without any human inputs	Calculated based on 13 different crop types representing ~82% of arable land in the EU. Calculation of actual flow was only possible in areas with total crop yield statistics
Timber provision	m^3 timber per km^2 in 2012	Ecosystem contribution to the annual growth and standing volume of all trees, living or dead, felled during a given reference period	Based on the amount of wood fellings
Regulating			
Carbon sequestration	Tonnes CO_2 sequestered per km^2 in 2012	Net flow of carbon dioxide (CO_2) sequestered by the ecosystems from the atmosphere	The difference between ecosystem removals of carbon dioxide and the emissions
Crop pollination	Tonnes crop attributable to pollinators per km^2 in 2012	Transfer of pollen by wild bees resulting in fertilization of crops in areas where environmental sustainability to support wild insect populations overlap with pollinator-dependent crops	Spatial overlap between areas with pollinator dependent crops and environments capable of sustaining wild bee populations
Cultural			
Nature-based recreation	Potential visits per km^2 in 2012	Potential visits to sustainable areas with opportunities provided by nature and biophysical qualities of ecosystems for daily recreation	Potential visits were calculated on a mobility function assuming that inhabitants should live within 4km from the recreational area for an area to qualify as accessible on a daily basis

The reclassification of the ecosystem types proceeded as follows: Areas where a CORINE land cover class matched a MAES ecosystem type were assigned a value of one. Areas without overlap were not assigned a value, indicating that the land cover type was nonexistent within the pixel. As the CLC raster has a resolution of 100 m x 100 m, I summed the number of CLC classes reclassified as 1 within a 1 km^2 resolution cell, to match the extend of the ecosystem service rasters. The resulting rasters had a 1 km x 1 km resolution and values ranging between 1 and 100, which correspond to the coverage percentage of the given land cover type.

Association between MAES ecosystem types and ecosystem services

Determining the relationship between ecosystem services and the MAES ecosystem types was done using a three-step approach:

1. Examination of distribution and potential correlations between the ecosystem services.
2. Modelling the relation between ecosystem services and land cover percent of each of the MAES ecosystem types.

3. Contrasting standardized ecosystem services valued at different levels of dominance of a given ecosystem type.

All data manipulation and analyses were done using R version 4.1.1 (R Core Team, 2021) and the following packages: "raster" (Hijmans, 2021), "maptools" (Bivand & Lewin-Koh, 2021), "corrplot" (Wei & Simko, 2021), "highcharter" (Kunst, 2020), and "ggplot2" (Wickham, 2016).

Step 1. Distribution and correlation assessment of the ecosystem services

The spatial patterns of the actual flow of each of the ecosystem services were mapped to visualize the distribution and range in values across the European Union. The legend intervals were selected in accordance with Vallecillo *et al.* (2019). Each of the five ecosystem services were compared using pairwise comparison and tested for correlations using Spearman's correlation coefficient to evaluate potential monotonic relationships between the services. A negative correlation coefficient is indicative of potential trade-offs whereas positive correlation coefficients are indicative of potential synergies between two ecosystem services.

Step 2. Relation between ecosystem services and percent cover of each ecosystem type

To analyze the effect of land cover type on the ecosystem functions, the relationship between ecosystem type coverage and the actual flow was compared using a random sample approach. As the size of the complete datasets posed computational constraints, regression analysis was done with fewer datapoints, which also ensured that the relationship analysis is based on roughly the same number of observations for each ecosystem type. For this, I took 1000 random samples of 500-10000 individual locations where the combination of all ecosystem services and the cover of an ecosystem type was extracted. I extracted 10000 for agricultural, artificial, forest and grassland, 1000 from heathland and wetland, and 500 locations in the case of the sparsely vegetated ecosystem type. Difference in sample size is a consequence of differences in the extent of the CLC types. For each random sample, I established the $Ecosystem\ service{\sim}Land\ cover$ relation using a loess regression approach. A loess regression was chosen over a linear regression due to the expectation of non-linear and non-monotonic relationships between the ecosystem services. Using the predicted mean values for ecosystem services for each of the 1000 replicates, I then plotted the average predicted ecosystem service as a function of percentage cover of each of the ecosystem types. A potential bias of the sampling locations was checked by comparing the distribution of the locations of a given ecosystem types to the sampled locations. Results of mapping the distribution of locations of a given ecosystem type and the sampled locations proved hard to evaluate. This was especially true for heathland, wetland, and the sparsely vegetated ecosystem types, as these types had very few locations with values for all five ecosystem services. The overall distribution of the sampled locations seemed to be representative of the dispersal of the ecosystem types across Europe.

Step 3. Contrasting the standardized ecosystem services

Following the regression analysis, I investigated whether the potentially associated ecosystem services promote each other. To make the actual flows of different ecosystem services comparable within a certain ecosystem type, the service values were standardized as recommended by Jopke *et al.* (2015) and Peters *et al.* (2019) by using a standard score (z-score). The z-score is calculated using the formula:

