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Finding the Green Grass in the Haystack? Integrated National Assessment of Ecosystem Services and Condition in Hungary, in Support of Conservation and Planning

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Abstract: Human well-being needs healthy ecosystems, providing multiple ecosystem services. Therefore, the assessment of ecosystems on large scales is a priority action. In Hungary, this work (MAES-HU) took place between 2016 and 2022. Twelve ecosystem services (ES) were mapped and assessed along with several ecosystem condition (EC) indicators. Their integrated spatial analysis aimed to identify patterns of ES multifunctionality, reveal relationships between EC and ES and delineate ES bundles. The results show outstanding multifunctionality of natural ecosystem types compared with the more artificial types, emphasizing the importance of natural areas in order to fulfil human needs. Native forests provide the most varied range of services, which underlines the importance of forest management to consider multiple services. There is a positive correlation between condition and multifunctionality in forests; areas in better condition (in terms of species composition and structure) provide more services at an outstanding level. ES bundles mainly reflect the major ecosystem types, topography and forest condition. Our analysis represents an example of synthesizing national MAES results with a combination of methods. Finding ES hotspots on a national scale and connecting them with an assessment of EC may help in finding optimal strategies to balance conservation targets and competing land uses.

Keywords: ecosystem services; ecosystem condition; national MAES; multifunctionality; ecosystem services bundles; Central Europe; Hungary

1. Introduction

Healthy ecosystems provide the basis for a multitude of services on which our well-being depends. However, despite earlier efforts to halt the trends of biodiversity decline and ecosystem degradation, these continue at an unprecedented rate [1,2]. Thus, the conservation and restoration of well-functioning ecosystems are now a priority [3,4]. Recent policies acknowledge this both at the global and EU levels. The new Kunming-Montreal

Global Biodiversity Framework [5] sets ambitious targets to halt biodiversity loss, like increasing the areas under effective conservation to at least 30% and restoring at least 30% of degraded ecosystems. The EU's Biodiversity Strategy for 2030 [4] and its Nature Restoration Law proposal define binding restoration targets for specific habitats and species, covering at least 20% of the EU's land and sea areas by 2030 [6]. Meeting these targets will require allocating nature restoration and conservation actions with the highest benefits but lowest costs on society, and thus must be based on the best available scientific evidence. A promising strategy for the highest benefit is to simultaneously consider biodiversity and ecosystem services hotspots as well as the socio-economic drivers behind them [7,8].

Determining how to manage multiple ecosystem services across landscapes sustainably is still a key challenge [9–11]. The relevance of different ecosystem services varies spatially, and this variance increases with the modelled system's complexity and the study area's size [12]. In order to take full advantage of using the ecosystem services framework and effectively support cross-sectoral decision-making for the optimal use of resources, an overarching approach is needed. Combining single ecosystem service assessments is essential for a balanced decision-making and management process. Such integration efforts bring associated challenges in indicator and scale choice, aggregation methods, and comparability of indicators calculated with different methods and often with different levels of detail [11].

One of the most common integrative ecosystem service assessment approaches is examining multifunctionality at one or more spatial scales [13]. Analysing the spatial patterns of multifunctionality metrics and hotspots can be essential for the spatial prioritisation of areas for protection or restoration [14–17]. Multifunctionality is a rather generic term with various understandings, which resulted in several recent conceptualisation efforts [18]. Related research is divided into two groups: one examining the relationship between biodiversity and overall ecosystem functioning ("biodiversity-ecosystem functioning research") and one looking at the management of multiple ecosystem services across landscapes ("land management research") [19]. Our work belongs to the latter group and uses the definition of [13], where "multifunctionality refers to the capacity of an area to supply multiple ecosystem services". The most common way to map and assess ecosystem service multifunctionality is to aggregate a set of ecosystem services into one metric [18]. This can be accomplished by calculating the number, average or sum of all the available services within a spatial unit or, alternatively, by including only the services provided at or above a certain level (the 'threshold' approach) [20–23]. The threshold method is widely recommended for indicating whether multiple functions have high value without the predominance of a single function or service affecting the result [24,25].

While the term multifunctionality implicitly suggests that "the more, the better", this is not necessarily true [13,26]. There is a need to acknowledge a diverse set of differing and often non-reconcilable functions and uses. Thus, such synthesising assessments should not only simultaneously consider multiple ecosystem services but also examine their interactions and their spatial patterns [18,27].

Bundles of ecosystem service capacity ("ecosystem service bundles" hereafter) are defined as sets of associated ecosystem services that are linked to a given ecosystem and that usually appear together repeatedly in time and/or space [28]. Correctly detecting and mapping bundles is an efficient way to support decision-making [29]. The interrelations between ecosystem services within these bundles can be positive or negative, resulting in synergies or tradeoffs [30]. There are numerous studies analysing tradeoffs, synergies and bundles of ecosystem services [18,31–34], some at the national level [29,35–37] and even at a global scale [38]. However, examples of policy-driven applications at the national scale, such as integrative national MAES assessments, are still not common in the literature [11,39] even though they can be considered the capstone and, at the same time, one of the most significant challenges of a MAES process.

1.1. Ecosystem Condition and Its Relations to Ecosystem Services and Multifunctionality

It is broadly acknowledged that only healthy ecosystems can provide ecosystem services at the appropriate level [4,40,41]. At the European scale, habitats with favourable conservation status provide a higher capacity for regulating and cultural ecosystem services than those with unfavourable conservation status [34]. In early versions of the ecosystem services framework, aspects of ecosystem condition (or state) appeared as services under the separate group of "supporting services" [42]. However, ecosystem condition was later recognised as "the overall quality of an ecosystem unit in terms of its main characteristics underpinning its capacity to generate ecosystem services" [43]. Finding and especially quantifying the essential links between ecosystem condition and ecosystem services delivery is not an easy task but is of utmost importance in linking the state of ecosystems to human well-being [44]. Consequently, research on this topic has increasingly been in focus in recent years [45,46]. Still, there are many knowledge gaps, especially concerning the effective integration of condition indicators into ecosystem services models [47].

Links between nature, its state and anthropogenic activity are the subject of research in several separate scholarly communities. These parallelly work on the subject, using different but overlapping terminologies and definitions [48]. It is especially true in the case of ecosystem condition, which is strongly related to numerous earlier concepts such as ecosystem health, ecosystem integrity, ecosystem quality and naturalness [49,50]. The concept itself and the indicators to measure condition have been subject to much debate [47,51,52]. The lack of consensus is evident in all related work. According to [19], much of the research on exploring multifunctionality includes a mix of state, rate and indicator variables in the calculations. In the "land management" group of research papers on ecosystem service multifunctionality, indicators of ecosystem condition are also often incorporated in multifunctionality indices. Sometimes they appear as indicators of supporting services (e.g., [37,53,54]) or are interpreted as a potential measure of ecosystem capacity [55]. Some studies use the framework designed in the MAES process [56], which separates the two [34,56]. Still, studies on the relationship between ecosystem service multifunctionality and condition within this framework seem, to date, mostly lacking.

Ecosystem condition can be described in many ways [57], and one of the most common is the use of biodiversity indicators [34,58]. Plant species richness and diversity are especially well-linked to the provision of multiple services and functions in forests and other ecosystems [25,46,59,60]. Forest structure and its connection to ecosystem services multifunctionality are less studied, especially on a large scale. However, specific structural elements (e.g., the presence of large trees or the shrub layer) were shown to have positive effects on ecosystem services [53]. Furthermore, as structural complexity can both promote species diversity and result from it [61], structural attributes can indirectly indicate the presence and diversity of less easily measurable but important taxonomic groups [62–64].

1.2. MAES-HU

In Hungary, an EU co-financed project mapped and assessed ecosystem types, condition, and services from 2016–2022 at the national level (Mapping and Assessment of Ecosystems and Services in Hungary—MAES-HU) within the frame of the EU Biodiversity Strategy for 2020 [65,66]. The team built spatial databases of the ecosystem types [67], their condition [66] and services and assessed these with biophysical, economic and social indicators. Twelve services were mapped and assessed at the four levels of the cascade model [68]: the condition of the ecosystems, their capacity to provide a particular service ('ecosystem service capacity'), the actual use of the services by people and their contribution to well-being. We use the term (cascade) level as described in [69]. As MAES-HU did not include primary data collection, all maps and assessments were based on existing national databases.

We present here the first integrative analysis of the ecosystem services and condition maps created in MAES-HU, using multiple methods and scales to answer the following questions:

- Q1: How is ecosystem services multifunctionality distributed across landscapes in Hungary?
- Q2: Is there a relationship between ecosystem services multifunctionality and ecosystem condition in forests in terms of species composition and structure?
- Q3: What are the interrelationships/synergies, tradeoffs and bundles/between the capacity indicators of the twelve ecosystem services mapped in MAES-HU? What bundles can be identified (at the capacity level)?
- Q4: How are the individual capacity indicators of the examined ecosystem services related to ecosystem condition Does better ecosystem condition ensure a higher capacity to provide ecosystem services?