$$z = \frac{x - \mu}{\sigma}$$

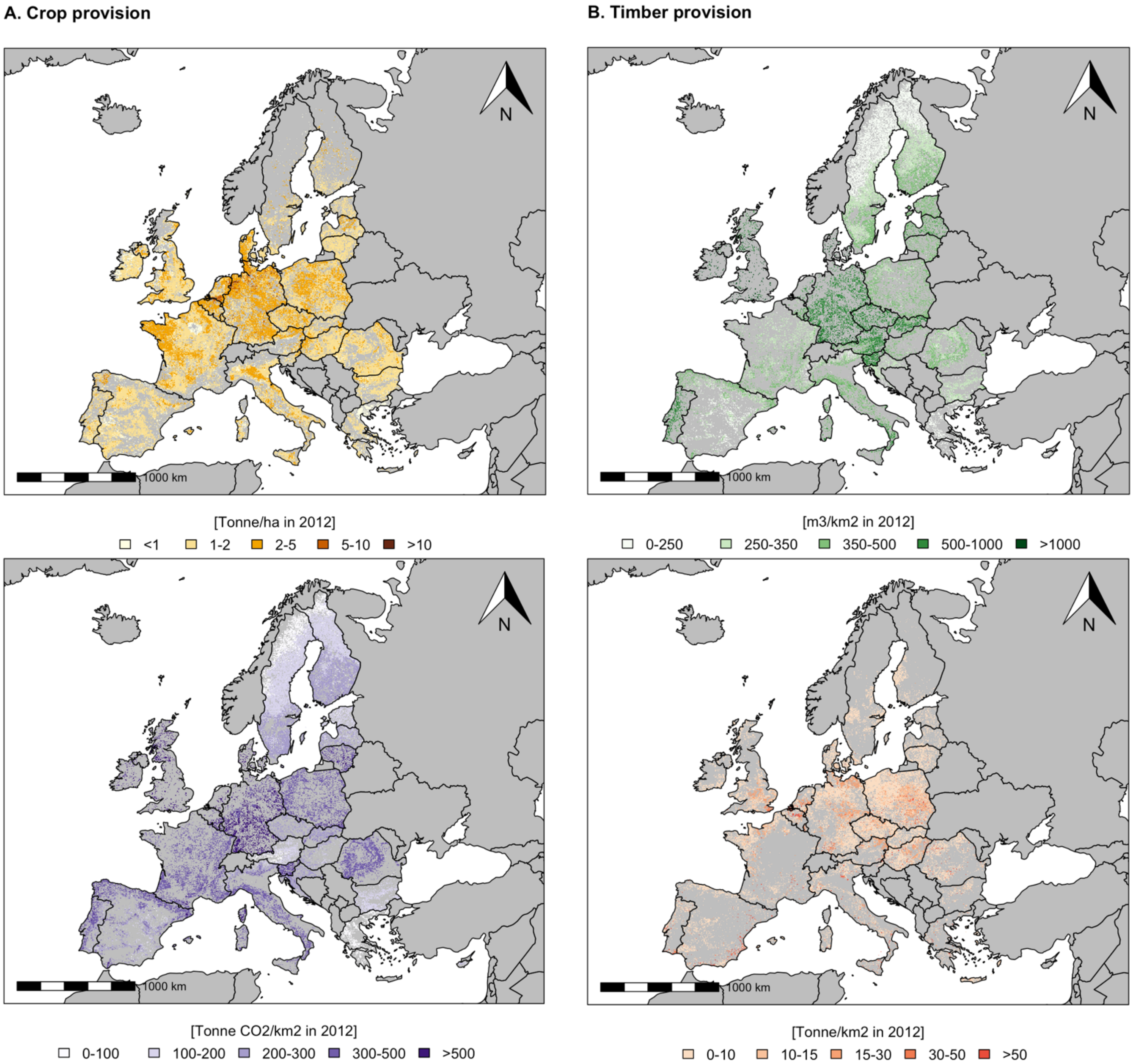
Where x is a raw score or value within a given grid cell, μ is the Europe-wide mean of the evaluated service, and σ is the Europe-wide standard deviation for the evaluated service. The z-score measures the number of standard deviations a given observation lies above or below the regional mean and is a representation of the variation within a dataset. Before calculating the z-score the top 1% of the ecosystem data values were eliminated to remove extreme values and outliers. The mean z-scores were calculated for different levels of dominance for each of the ecosystem types. Synergies should show the same directionality and magnitude in the z-score, and trade-offs should show the opposite.

Results

Distribution and correlation assessment of the ecosystem services

The projected maps of the actual flow of the five ecosystems services across the European Union show differences in the spatial distribution pattern of the ecosystem services (Fig. 1). The geographical patterns of potential ecosystem service interactions are revealed e.g., overlap between high and low values for timber provision (Fig. 1b) and carbon sequestration (Fig. 1c) while substantially less overlap is found between the two provisioning services (Fig. 1a) and (Fig. 1b).

At the level of the EU, Spearman-rank correlation coefficients between pairs of the five ecosystem services revealed weak (0.01-0.55), but positive, relationships (Fig. 2). The observed correlation coefficient between crop pollination and timber provision/carbon sequestration was negligible ($\rho < 0.10$) signifying no association between these ecosystem services. The relationship between timber provision and carbon sequestration showed the highest correlation coefficient of all pairwise comparisons, indicating a moderate correlation and a somewhat monotonic relationship between the services. Regression coefficients for the rest of the pairwise comparisons are low ($\rho < 0.32$) signifying weak associations. No clear trade-offs were found between the ecosystem services, as none of the correlation coefficients reported negative monotonic relationships.



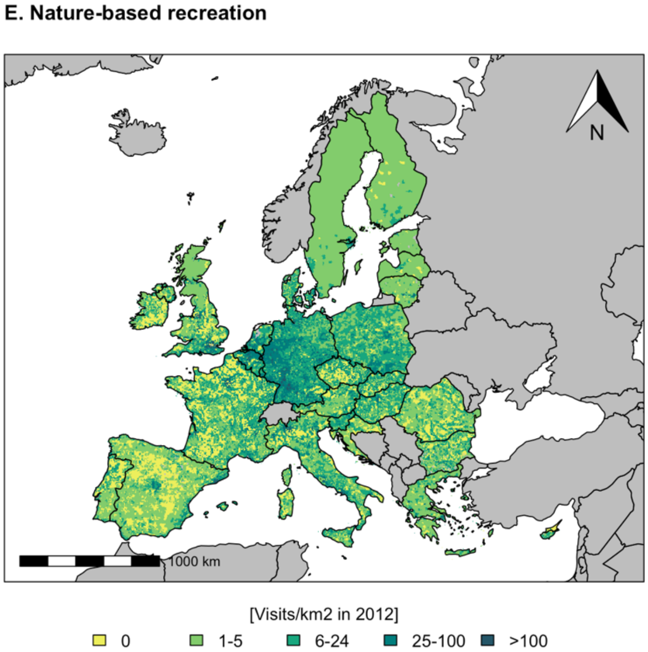


Figure 1. *Maps of the actual flow of the ecosystem services: (A) Crop Provision, (B) Timber Provision, (C) Carbon sequestration, (D) Crop pollination, and (E) Nature-based recreation. The legend brakes of the data was determined according to Vallecillo et al. (2019).*