2. Materials and Methods

2.1. Data

2.1.1. Ecosystem Services Indicators

For the analysis described in this paper, we used the indicators developed and mapped in the MAES-HU project. Twelve ecosystem services were chosen after a lengthy prioritisation process. This consisted of four participatory workshops where the representatives of the most important sectors prioritized the services according to pre-defined criteria. Indicators for the chosen services were developed, mapped and assessed in six thematic working groups consisting of experts from different fields [66]. While the underlying conceptual framework of the ecosystem service cascade [68] was common to all, and indicator development for all ES was targeted at all levels of the cascade, slight differences in interpretation occurred, which made an alignment necessary. As a first step towards synthesis, we therefore defined the place of all the available service indicators within a slightly refined cascade model [68]. We chose ecosystem service capacity (the capacity of the ecosystems to provide ecosystem services), as this was the level where most of the services were successfully mapped and assessed. We took care to only choose conceptually similar indicators that aligned well with our stricter definition of capacity. The chosen indicators were to reflect the 'current' or 'actual' capacity, which refers to the amount of service that could be immediately used (e.g., the wood supply currently available at a certain location or the wood yield/year and not a theoretical amount of wood that could be sustainably produced there in a period of, e.g., 120 years). Analysing the 'actual' capacity was considered useful for both conservation and spatial planning. For the sake of consistency, in certain cases, we slightly modified the (cascade) level of the indicator or the calculation method compared to the original level (Table 1). By 'original level', we mean the cascade level where the expert working group developing that indicator had originally placed it. The list of indicators and a short description can be found in Table 1. More details are available in [70].

2.1.2. Ecosystem Condition Indicators

The good condition of ecosystems ensures their ability to provide services. However, the use of these services, in turn, affects their condition [40,58]. In order to acknowledge this complex relationship, we included some ecosystem condition indicators in the analysis, also created in the MAES-HU project. There were two types of condition indicators in MAES-HU. 'Service-specific' condition indicators, which directly determine ecosystem service capacity, were selected and assessed by the thematic working groups working on the assessment of individual ecosystem services. 'General' ecosystem condition indicators aimed to describe ecosystem integrity; they reflect the intrinsic values of nature and those aspects of condition which are hard to directly link to the capacity of ecosystems to provide services. Of the service-specific condition indicators, we included only a few that have significance for more than one service or ecosystem type. Three of these are related to soil characteristics, and one describes the diversity of ecosystem types. Of the other general group, we used the composite indicators explicitly designed for the major ecosystem types. These composite indicators serve to characterise ecosystem condition for conservation purposes and also provide the means to relate the typical range of service provisioning of ecosystems to their condition. These are mainly built from pressure-based proxies, except in the case of forests. As the indicators of forests are based on more detailed and direct data, we included not only the final composite indicator but also its two main components (or sub-indicators). As the two focus on different aspects of forest condition, this allowed us to obtain a more nuanced picture in the analysis. The indicators and their short descriptions can be found in Table 2. The MAES-HU ecosystem condition mapping concept and the indicators are described in detail in [57].

Table 1. Summary of the ecosystem service indicators chosen for the MAES-HU synthesis and their short description. The term 'original' refers to the cascade level initially defined by the expert group creating the indicator.

Ecosystem Service	Indicator	Original Level	Short Description
Cultivated crops for nutrition	Crop yield	Level 3	The ratio of the actual yield (t/ha) of a certain cultivated plant to the national average of that crop (%) in 2015.
Reared animals and their outputs for nutrition	Grass yield	Part of level 2	(t/ha) landscape-level rough estimation based on the proportion of different grassland vegetation types defined by the Á-NÉR classification system [71] (the spatial units are 'vegetation landscapes' delineated based on the MÉTA database [72]).
Plant-based energy resources (firewood production)	Wood supply	Level 1	Living wood stock (m^3/ha) from the National Forestry Database.
Plant-based energy resources (firewood production)	Wood yield	Level 2	Annual average wood production expected in the ten years following the baseline year (2015) (m^3/ha/year)
Global climate regulation	Greenhouse gas (GHG) balance	Level 2 (modified)	Modelled GHG balance of a longer period (t CO_2eq./ha/year; 1988–2014) (the original separate maps for ecosystem types were combined in one, and wetlands obtained a constant value).
Microclimate regulation	Local climate index	Level 1	Expert estimate for each MAES-HU ecosystem type based on the literature adapted to Hungarian circumstances.
Microclimate regulation	F-index	Level 1	The ratio of the maximum evapotranspiration for the considered land-use class and the reference evapotranspiration of 12 mm high grass in a given climate (expert estimates based on the literature)
Pollination	Relative pollination potential	Level 2	The relative potential of ecosystems to support wild bees, which play an important role as pollinators (flower sources and nesting places)—expert scoring of ecosystem types with modifying factors (flowering tree species in forests, edges).
Mediation of waste and toxics—filtration of water-soluble pollutants	Filtration by ecosystems	Level 2	Estimated filtration capacity of the vegetation, also considering the soil (hydrologic capacity) and the elevation (topographic wetness index).

Table 1. *Cont.*

Ecosystem Service	Indicator	Original Level	Short Description
Mitigation of surface degradation and erosion control	Erosion risk	Level 3	The amount of non-eroded soil. USLE empirical equation with expert estimates on vegetation coefficients (t/ha/year).
Hydrological cycle and water flow regulation	Excess water probability	Level 2	Capacity to store excess water (Complex Excess Water Risk Probability map)
Flood and rainwater runoff control (in hilly areas)	Runoff retention	Level 2	Runoff retention of vegetation (density), also considering the soil (hydrologic capacity) and the elevation (topographic wetness index), with expert estimates on vegetation coefficients.
Recreation—hiking	Hiking	Level 1 and partly Level 2	Landscape-level and local natural and anthropogenic attractions together. Level 1: "Naturalness" (expert scoring of ecosystem types), level of protection, water-related properties (distance from water, size of water surface, naturalness of the shoreline) and landscape diversity (both elevation and habitats). Part of the original Level 2: accessibility (hiking trails) + attractions (natural and anthropogenic).
Mushroom gathering	Fungi site suitability	Level 2	Expert scoring of ecosystem types modified by further factors: forest condition index, soil pH and climate type (Feddema-index).

Table 2. Summary of the ecosystem condition indicators included in the analysis (with their short description).

Related Ecosystem Service or Mapping Approach	Indicator	Short Description
Service-specific indicator: filtration Level 1	Potential runoff coefficient	A dimensionless coefficient relating the amount of runoff to the amount of precipitation received (modelled based on soil types)
General condition indicator (ecosystem specific, direct)	Forest condition (structure)	Composite condition indicator, based on expert scoring Sub-indicators: number of age groups, at least a 30-year age difference, presence of old and large trees, number and diversity of dbh classes and characteristics of the shrub layer. The indicator used in the analysis is the ratio of the local score to the national maximum (%).

Table 2. *Cont.*

Related Ecosystem Service or Mapping Approach	Indicator	Short Description
General condition indicator (ecosystem specific, direct)	Forest condition (tree species composition)	Composite condition indicator, based on expert scoring. Sub-indicators: *Non-plantation forests*: number of native admixing species, the ratio of non-native and invasive tree species, the presence of the main species in the right ratio for the ecosystem type and the ratio of admixing native species compared with that expected. *Plantation forests*: species number and the ratio of native tree species, and the ratio of invasive species. The indicator used in the analysis is the ratio of the local score to the national maximum (%).
General condition indicator (ecosystem specific, direct)	Forest condition (final score)	Composite condition indicator, created from the forest composition and structure indicators with the following formula: summed score is 1.5 $\times$ composition score + structure score. The scores and the formula were based on expert decisions. The summed score was simplified into five categories using percentiles and expert decisions.
Service-specific indicator: Global climate regulation, Level 1	Soil organic C content	Based on the DoSoReMi soil database [73], the map is simplified to an ordinal 1–10 scale.
General condition indicator	Soil fertility index	A general soil fertility map was created by scoring units of genetic soil classification [74]. A ten-grade version of the original 100-point assessment [75].
General condition indicator landscape-level	Habitat diversity	Shannon diversity of ecosystem types within a 1 km radius (ratio to the national maximum, %)
General condition indicator (ecosystem-specific, pressure-based proxy)	Grassland condition	Binary indicator (1: less favourable, 2: favourable) modelled from proxy pressure indicators (using decision trees) Teaching dataset: Németh-Seregélyes naturalness (ordinal variable on a scale of 1–5) Variables: proportion of grasslands and near-natural ecosystem types within 300, 500 and 1000 m; distance from roads and surface waters; the presence of specifically protected grasslands; and frequency of inundation (Copernicus WWPI—[76])
General condition indicator (ecosystem-specific, pressure-based proxy)	Wetland condition	Expert scoring using the sub-indicators: frequency of inundation (Copernicus WWPI [76]), presence of roads, the proportion of wetlands and near-natural ecosystem types, presence of surface waters and waterlogged areas, heterogeneity of wetlands (all within 220 m). The indicator used in the analysis is an ordinal variable, the summed expert score.

Table 2. *Cont.*

Related Ecosystem Service or Mapping Approach	Indicator	Short Description
General condition indicator (ecosystem-specific, pressure-based proxy)	Cropland condition	Expert scoring using the sub-indicators: average proportion of near-natural ecosystem types within 300 m, mean parcel size, number of cultivated plants, the proportion of alfalfa and green fallow, proportion of fallow, proportion of maize, proportion of specifically protected areas (spatial unit: variable-sized blocks related to the Hungarian Land Parcel Identification System) The indicator used in the analysis is an ordinal variable, the summed expert score.

2.2. Study Area

The study area was Hungary (Central-Eastern Europe). As the study subject was shown to be scale-dependent [77–79], some of the analyses were carried out at multiple scales, not only for the entire country but also for sub-areas delimited according to specific criteria. The sub-areas were partly defined as larger landscape units according to the official landscape cadastre of Hungary (lowlands versus hilly and mountainous areas [80]) and partly according to main ecosystem types (forests, grasslands, wetlands and agricultural areas). The two approaches were combined in some cases (e.g., lowland forests). In MAES-HU, the analysis was separately carried out for all major ecosystem types as well as for the whole country. Still, in this study, we present only the results for some of the sub-areas: (1) the entire country, (2) all forests, (3) forests of hilly and mountainous regions and (4) lowland forests (Figure 1). Of all the major ecosystem types, forests had the most detailed data available, allowing a more in-depth analysis.

2.3. Analysis Methods

2.3.1. Multifunctionality

We applied a simple measure of multifunctionality, a type of ‘Ecosystem service richness’ indicator according to the definitions of [18] and created hotspot maps covering most of the country.

The original ecosystem service capacity maps were aggregated to 100 m spatial resolution (for those that initially had a finer resolution, e.g., of 20 m, we calculated the median of the smaller cells within the new 100 m cells). Urban areas, other artificial surfaces and water surfaces were not included in this evaluation. Urban areas were separately analysed, but this analysis is not part of this paper as they differ in too many ways from the more natural ecosystem types. Artificial surfaces, such as roads or railways, are not relevant to our analysis. As for water surfaces, too many of the examined services were not informative or relevant. As a consequence, these areas would have been shown to underperform in terms of multifunctionality, but this would have been a false result, so they were omitted. On all individual maps, we masked the non-relevant and the data-scarce areas. Each service capacity map was binarised using multiple thresholds (the upper 5th, 10th, 20th and 50th percentiles of the values of each map) to highlight high-capacity areas. These binary maps were then summed, and the sum was used as the measure of multifunctionality in our study. The resulting hotspot maps highlight the areas that are able to provide several ecosystem services at a relatively high level. The GIS work was partly carried out with ArcMap 10.2 and partly with the R statistical software [81] “raster” package [82]. Of the multifunctionality maps created with different thresholds, we chose to use the one with the median (top 50%) threshold for further analysis, as the maps with stricter thresholds would only differentiate within the hilly and mountainous regions.

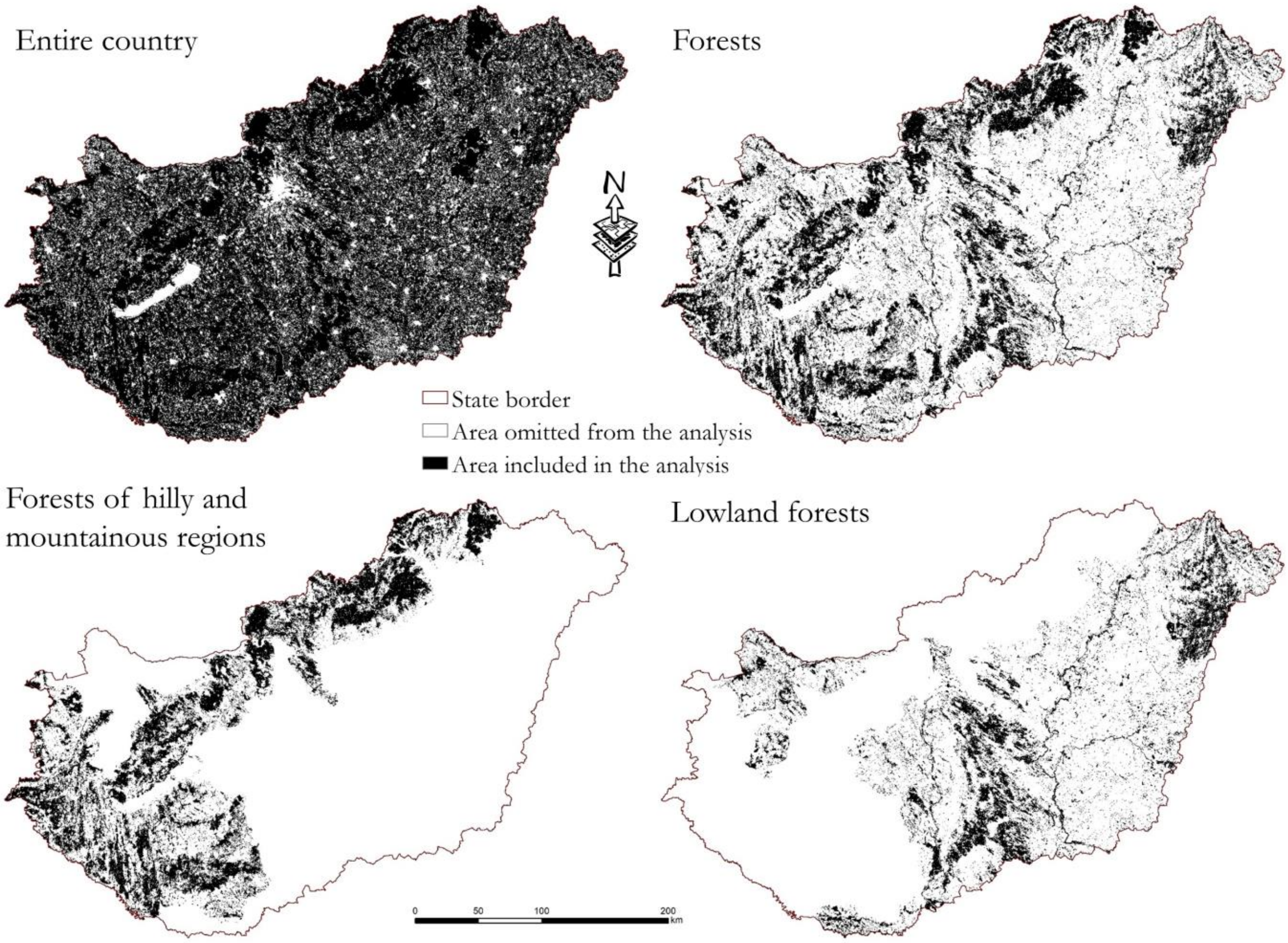

Figure 1. The sub-areas used for the analyses presented in this paper. White areas were omitted from each analysis either for being non-relevant or lacking data.

In addition to creating a hotspot map, we analysed the resulting multifunctionality metric by comparing the most common values (the majority of pixels) within the major ecosystem types. These were defined based on the ecosystem-type map of Hungary [67]. The following categories were included: agricultural areas, grasslands, forests and wetlands. Forests were further divided to allow more in-depth analysis; we separated the relatively more natural native forests from tree plantations. According to the FAO's definition [83], tree plantations are "intensively managed forests, mainly composed of one or two tree species, native or exotic, of equal age, planted with regular spacing and mainly established for productive purposes". According to the definition used in MAES-HU and this paper, native forests are defined as those stands where the ratio of native tree species is at least 50%, whereas the rest are considered plantations. However, it is important to note that in Hungary, many of the forests with predominantly native species are also plantations and/or monocultures, according to the FAO definition. In MAES-HU, these were not considered a separate ecosystem type; the lack of admixing species and the homogeneity of structure is reflected in their condition score.

The measure of ecosystem services multifunctionality we calculated did not include ecosystem condition indicators. That allowed us to examine the relationship between the two, which can yield much-needed insights into underlying links between the condition of ecosystems and the multiple benefits they provide to humanity [45,47]. We carried out this analysis only for the forests because this type had the most detailed and reliable data.

2.3.2. Network-Based Visualisation of the Relationships between Individual Ecosystem Service and Condition Indicators

As a first step, we carried out correlation analyses using packages "Hmisc" [84] and "corrplot" [85] in R software in order to reveal the relationships between the individual indicators (both for services and condition). Because some of our variables (mainly the condition indicators) are ordinal, Spearman's rank correlation (Spearman's rho—hereafter 'r') was calculated. The correlation coefficients were then used for building networks to visualise the connections between the services. The network representation was carried out using the package "igraph" [86] in R software. The pre-calculated correlation coefficients were analysed for each mask to reveal basic similarities/differences. The coordinates were separately calculated with the Fruchterman–Reingold algorithm (with default settings) for each network. The distance between the indicators in conjunction correlates with Spearman's correlation coefficients (i.e., variables with strong positive correlations are close to each other, while those with a strong negative correlation are situated far from each other). The width of the links between the indicators reflects the strength of the correlations, too; stronger (negative or positive) correlations are represented by thicker links, while the colour of the links shows the direction of the relationships (i.e., green for positive connections and red for negative connections).