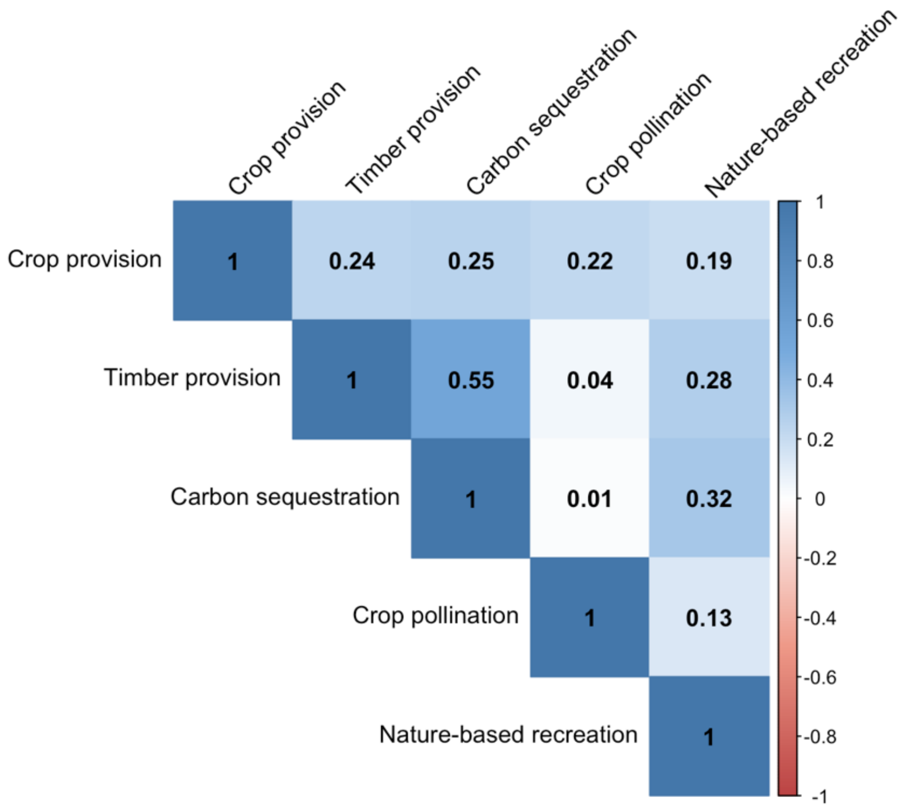


Figure 2. *Matrix of Spearman rank correlation coefficients ρ (rho) of monotonic relationships between the actual flow of the five ecosystem services: Crop provision, timber provision, carbon sequestration, crop pollination and nature-based recreation.*

Relation between ecosystem services and ecosystem type cover

The mean predicted ecosystem service values as a function of each cover percentage of the ecosystem types are shown in Fig. 3. The agricultural ecosystem cover (Fig. 3a) suggests the support for a potential synergy between timber provision, carbon sequestration and nature-based recreation, as the trendlines are similar. We observe an asymptotic decline in the timber provision and nature-based recreation. The mean predicted trend of carbon sequestration in agricultural ecosystems is bell shaped, with an initial decrease in carbon sequestration followed by an increase in areas with agricultural percentage cover higher than approx. 45%. Possible trade-offs are identified at low cover percentage (<50%) as crop provision and crop pollination increase while timber provision, carbon sequestration, and nature-based recreation decrease.

The artificial ecosystem type suggests a potential for synergies between crop pollination, carbon sequestration and nature-based recreation (Fig. 3b). The mean predicted values of these ecosystem services follow the same trend; a linear increase with the increase of artificial cover, suggesting potential multifunctionality. A potential trade-off between these services and timber provision is identified at high (>70%) artificial land cover.