2.3.3. Identification of Ecosystem Service Bundles by k-Means Cluster Analysis

We used the k-means classifier of the package "h2o" [87] in R software (version 4.2.0). We created a model in which the number and centre of the clusters dynamically changed in an iterative process, and the optimal cluster number was determined according to the proportional reduction in error (PRE) in a 5-fold cross-validation. The cluster number was maximised at 25, and the number of iterations at 100. For this analysis, we only used ecosystem services indicators. Two of those described in Table 1 were omitted. Runoff retention (the indicator chosen for the service "Flood and rainwater runoff control (in hilly areas)") correlates very strongly with filtration and can only be interpreted at higher elevations. Drought mitigation had to be omitted because it is only calculated for part of the study area. The resulting groups were characterised using rose diagrams. These enable the joint representation of several properties in such a way that the standardised average (potential) value of all examined services is placed along one axis.

Figure 2 summarises the whole work process.

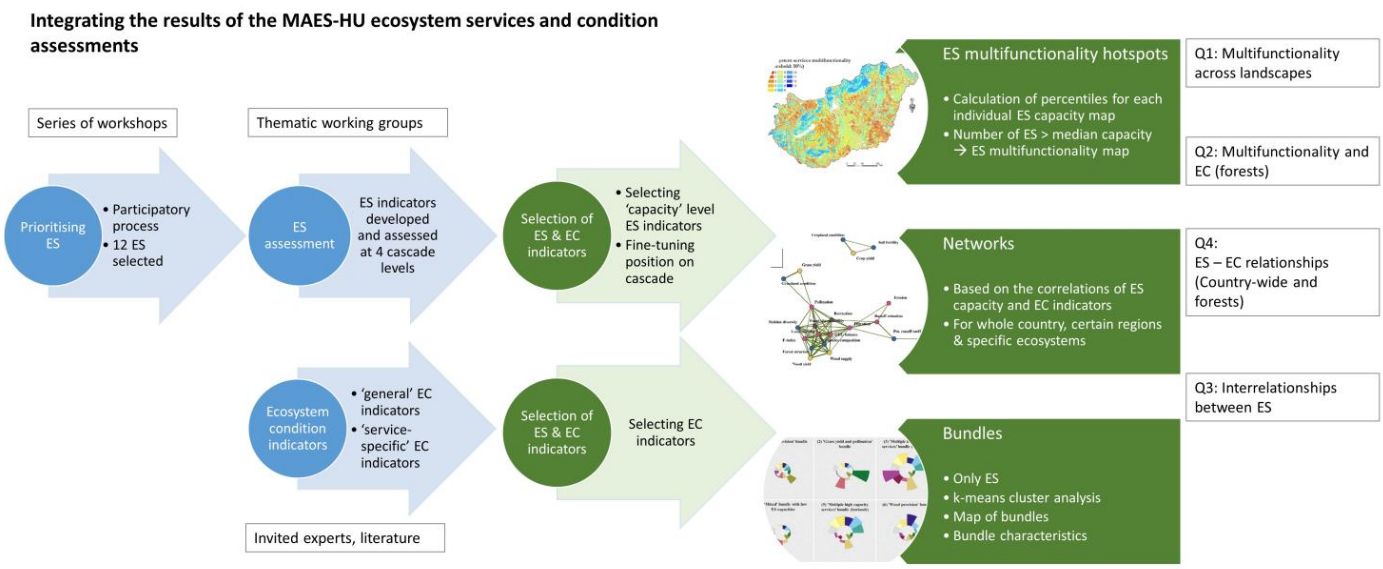

Figure 2. The work process. The blue arrows show those steps in the MAES-HU project that the present work was built on. The green arrows and green boxes show the steps and methods of the integrated analysis presented in this paper (Section 3, Results).

3. Results

3.1. The Ecosystem Services Multifunctionality of Hungarian Ecosystems

Figure 3 shows the ecosystem services multifunctionality map of Hungary. The map shows the strong effects of both ecosystem type and topography on the result.

Table 3 and Figure 4 illustrate the most typical number of services that perform outstandingly in the given ecosystem type (i.e., the majority of the multifunctionality values within each main ecosystem type). As we were only considering the present land use type, certain provisioning services were mutually exclusive (e.g., crop yield is zero in forests, whereas wood supply and yield are zero in all non-forest types). Thus even in the case of mixed pixels, we did not obtain a multifunctionality value higher than 13. The prominent role of native forests is evident, while grasslands and wetlands have slightly lower multifunctionality values. Significant differences exist between the more natural forests and the non-native tree plantations in favour of the former. Though plantations may provide outstanding services, more natural forests simultaneously perform several functions more efficiently.

3.2. Multifunctionality and Ecosystem Condition in Forests

Table 4 shows the results of the correlation analysis used to explore the relationship between ecosystem condition and ecosystem service multifunctionality in forests. When considering all forests, the final forest condition score and the forest composition score show a moderate correlation with multifunctionality, whereas forest structure has a lower r value. The r values are much lower when looking at the native forests and the non-native plantations separately, showing only a weak but still existing relationship. In native forests, there is no correlation between multifunctionality and structure. In contrast, in tree plantations, the correlation with the structure is somewhat stronger (albeit still weak) than with the species composition.

3.3. Ecosystem Service Correlation Networks

3.3.1. Entire Country

The correlation values used for drawing the network of ecosystem services for the entire area of Hungary can be found in the Supplementary Material in tabular format (Table S1). Figure 5 shows that the ecosystem condition and service indicators are mainly grouped by ecosystems (for croplands, grasslands and forests), whereas the soil characteristics form a separate group together with the (thematically closely related) hydrological services. Natural or close-to-natural ecosystems and agricultural areas are separated from each other, which is in line with the results of the multifunctionality analysis. The relationships between the indicators linked to these two main groups are mostly negative, as the areas reserved for crop production usually do not perform well (i.e., have low capacity values) in terms of other services. Wetland condition does not strongly correlate with any of the service or condition indicators examined.

Figure 6 shows the network obtained using only the positive relationships classified as "relatively strong". The above-mentioned groups and their connections can be seen more clearly in this figure. The service and condition indicators unique to a given ecosystem type are better separated, similar to the (mainly hydrological) services strongly influenced by soil characteristics. The positive relationships between cultural and regulating services are strong, and they are most closely connected to the services and condition of forests. Among the hydrological services, filtration capacity is the one that shows a strong positive relationship with several indicators.

3.3.2. Forests

Figure 7 shows the positive relations of ecosystem services (synergies) and condition only within forests (and separately for hilly/mountainous and lowland regions). The correlation values can be found in Supplementary Material (Tables S2–S4). Some relationships appearing particularly strong in the national evaluation are much weaker when considering only forests. For example, wood supply and yield, which showed a solid positive relationship (r = 0.94) with each other, produce a much weaker correlation value in the within-forest analysis (r = 0.2 in the hilly/mountainous regions and 0.25 in the lowlands).

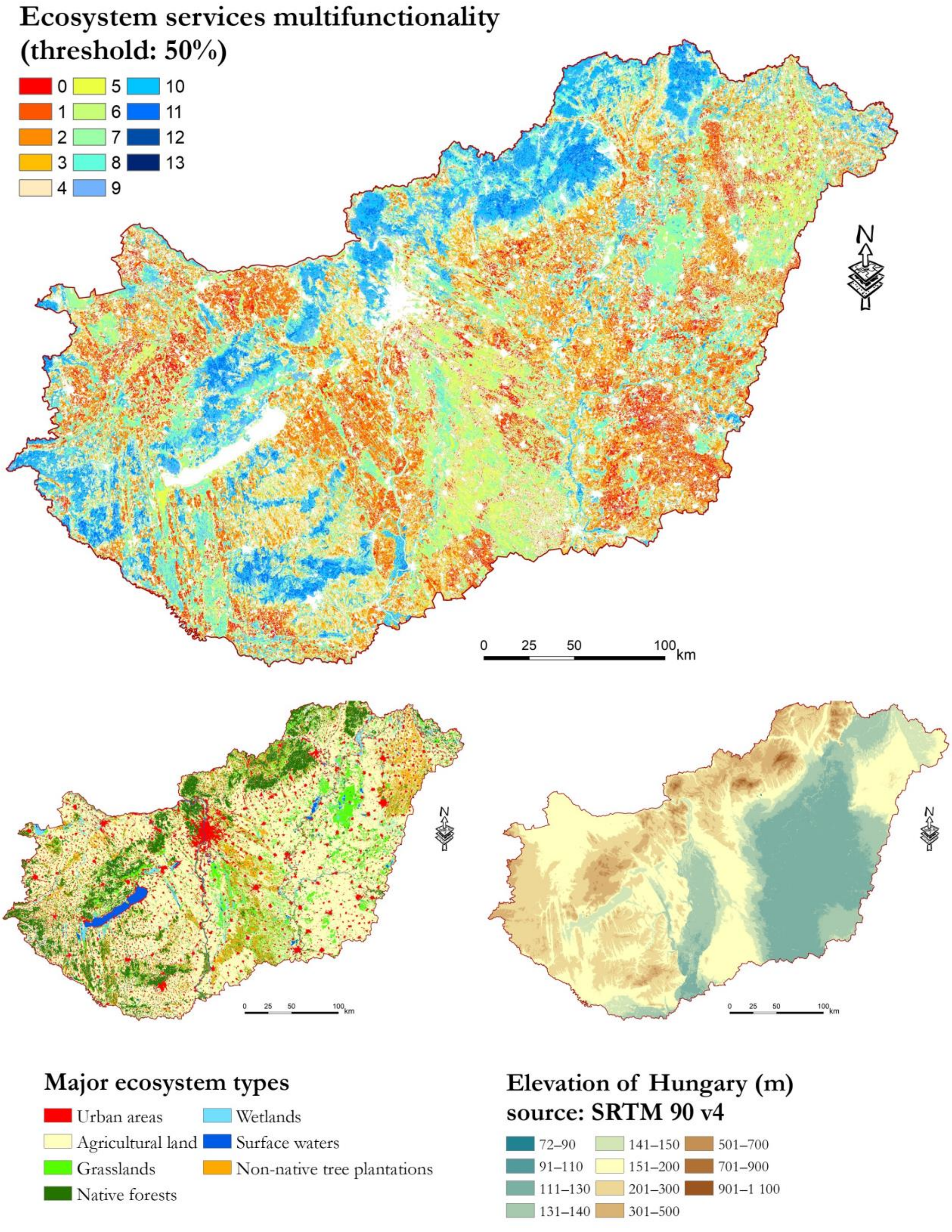

Figure 3. Map of the ecosystem service multifunctionality for Hungary (the number of services of which the local capacity exceeds the national median). White patches are surface waters, urban areas, artificial surfaces and data-scarce areas, which were omitted from this analysis. The two smaller maps display the major ecosystem types (**left**) and the elevation (**right**) of Hungary.