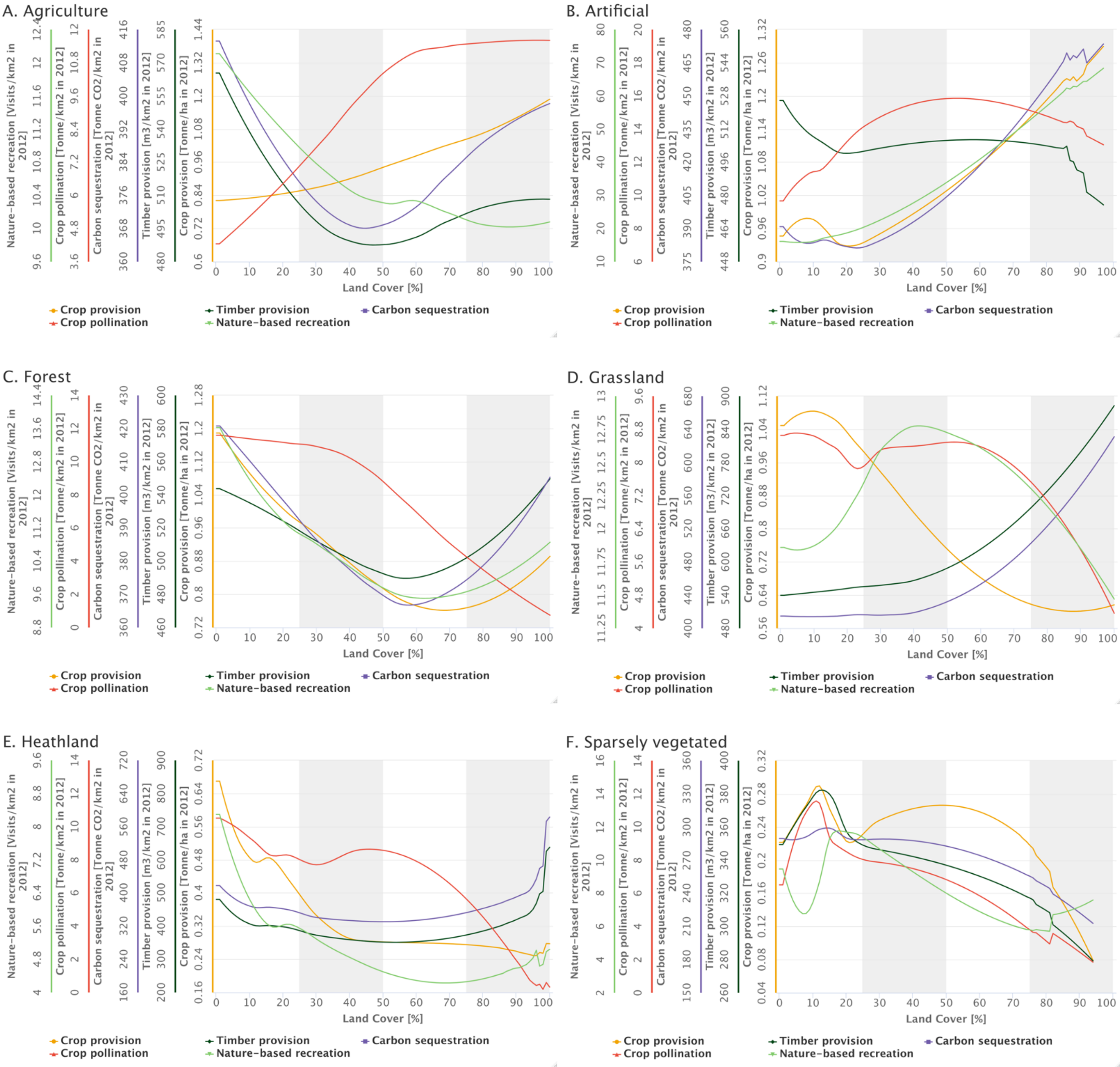
All ecosystem services except crop pollination follow the same overall pattern within forest land cover (Fig. 3c), which suggests a synergy between these ecosystem services. The mean predicted values of the four ecosystem services decrease within areas with a low (<55-60%) forest land cover and increase at the higher percentages. The predicted mean values of crop pollination decrease linearly as forest cover increases.

The mean predicted ecosystem services as a function of grassland (Fig. 3d) causes an asymptotic decrease of the predicted mean values of crop provision along with a decrease in crop pollination. The curve of nature-based recreation is bell-shaped with an initial increase followed by a decrease starting at approx. 40% grassland cover. Increase in grassland reveals a potential trade-off between the timber provision/carbon sequestration and the remaining three ecosystem services. A potential association exists between crop pollination and nature-based recreation as both ecosystem services decrease with increases in grass cover.

In heathland (Fig. 3e) the average predicted ecosystem service values of crop provision, crop pollination, and nature-based recreation are generally decreasing with at higher land cover percentage. Especially crop provision and nature-based recreation show a similar pattern which suggest a potential relationship between the services. The predicted values of timber provision and carbon sequestration continue to exhibit association with a slight decrease and stabilization across most land cover percentages, followed by a rapid incline in the mean predicted values at approx. 90-100% heathland cover.

The mean predicted values for the ecosystem services; crop provision, timber provision, carbon sequestration and crop pollination follow the same overall trend for increase in the sparsely vegetated land cover type (Fig. 3f). Initially, the values of the four services rapidly increase and reach their maximum values at approx. 10-15% land cover, followed by a short steep decrease until approx. 20-25% land cover. The predicted mean values of nature-based recreation follow the opposite trend in the beginning; a rapid decrease followed by a rapid increase. Values of nature-based recreation decrease alongside the other ecosystem service values from approx. 20% until approx. 80% sparsely vegetated land cover, followed by a slight increase at the final cover percentages.

Inland wetland ecosystem types show great potential for multifunctionality (Fig. 3g). A potential synergy exists between crop provision, timber provision, carbon sequestration and nature-based recreation as the mean predicted values follow the same general pattern. The values increase as the land cover percentage increases. The three first services have an initial decrease in the mean values, whereas nature-based recreation increases even at low land cover percentages. At an approx. 65% wetland cover the predicted value of timber provision is decreasing. A potential trade-off exists between the associated services and crop pollination. The mean estimated ecosystem service value of crop pollination increase until a land cover percentage of approx. 15 and is followed by a decline of the predicted value for the remaining land cover percentages.



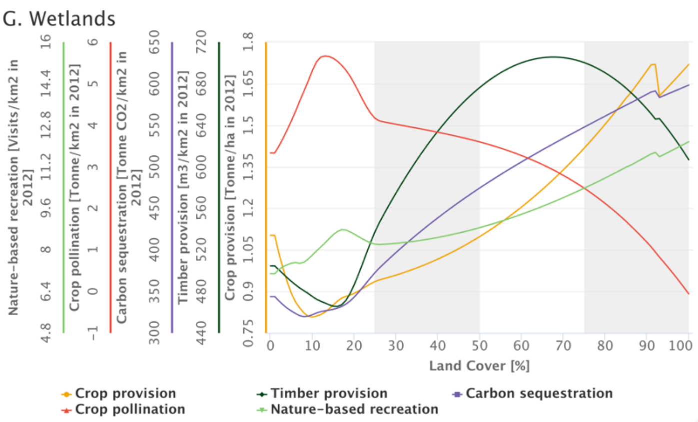


Figure 3. *Mean predicted ecosystem service value for land cover percentage. The predicted mean values of the given ecosystem services plotted against a 1% increase of the following land cover types:* ***(A)*** *Agricultural areas (N=10000 samples),* ***(B)*** *Artificial areas (N=10000 samples),* ***(C)*** *Forest (N=10000 samples),* ***(D)*** *Grassland areas (N=10000 samples),* ***(E)*** *Heathland (N=1000 samples),* ***(F)*** *Sparsely vegetated areas (N=1000 samples), and* ***(G)*** *Wetland areas (N=500 samples).*

Contrast of standardized ecosystem service values

The standardized average effect size for the ecosystem services calculated as z-score for different levels of land cover dominance showed varying trends for each of the seven ecosystem types (Fig. 4).