Table 3. Characteristics of the main ecosystem types in terms of area and the most typical number of services that perform outstandingly within the type. 'Area' here means the area of the ecosystem type which could be evaluated (some data-deficient areas were omitted). Percentage values mean the approximate ratio to Hungary's entire area.

Major Ecosystem Type	Area (ha)	The Most Characteristic Multifunctionality Score within the Type (Majority of Values)
Native forests	1,082,500 (12%)	10
Grasslands	922,400 (9%)	8
Wetlands	348,600 (3.5%)	7
Non-native tree plantations	772,200 (8%)	6
Agricultural areas	28,007,600 (32%)	2

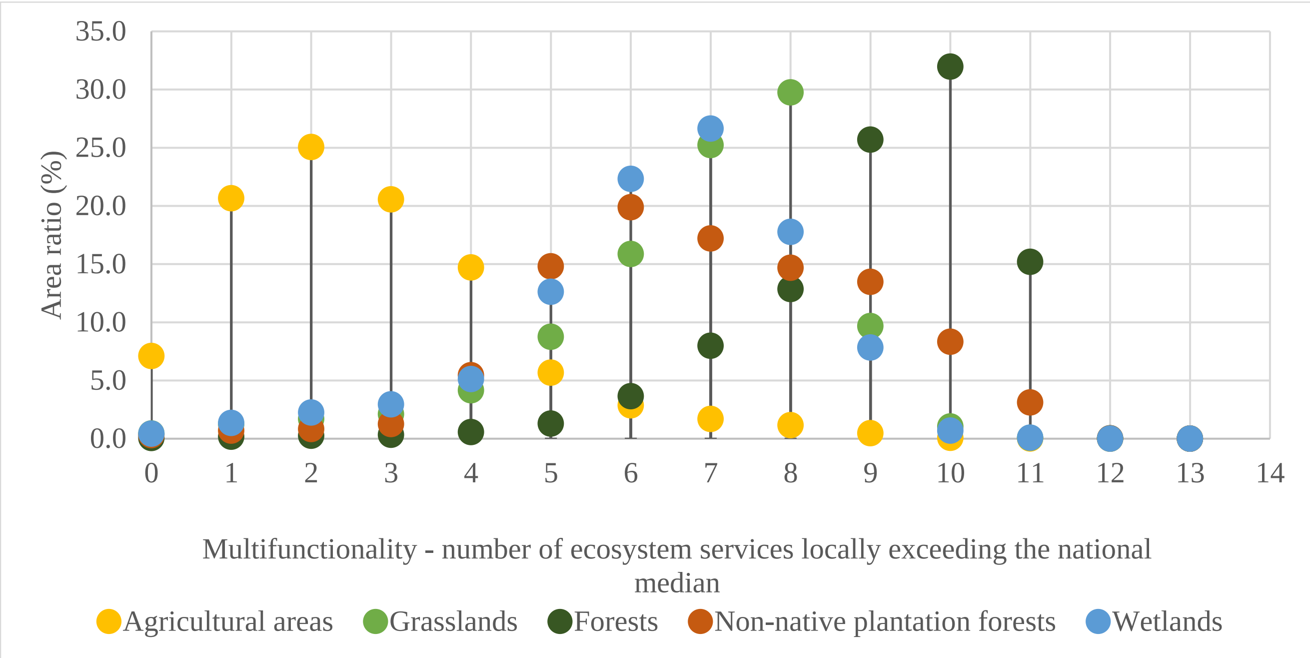

Figure 4. The ratio of the area characterised by a specific multifunctionality value within each ecosystem type.

Table 4. Spearman's rho correlation coefficients between the multifunctionality index and the forest condition scores. All correlations were significant at the 0.01 level.

Spearman's rho	Ecosystem Services' Multifunctionality		
Forest Condition	All Forests	Native Forests	Non-Native Tree Plantations
Final forest condition score	0.56	0.25	0.25
Forest structure score	0.32	0.06	0.29
Forest composition score	0.57	0.27	0.12

Of the two indicators characterising the firewood production capacity, the most important provisioning service of forests, wood yield does not show a strong relationship with any of the examined variables. However, there is a weak negative correlation with cultural services, the majority of regulatory services, soil characteristics and both forest condition characteristics included in the analysis. These negative correlations are somewhat stronger in hilly/mountainous regions. On the other hand, wood supply is positively correlated with the two forest condition indicators, tree species composition and structural condition, as well as with the service indicators fungi site suitability and f-index (the latter representing microclimate regulation).

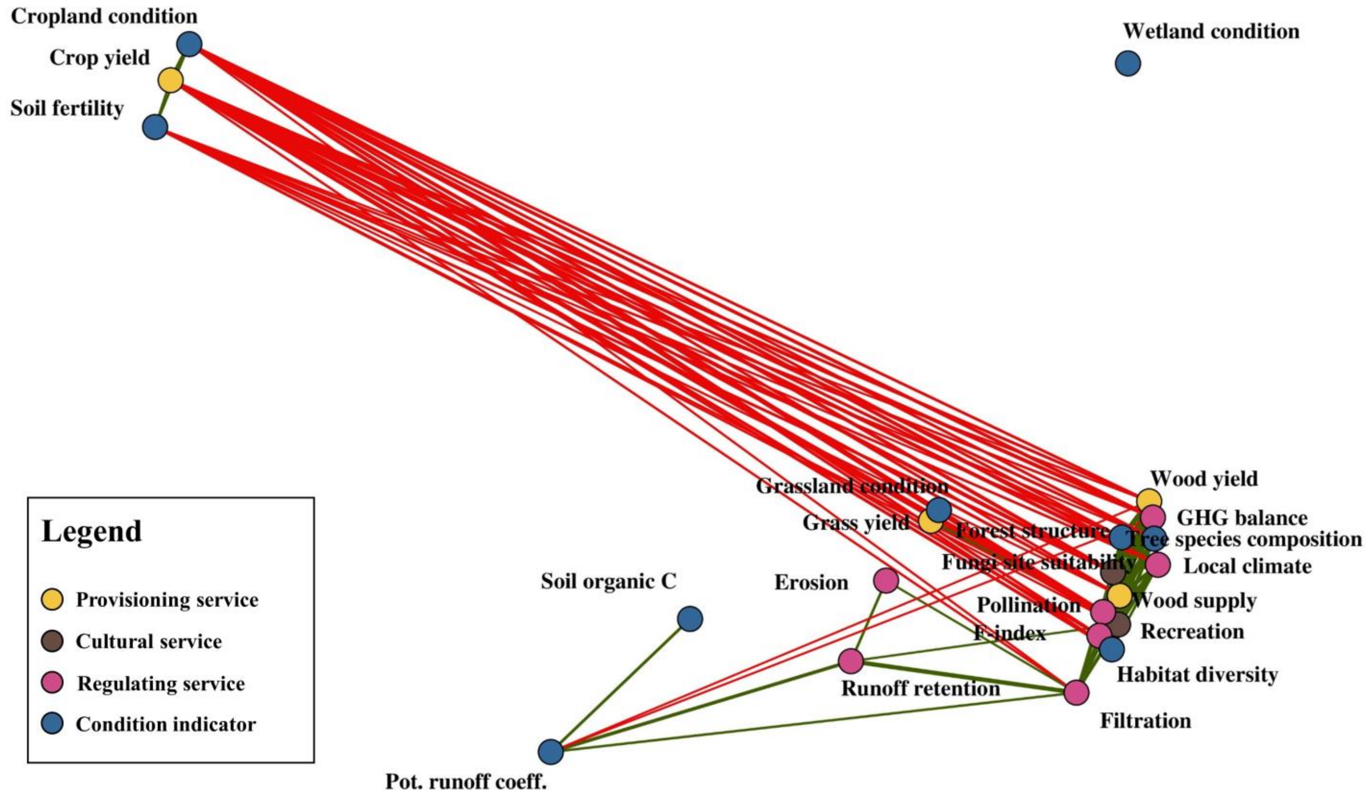

Figure 5. Network-based visualisation of the correlations between ecosystem service and condition indicators for the entire country. The position of the variables in the diagrams is determined by their relationship to each other (variables with a strong positive correlation are close to each other, while those with a strong negative correlation are far; variables with no (strong) correlations are not connected to the network). Red lines represent negative and green lines positive relationships. The thickness of each line is proportional to the strength of the given correlation. Only the relatively stronger connections ($r > 0.3$ for positive relationships and $r < -0.3$ for negative relationships) are displayed.