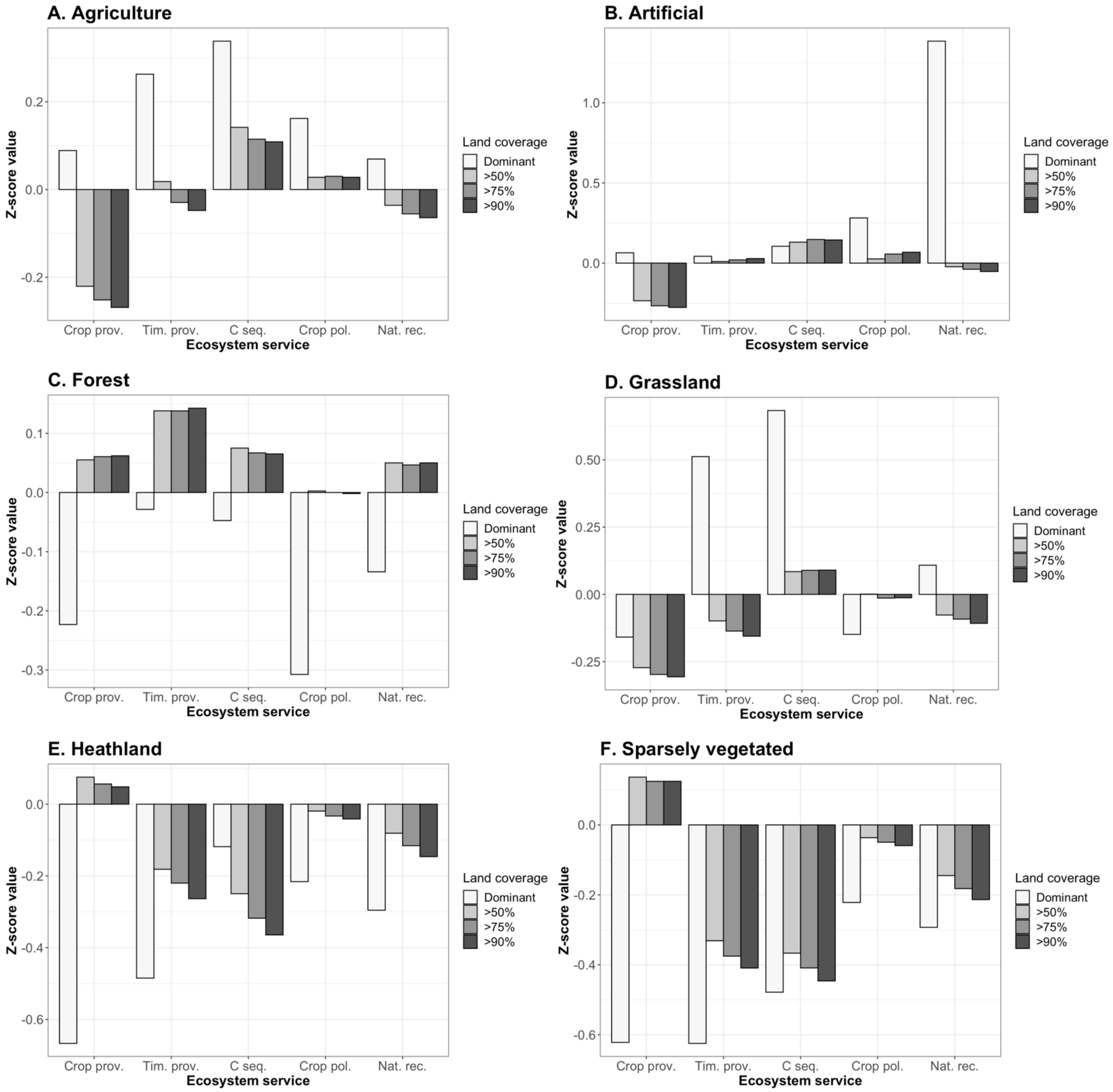
Fig. 4a indicate a difference between the ecosystem services provided in locations with a dominating agricultural ecosystem cover and locations that are entirely agricultural (>90%). The ecosystem service value for all five ecosystem services is higher than the mean (positive z-score) in areas where agriculture is the dominating land cover type. Dominance is not mutually exclusive of the presence of other land cover types within a given area. At high (>75%) agricultural cover percentages, only values for carbon sequestration and crop pollination are above the mean across Europe. An almost exclusively agricultural land cover (>90%) causes the lowest mean ecosystem service yield for all services.

A dominating artificial land cover (Fig. 4b) results in the highest mean ecosystem service value for all ecosystem services but carbon sequestration. In all cases the observed z-scores for a dominating artificial land cover are positive, with nature-based recreation being the only ecosystem service with a z-score value exceeding ± 1. A z-score value of ± 1 indicates that the mean ecosystem service value is more than one standard deviation above the mean and thereby show higher variability and distance from the norm. At high percentages of artificial land cover (>90%) z-score values are positive for timber provision, carbon sequestration and crop pollination, and negative for the remaining two ecosystems services. Artificial ecosystems show the potential for multifunctionality between timber provision, carbon sequestration, and crop pollination across all levels of coverage.

A dominating land cover of forest (Fig. 4c), heathland (Fig. 4e), sparsely vegetated land (Fig. 4f), and wetland (Fig. 4g) results in negative z-score values. At very high cover percentages (>90%) all four ecosystem types have positive mean z-score values for crop provision. At 90% forest (Fig. 4c) and wetland cover (Fig. 4g), a synergy between crop provision, timber provision, carbon sequestration and nature-based recreation is supported by low but positive z-score values. In both ecosystem types the mean predicted value of crop pollination is negative at very high (>90%) cover percentages. A potential trade-off exists between the associated services and crop pollination within wetlands.

Overall, heathland and sparsely vegetated ecosystem types show no potential for multifunctionality. At a 90% cover of heathland (Fig. 4e) and sparsely vegetated land (Fig. 4f) only crop provision has a positive mean z-score value.

A dominating land cover type of grassland (Fig. 4d) results in negative mean z-score values for crop provision and pollination, and positive values for timber provision, carbon sequestration and nature recreation, while 90% coverage only results in a positive z-score value for carbon sequestration.



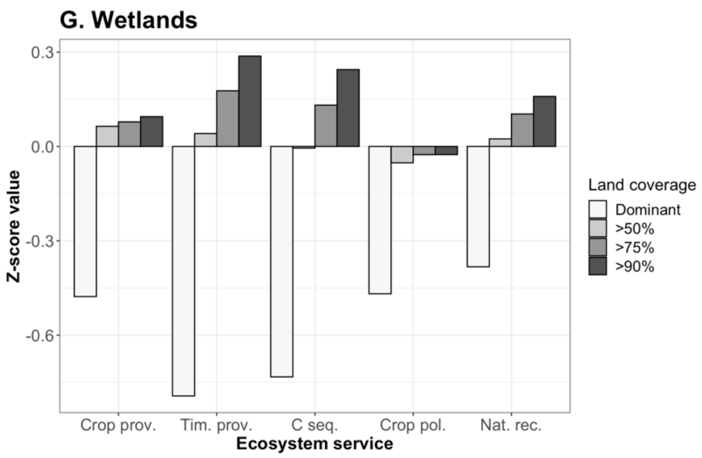


Figure 4. *Barplots of the mean of standardized z-score values representing each of the five ecosystem services: Crop provision, timber provision, carbon sequestration, crop pollination and nature-based recreation at different degrees of land cover for the following land cover types:* ***(A)*** *Agricultural areas,* ***(B)*** *Artificial,* ***(C)*** *Forest,* ***(D)*** *Grassland areas,* ***(E)*** *Heathland,* ***(F)*** *Sparsely vegetated areas, and* ***(G)*** *Wetland areas.*

Generally, the mean z-scores for a dominating land cover type shows the most divergence from the mean values for the EU, ranging from approx. -0.8 to 1.4 across all ecosystem types, while the mean values for 90% coverage range from approx. -0.45 to 0.3.

Discussion

The initial spatial projection of the actual flow of ecosystem services and the correlation analysis was done to investigate the potential for synergies and trade-offs between the five ecosystem services at a large scale across all of Europe. The weak correlations between the ecosystem services across Europe, would suggest that the services generally can be considered independent. The moderate positive correlation coefficient between timber provision and carbon sequestration indicated a potential synergy between the two services, but apart from this, no expectation of associations between the observed ecosystem services values were found based on the initial analyses.

To further investigate potential synergies and trade-offs between the ecosystem services, I tested whether the patterns from the correlation analysis holds true within a specific ecosystem type. Due to the assumption of independence, synchronous trendlines for the predicted mean ecosystem service flows within a certain ecosystem type is indicative of an ecosystem type's ability to express and provide more than one service at once, which suggest the potential for multifunctionality. The correlation pattern holds true for timber provision and carbon sequestration. The tendencies for these ecosystem services follow the same overall direction and pattern in all ecosystem types except for high (>50%) artificial land cover. These results further support a synergy between the two services, indicating that areas with a high potential for either timber provision or carbon sequestration most likely will have a high potential for supporting the other service as well. However, within all ecosystem types additional relationships between ecosystem services are revealed. All ecosystems show the potential for multifunctionality as synchronous trendlines for multiple predicted mean ecosystem service values are observed (Fig. 3). Including the ecosystem type in the analysis of ecosystem service relationships can therefore prove to be crucial as additional relationships are revealed by considering the ecosystem type.

The impact an ecosystem type has on the mean ecosystem service value differs for each type, but also between different cover percentages. The z-score value indicates how the difference between the observed and continual mean relates to the continual variability. The sign of the z-score values for the ecosystem services indicates whether the observed ecosystem service value for a specific ecosystem type is higher (positive z-score) or lower (negative z-score) than the mean ecosystem service value across all of Europe.

Results show that for all ecosystem types the z-score values differ between a dominating and very high (>90%) land cover, indicating that the ecosystem uniformity also affect the multifunctionality and potential trade-offs and synergies between ecosystem services. It is important to note that at low cover percentages for any given ecosystem type, we cannot exclude the effect of other ecosystem types that may influence the observed flow of a given ecosystem service. Specifically, areas where either of the seven ecosystem types is the one with the highest percentage cover (what I defined as dominant), does not necessarily signify a high cover percentage. As the seven ecosystem cover types have been generated with values ranging from 1-100, in the case of an even distribution between ecosystem types, cells with dominating ecosystems could potentially have a cover percentage as low as 15% (100/7=14.3) and still classify as the most predominant ecosystem type within a land cover cell. To account for this, I also evaluated the patterns of ecosystem service flows for areas where a given ecosystem type had a high cover percentage (either more than 50%, 75% or 90% of the cell is covered by a given type). The general trend for the ecosystem services across all ecosystem types is that the z-scores of the three high coverage levels are consistent amongst each other but differ from the areas where an ecosystem type is considered dominant.

Synergies and trade-offs

Synergies and trade-offs can be inferred from both the z-scores and from the models of the mean ecosystem service flow as a function of the ecosystem cover percentage. However, the deduction of whether inferred relationships qualify as either a trade-off or synergy must include results from both analyses. Synergies between ecosystem services cause the services to vary with the same directionality and magnitude, while trade-offs cause variation in opposite directions due to negative correlations between the variables. Ecosystem types with potential for multifunctionality must be able to sustain multiple ecosystem services simultaneously even at high cover percentages, therefore the mean standardized ecosystem service value should be positive or equal to zero.