The two cultural services, which are also strongly correlated with each other, have a central place in the networks (Figure 7). The relationship of fungi site suitability is stronger with tree species composition than with the structure, whereas recreation (hiking) capacity has a relatively strong correlation with both indicators of the forest condition, especially with stand structure.

Considering all forests, habitat diversity only shows a relatively stronger (positive) correlation with pollination and, in the case of lowland forests, with hiking potential. The correlation of habitat diversity with the soil fertility index, which was nationally negative, turns positive when only looking at forests.

Some differences emerge when separating the lowlands and hilly regions' forests. The number of variables with absolutely no stronger (positive) relationship is lower in the lowland forests. In hilly/mountainous forests, the soil fertility index has a (negative) correlation with several regulating, and both examined cultural services, as well as with the condition indicator characterising the tree species composition of the forests.

3.4. Ecosystem Services Bundles in Hungary—The Result of the Cluster Analysis

Figure 8 shows the map of clusters (the obtained ecosystem service bundles) created using k-means cluster analysis performed on the ecosystem service indicators and the rose diagrams showing details of the bundle characteristics. The statistically optimal number of bundles is found to be six. They are named according to their most important characteristic in terms of service capacities. The results support the findings of the previous analyses: most of the bundles correspond with a dominant ecosystem type (Figure 9). Three of the six bundles are predominantly forested, with the forests divided according to topography and ecosystem condition.

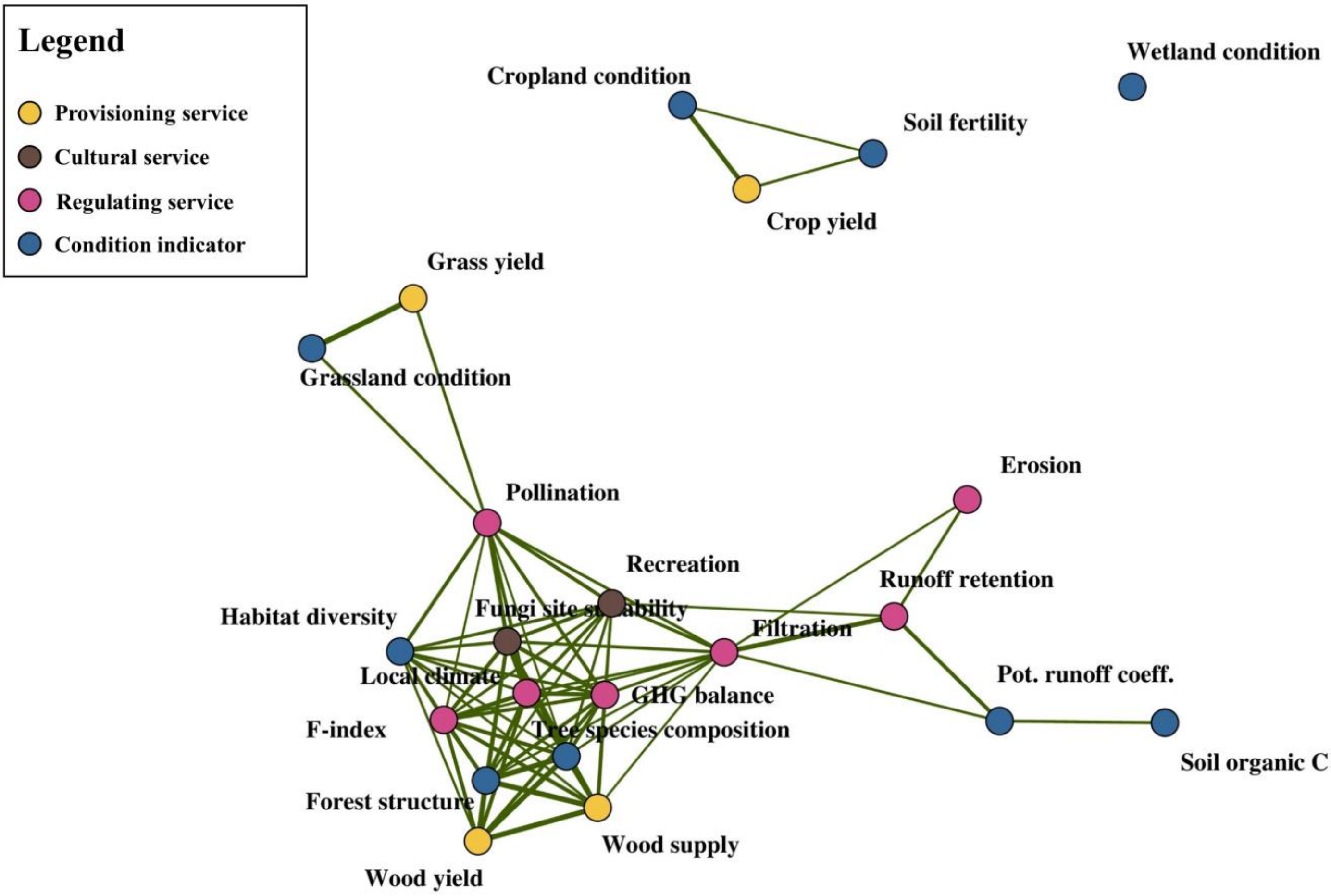

Figure 6. Network-based visualisation of the correlations between ecosystem service and condition indicators for the entire country (only positive connections). The position of the variables in the diagrams is determined by their relationship to each other (variables with a strong positive correlation are close to each other, while those with a strong negative correlation are far; variables with no (strong) correlations are not connected to the network). Red lines represent negative and green lines positive relationships. The thickness of each line is proportional to the strength of the given correlation. Only the relatively stronger connections ($r > 0.3$) are displayed.

In Bundle 1, which covers mostly agricultural areas, the crop yield is the only indicator that shows an outstanding value; all other services have low capacities (Figure 8). Areas belonging to Bundle 2 are dominated by grasslands, with an outstanding capacity for grass yield and pollination. In Bundle 3, comprising mainly native forests in the mountainous regions, many service capacity indicators show outstanding values. The f-index (for micro-climate), wood supply, greenhouse gas balance, recreational (hiking) capacity, fungi site suitability, erosion protection and filtration capacities are generally high. These areas also perform relatively well in terms of pollination capacity. Bundle 4 includes mixed areas (most of the non-forest wetlands and orchards belong here as well as some grasslands) with relatively high values in pollination and GHG-balance but low capacities for the other services. Bundle 5, comprising mostly lowland forests, is similar to Bundle 3, differing mainly in lower capacities for certain hydrological services (filtration and erosion prevention). These areas also have slightly lower fungi site suitability or recreation capacity. The last group mainly consists of lowland tree plantations and is particularly outstanding regarding wood yield. These areas still show relatively higher values for climate regulation service capacities but perform poorly in the examined hydrology-related and cultural services.