Not all the ecosystem types have the same level of multifunctionality and number of synergies at high cover percentages. High coverage of forest and wetland ecosystem types show the highest level of multifunctionality among all the ecosystem types. A synergy exists between crop provision, timber provision, carbon sequestration and nature-based recreation, as all four ecosystem services are supported at high cover percentage. Forest ecosystems has the potential for multifunctionality between all ecosystem service types, as mean standardized crop pollination is equal to the European average. In wetland ecosystems a trade-off exists between the synergy and crop pollination, but both ecosystems show great potential for multifunctionality at high cover percentages.

Heathland and sparsely vegetated ecosystems show no potential for multifunctionality for any of the dominance levels. Agriculture, artificial, and grassland ecosystem types show varying degrees of multifunctionality depending on the land cover percentage. As the definition of dominance in this case allow an assumed influence of other ecosystem types, we see that their effect on the ecosystem service flow differs based on the dominating ecosystem type.

In locations where artificial ecosystems are the dominating ecosystem type, nature-based recreation is substantially higher than the European average. This is surprising, and most likely the result of the presence of other ecosystem types within the same cell and the definition of nature-based recreation (Table 1). Specifically, the definition of actual flow of nature-based recreation as the number of daily visits to recreational areas within a 4km radius. Populated areas, such as cities which qualify as artificial ecosystems (Maes *et al.*, 2020), near other ecosystem types (e.g., within the same 1km2 cell or nearby cells) will have a greater access to recreational services provided by nature and hence a higher actual flow (Vallecillo *et al.*, 2019).

Ecosystem heterogeneity and biodiversity implications for multifunctionality

The relationships between only five different ecosystem services were investigated within a single terrestrial ecosystem type, although many other ecosystem services can potentially exist in the same 1km^2 grid. Therefore, the observed potential for multifunctionality that areas with a heterogenous mosaic of ecosystem types can provide, is most likely greatly underestimated. The agricultural, artificial, and grassland ecosystem types generally showed greater potential for multifunctionality in locations where the land type was classified as dominating, and less potential in areas with high coverage suggesting that the presence and proximity of other ecosystem types impact the multifunctionality of ecosystem services in these landscapes. Multiple studies have shown that heterogeneity of landscape characteristics is highly relevant for ecosystem functions and services, and for biodiversity (Fahrig *et al.*, 2015; Stein *et al.*, 2014; Tuanmu & Jetz, 2015). Furthermore, several studies have concluded that high biodiversity is correlated with multifunctional relationships between ecosystem services e.g., Fitter *et al.* (2010) or Van der Plas *et al.* (2016). It is therefore likely that the potential for multifunctionality in ecosystem types such as the agricultural, artificial, and grassland cover is present at lower percentages (but still qualifying as the dominant type) can be enhanced by combining multiple ecosystem types which overall would augment the heterogeneity and most likely also the biodiversity of these landscapes.

Continental vs. regional or local levels

I tested for synergies, trade-offs and multifunctionality across specific ecosystem types at the continental level of the European Union. While results indicated that detecting interactions between ecosystem services is possible at a continental level, synergies and trade-offs between ecosystem services are produced at regional and local levels, and results are therefore likely to differ across different scales (Hauck *et al.*, 2013; Rodríguez-Loinaz *et al.*, 2015; Willemen *et al.*, 2012). The proposed methods for detecting synergies and trade-offs could most likely be further improved by conducting analyses at regional or local scales e.g., country or municipality levels, to eliminate the effects of region-specific characteristics such as temperature, precipitation, and drought which has been shown to impact ecosystem functions and services (De Groot *et al.*, 2002; Lohrer *et al.*, 2015). Another potential way to account for spatial and temporal heterogeneity between regions is dividing European landscapes based on the 13 Environmental Zones (EnZs) proposed by (Metzger, 2003). Examination of ecosystem services within the same EnZs ensures that differences in associations and interactions are not caused by inherently different environments between the analyzed locations (Metzger, 2003).

Potential bias

The definitions and methods used to calculate the use and actual flow of the ecosystem services may lead to bias (Table 1). Some ecosystem services are location dependent and calculated based on the sustaining land cover such as agricultural land for crop provision and forest cover for timber provision (Vallecillo *et al.*, 2019). This could lead to an altered mean ecosystem service value for these services within the associated land cover type. This should not affect the overall results of the analysis, as the directionality is likely to stay the same. The ability to infer trade-offs and synergies between ecosystem services therefore shouldn't change. It could however affect the magnitude of the estimated deviation from the mean values within the individual ecosystem types compared to other ecosystems, and effects may be under- or overestimated in areas where only few observations are available.

Conclusion

Changes in the European land use over the next decade will likely influence the flow of ecosystem services. The results of this study have shown that ecosystem types along with the level of dominance greatly impacts the level of multifunctionality that an ecosystem can sustain. Some ecosystem types proved more successful in combination with other land cover types, while forests and wetlands provide the highest levels of multifunctionality at very high cover percentages. An understanding of the relationships between the interaction of ecosystem services, and the role of ecosystem types is key to successful management and to ensure the desired outcome of conservation practices. Within urban and agricultural areas, the promotion of heterogeneity should increase the potential for multifunctionality, while wetlands and forests require high cover percentages to fulfill the potential for a high level of multifunctionality between the five examined ecosystem services. Although the examined influence of ecosystem types on ecosystem service relationships proved to be important, the continental scale correlation between timber provision and carbon sequestration was valid in all but two ecosystem types. This infers a great potential for initial examination of likely multifunctionalities using correlation analyses across a larger scale, but when leaving out consideration of ecosystem types important trade-offs and multifunctionalities can go unnoticed.

References

Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N., . . . Klaus, V. H. (2015). Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. *Ecology letters, 18*(8), 834-843.

Bennett, E. M., Peterson, G. D., & Gordon, L. J. (2009). Understanding relationships among multiple ecosystem services. *Ecology letters, 12*(12), 1394-1404.

Bivand, R., & Lewin-Koh, N. (2021). maptools: Tools for Handling Spatial Objects (Version R package version). Retrieved from https://CRAN.R-project.org/package=maptools

Büttner, G. (2014). CORINE land cover and land cover change products. In *Land use and land cover mapping in Europe* (pp. 55-74): Springer.