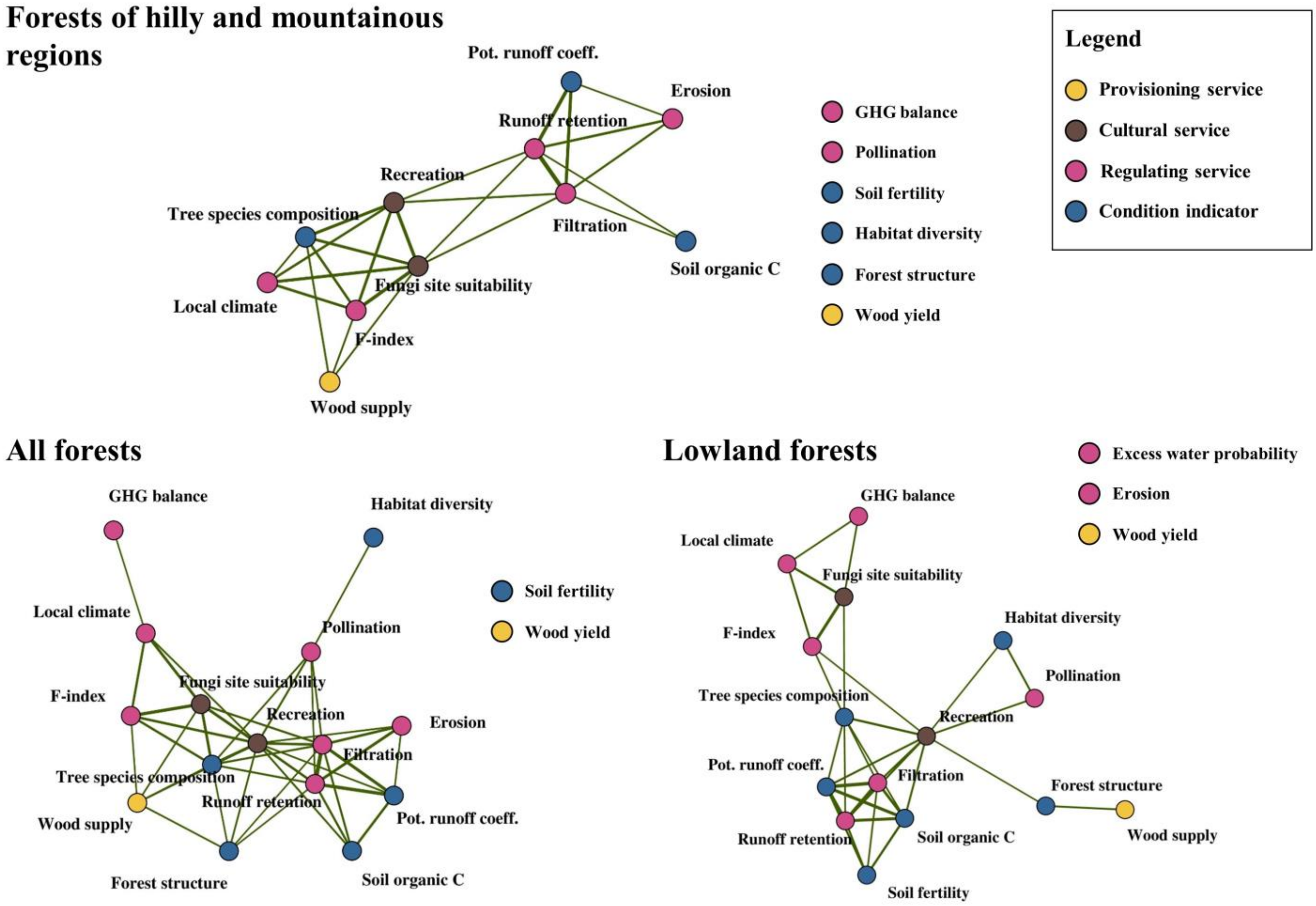

Figure 7. Network-based visualisation of the correlations between ecosystem service and condition indicators for the forests. The position of the variables in the diagrams is determined by their relationship to each other (variables with a strong positive correlation are close to each other, while those with a strong negative correlation are far; variables with no (strong) correlations are not connected to the network). Red lines represent negative and green lines positive relationships. The thickness of each line is proportional to the strength of the given correlation. Only the relatively stronger connections ($r > 0.3$) are displayed.

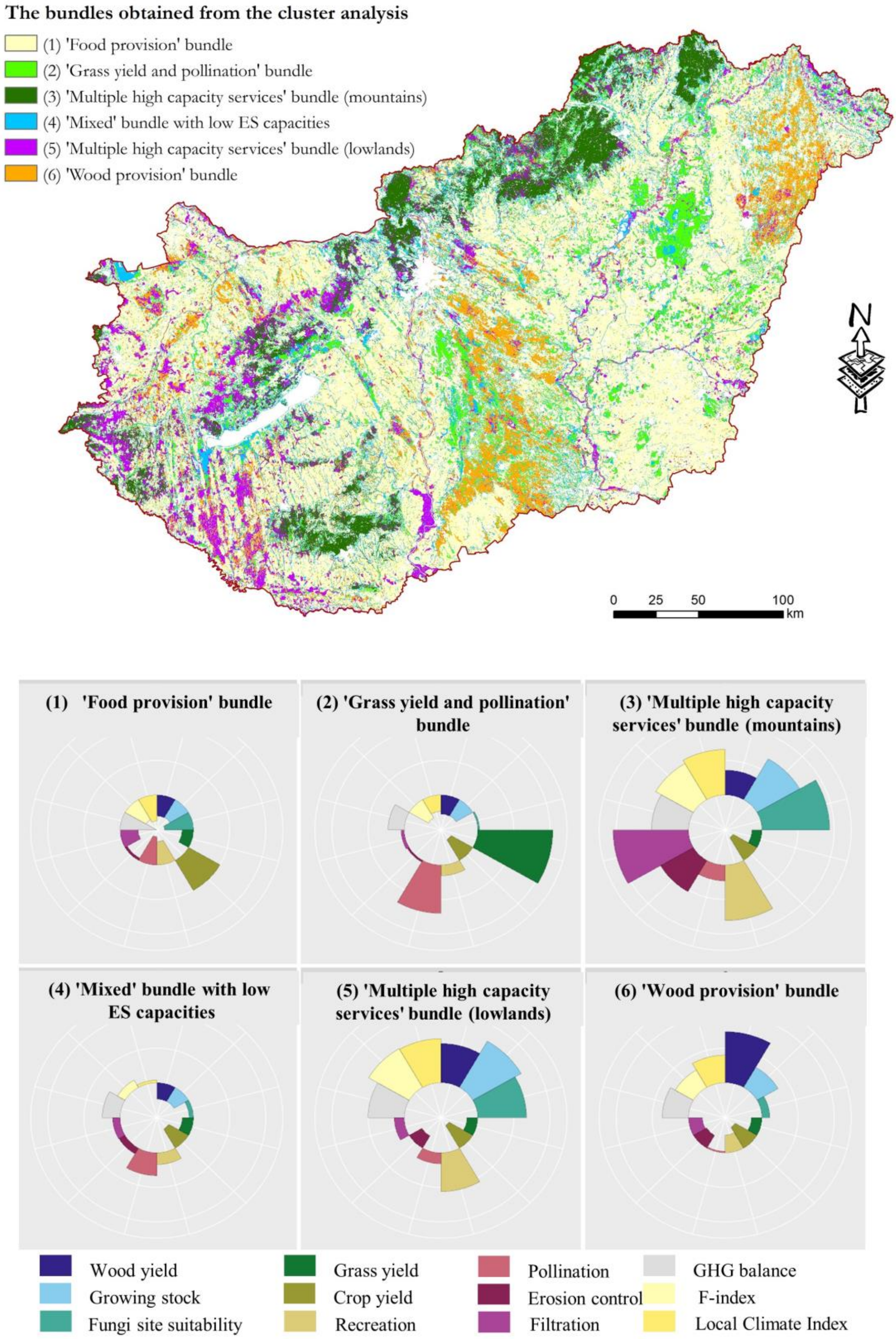

Figure 8. Map of the six ecosystem services bundles resulting from the cluster analysis and the rose diagrams of each bundle's standardised values of ecosystem service (ES) capacities. Outer petals mean indicator values greater than the mean, while inward petals correspond to indicator values less than the mean.

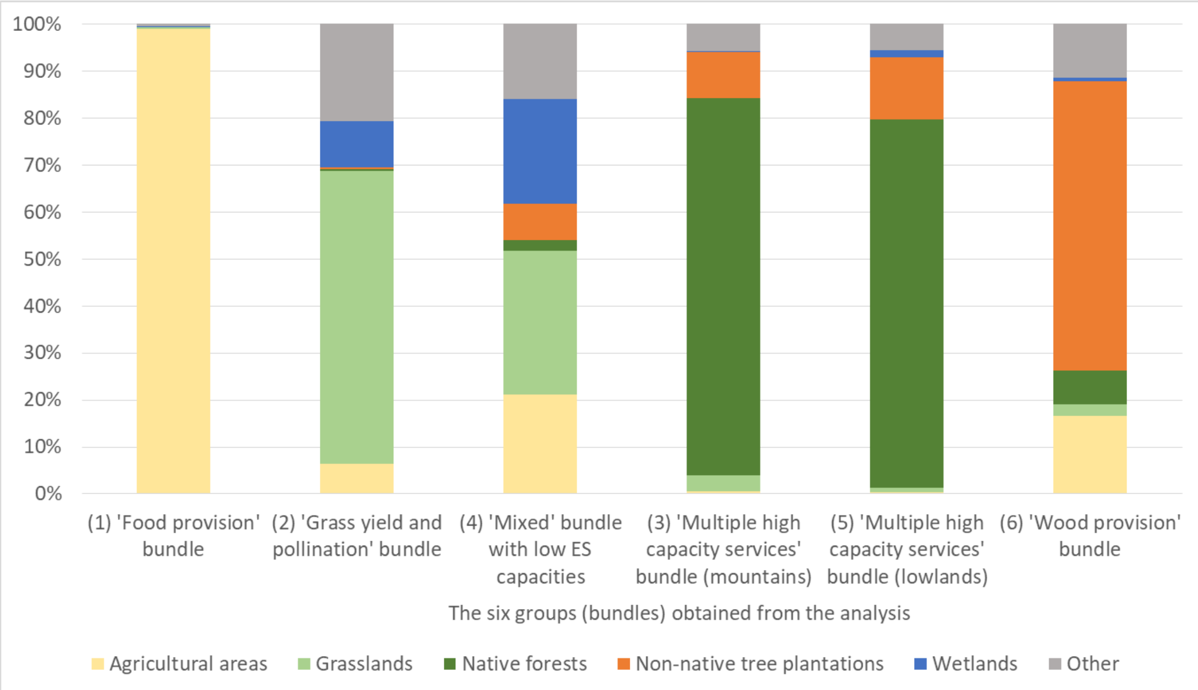

Figure 9. The area ratio of the major ecosystem types within the six bundles obtained from the cluster analysis (the colours represent the most common ecosystem type within the 100*100 m cell that was the spatial unit of the analysis).