Byrnes, J. E., Gamfeldt, L., Isbell, F., Lefcheck, J. S., Griffin, J. N., Hector, A., . . . Emmett Duffy, J. (2014). Investigating the relationship between biodiversity and ecosystem multifunctionality: challenges and solutions. *Methods in Ecology and Evolution, 5*(2), 111-124.

Daily, G. C. (1997). Introduction: what are ecosystem services. *Nature's services: Societal dependence on natural ecosystems, 1*(1).

De Groot, R. S., Wilson, M. A., & Boumans, R. M. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological economics, 41*(3), 393-408.

European Commission Directorate-General for Environment. (2021). *EU biodiversity strategy for 2030 : bringing nature back into our lives*: Publications Office.

Fahrig, L., Girard, J., Duro, D., Pasher, J., Smith, A., Javorek, S., . . . Tischendorf, L. (2015). Farmlands with smaller crop fields have higher within-field biodiversity. *Agriculture, Ecosystems & Environment, 200*, 219-234.

Fitter, A., Elmqvist, T., Haines-Young, R., Potschin, M., Rinaldo, A., Setala, H., . . . Murlis, J. (2010). An assessment of ecosystem services and biodiversity in Europe. *Issues in Environmental Science and Technology, 30*, 1-28.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., . . . Gibbs, H. K. (2005). Global consequences of land use. *science, 309*(5734), 570-574.

Garland, G., Banerjee, S., Edlinger, A., Miranda Oliveira, E., Herzog, C., Wittwer, R., . . . van Der Heijden, M. G. (2020). A closer look at the functions behind ecosystem multifunctionality: A review. *Journal of Ecology, 109*(2), 600-613.

Hauck, J., Görg, C., Varjopuro, R., Ratamäki, O., Maes, J., Wittmer, H., & Jax, K. (2013). "Maps have an air of authority": potential benefits and challenges of ecosystem service maps at different levels of decision making. *Ecosystem Services, 4*, 25-32.

Hijmans, R. J. (2021). raster: Geographic Data Analysis and Modeling (Version R package version 3.5-2). Retrieved from https://CRAN.R-project.org/package=raster

Hölting, L., Jacobs, S., Felipe-Lucia, M. R., Maes, J., Norström, A. V., Plieninger, T., & Cord, A. F. (2019). Measuring ecosystem multifunctionality across scales. *Environmental Research Letters, 14*(12), 124083.

Jiang, M., Bullock, J. M., & Hooftman, D. A. (2013). Mapping ecosystem service and biodiversity changes over 70 years in a rural E nglish county. *Journal of Applied Ecology, 50*(4), 841-850.

Jopke, C., Kreyling, J., Maes, J., & Koellner, T. (2015). Interactions among ecosystem services across Europe: Bagplots and cumulative correlation coefficients reveal synergies, trade-offs, and regional patterns. *Ecological indicators, 49*, 46-52.

Kunst, J. (2020). highcharter: A Wrapper for the 'Highcharts' Library. (Version R package version 0.8.2). Retrieved from https://CRAN.R-project.org/package=highcharter

Lohrer, A. M., Thrush, S. F., Hewitt, J. E., & Kraan, C. (2015). The up-scaling of ecosystem functions in a heterogeneous world. *Scientific reports, 5*(1), 1-10.

Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J. I., . . . Santos-Martín, F. (2020). *Mapping and Assessment of Ecosystems and their Services: An EU ecosystem* assessment. EUR 30161 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17833-0, doi:10.2760/757183, JRC120383.

Mastrangelo, M. E., Weyland, F., Villarino, S. H., Barral, M. P., Nahuelhual, L., & Laterra, P. (2014). Concepts and methods for landscape multifunctionality and a unifying framework based on ecosystem services. *Landscape Ecology, 29*(2), 345-358.

Metzger, M. (2003). The environmental classification of Europe, a new tool for European landscape ecologists. *Landschap: tijdschrift voor landschapsecologie en milieukunde, 20*(5), 50-54.

Millennium Ecosystem Assesments. (2005). *Ecosystems and human well-being* (Vol. 5): Island press United States of America.

Peters, M. K., Hemp, A., Appelhans, T., Becker, J. N., Behler, C., Classen, A., . . . Frederiksen, S. B. (2019). Climate–land-use interactions shape tropical mountain biodiversity and ecosystem functions. *Nature, 568*(7750), 88-92.

R Core Team. (2021). R: A language and environment for statistical computing. Vienna, Austria.: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/.

Rodríguez-Loinaz, G., Alday, J. G., & Onaindia, M. (2015). Multiple ecosystem services landscape index: A tool for multifunctional landscapes conservation. *Journal of environmental management, 147*, 152-163.

Stein, A., Gerstner, K., & Kreft, H. (2014). Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. *Ecology letters, 17*(7), 866-880.

Tsujimoto, M., Kajikawa, Y., Tomita, J., & Matsumoto, Y. (2018). A review of the ecosystem concept—Towards coherent ecosystem design. *Technological Forecasting and Social Change, 136*, 49-58.

Tuanmu, M. N., & Jetz, W. (2015). A global, remote sensing-based characterization of terrestrial habitat heterogeneity for biodiversity and ecosystem modelling. *Global Ecology and Biogeography, 24*(11), 1329-1339.

Vallecillo, S., La Notte, A., Ferrini, S., & Maes, J. (2019). How ecosystem services are changing: an accounting application at the EU level. *Ecosystem Services, 40*, 101044.

Van der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C., . . . Baeten, L. (2016). Jack-of-all-trades effects drive biodiversity–ecosystem multifunctionality relationships in European forests. *Nature communications, 7*(1), 1-11.

Wei, T., & Simko, V. (2021). R package 'corrplot': Visualization of a Correlation Matrix (Version 0.92). Retrieved from https://github.com/taiyun/corrplot

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Willemen, L., Veldkamp, A., Verburg, P., Hein, L., & Leemans, R. (2012). A multi-scale modelling approach for analysing landscape service dynamics. *Journal of environmental management, 100*, 86-95.