4. Discussion

The work described in this paper constitutes a first step in exploring the large-scale spatial patterns and interrelations of ecosystem services and condition in Hungary.

4.1. Patterns of Ecosystem Services Multifunctionality in Hungary

The multifunctionality hotspot map and the comparison of ecosystem types show marked differences. Native forests were found to show an outstanding performance in terms of ecosystem service multifunctionality. Numerous studies on forests identified them as being of paramount importance for multiple functions in terms of ecosystem services (as well as for biodiversity) from local to global scales [8,37,42]. The term 'forest' is often used to cover tree plantations as well as more natural forests. Plantations play an important role in wood production throughout the world while also providing a range of other ecosystem services [88,89]. However, our results from MAES-HU show a marked difference between native forests and non-native tree plantations in Hungary, with the former performing better in terms of ecosystem services multifunctionality. Mixed forests are considered better alternatives to monocultures in terms of increased water quality regulation, aesthetic and recreational values, as well as reduced stand vulnerability to pest and pathogen damage [90].

Grasslands and wetlands in Hungary show slightly lower multifunctionality values than native forests, although, in the scientific literature, they are also identified as potential multifunctionality hotspots [8,60]. The former, especially extensively managed near-natural grasslands, can support high levels of biodiversity [91] and a range of services, from supporting grazing livestock to storing and sequestering (soil) carbon, preventing erosion and filtering water-soluble pollutants [92,93]. Wetlands are also essential biodiversity hotspots and provide a wide range of ecosystem services such as water flow regulation (including flood protection and groundwater recharge), erosion prevention, nutrient cycling, pollination and inspiration for culture [94–97]. Via drought mitigation, they can also contribute to the increased production of provisioning services (crop or wood production). They can, in some cases, present an alternative to more costly flood protection solutions [98]. However, their services and significance are often underestimated and underreported [95,99], and even within Europe, they are one of the most threatened ecosystem types [100]. Given the method that we used for calculating, multifunctionality and its sensitivity to the number of relevant categories [13], our result is mostly explained by the particular set of services and indicators chosen for assessment at the beginning of the MAES-HU process and the lack of appropriate data for these ecosystem types.

Data scarcity entailed already when performing the ecosystem type mapping, fewer subtypes were distinguishable within the grasslands and wetlands [67]. This, in turn, affected the ecosystem service mapping, especially where lower-tier models [101] were used, or large areas obtained the same (estimated) value without finer distinctions being possible (e.g., grass yield, greenhouse gas balance). This is an important indication that we currently have too little information about these ecosystem types nationally, and this should be remedied as soon as possible. National-level mapping and assessments require wall-to-wall (spatial) data with consistent data quality for the whole area. There are suggestions on how to deal with data scarcity issues [102,103]. However, rough proxies and modelled data (often the number one solution) can only partly replace primary information (based on field data collection), as model output is strongly defined by the quality of the input and their base assumptions [103]. Entirely relying on already available databases and/or models to optimise resource needs may lead to the use of data or models with well-known errors and high uncertainty [11], limiting the usefulness of the overall output of the integrated assessments for decision-making [104].

The abiotic environment can also induce variation in ecosystem functions and services, even independently of biotic variation [105]. In addition to the differences between ecosystem types, the effect of topography is also visible on our multifunctionality map; mountainous regions show higher ecosystem service multifunctionality. One reason is the inclusion of a relatively high number of topography- (and soil-) dependent hydrological services (see Table 1 and [23]). However, there is also an interplay between topography and ecosystem types as the hilly and mountainous regions of Hungary are covered primarily by native near-natural forests, which performed well in terms of most of the examined services. A higher overall capacity of ecosystem services in mountainous areas than in the lowlands is also reported in Slovakia [37].

4.2. The Relationship between Multifunctionality and Ecosystem Condition in Forests

Our measure of ecosystem services multifunctionality did not directly include ecosystem condition indicators, which allowed us to examine their relationship. We found (moderate) positive correlations between multifunctionality and forest condition scores, particularly with the species composition score. The results are in line with related findings from the literature. Communities with higher biodiversity have been shown to be able to deliver ecosystem functions and services at a higher level [25,60], while biotic homogenisation in forests may have substantial negative impacts on their ecosystem services [59]. The correlations between forest condition and multifunctionality are stronger than those with individual ecosystem services (see Tables S2–S4), which is also in accordance with earlier results [106].

The correlation between ecosystem services multifunctionality and the structure score is considerably weaker than with the species composition score. Relationships between certain elements of forest structure and individual ecosystem services have been verified [53]. However, some authors warn that relationships between ecosystem services and biodiversity may differ according to the chosen service, indicator, diversity measure, and even the method to link them [107]. The same may apply in this case, as some service indicators were based on Tier 1 and 2 models. Even though forest types in Hungary were shown to differ not only in terms of species composition but also structure [108,109], the structural condition indicator generally shows low values across the country and less variability than the species composition [57]. The scarcity of stands with higher structural complexity may also blur potential relationships.

We also examined the same relationships separately for native forests and non-native plantations. The correlations were similarly positive but weaker than those without separating the two categories. The correlations between the two sub-indicators of condition (species composition and structure) and multifunctionality were found to differ for the native forests and the non-native plantations. This can be explained by the uneven distribution of condition scores within the two categories. Plantations generally have lower condition scores both in terms of species composition and structure and, as a result, mostly belong in the 'least favourable' forest condition category (see Figure S1). The connection between the structure indicator and multifunctionality was shown to be relevant mainly in the case of non-native tree plantations, i.e., at the lower range of condition scores.

4.3. Interrelations between Ecosystem Services

We have explored the correlations and built networks between indicators of ecosystem service capacity and ecosystem condition at the national level. Interpreting the obtained relationships needs some caution. The analysis is based on spatial data from one period (baseline year: 2015) rather than time series, and thus the observed patterns may only indirectly indicate cause-and-effect relationships [30,31]. In certain cases, strong relationships may simply stem from a similar calculation methodology or the same background factors determining both variables [110,111]. In this study, we focused only on the connections considered genuinely meaningful and omitted apparent artefacts.

Most similar studies show tradeoffs between regulating and provisioning services [79]. We also found that the most apparent capacity tradeoffs at the national level were related to food production, similarly to other countries [35,36]. In MAES-HU, expert groups carrying out the assessments were arranged according to (groups of) ecosystem services rather than major ecosystem types to avoid parallel work on the same service in different settings and by different experts and stakeholders. This approach allows the easy integration of all the assessed services in one nationwide analysis and is more suitable for studying the spatial flow of services, which are more likely to occur across habitat boundaries than within habitats [103]. However, when examining the entire country, the relationships and groupings we found between individual variables mainly reflect the differences between the competing ecosystem types (and related services), which override within-type patterns.

The supply and interactions of ecosystem services have been shown to vary significantly among land-use types and across spatial scales [77–79]; therefore, we chose also to examine the main ecosystem types separately. We found that the strength and sometimes even the direction of the relationships differed when examining them within a specific area or ecosystem type, as demonstrated by wood supply and yield. As both are only relevant for forests, these have a strong correlation at the national level but a much weaker one when considering only the forests. Similarly, the correlation of habitat diversity with the soil fertility index, which was nationally negative, turned positive in the case of forests due to the higher diversity of habitats in the foothill regions, characterised by higher soil fertility compared to the mountainous areas.

Within forests, the positive correlations of wood supply with the forest condition indicators (tree species composition and structure), as well as with indicators of cultural (recreation and mushroom picking) and regulating services (e.g., microclimate regulation), draw attention to the huge significance of old-growth near-natural forests and the potential conflicts coded into their high multifunctionality. The conflicts would emerge between groups using different services (e.g., recreationists vs foresters [8,112]) as soon as the trees are harvested, i.e., the wood production service is actually used. The demonstrated synergies only apply to the 'capacity' level of the cascade; following the removal of trees, the potential of all non-timber services would decrease, and the level of the tradeoffs depending on the forest management regime [113,114]. Recovery and the restoration of multiple ecosystem service potentials may be non-linear and may require a very long period of time, especially in old-growth forests [115]. These tradeoffs should be seriously considered in management planning, as the value of non-timber benefits can be comparable to that of wood production. Regulating and cultural services together can even exceed its value [116]. Researchers estimated that in Hungary in 2020, the value of forest recreation services alone corresponded to approximately ~20% of the monetary value of wood production nationally. This ratio can be even higher in popular tourist destinations [117].

According to our results, the interrelations of ecosystem services and condition in the lowland forests of Hungary also differ markedly from those in the hilly and mountainous regions. One example is the (negative) correlation of the soil fertility index in the hilly/mountainous regions with several regulatory and both examined cultural services, as well as with the tree species composition condition indicator. In these regions, most forests situated on land suitable for agricultural cultivation (i.e., relatively high soil quality) were removed. The still remaining stands are often plantations of non-native tree species or heavily infected with invasive tree species. These stands represent a sharp contrast to the near-natural forests of the mountain regions where soil fertility is generally lower. There is no such contrast within the lowland forests, where only a fraction of the original forest cover remains, and recreational use is less typical. The difference between regions thus also indicates differences in service demand and, as a result, in decision-making concerning land management. Spatially explicit inclusion of stakeholder demand is considered an essential and important way forward in assessing multiple ecosystem services [19,54,118,119]. The MAES-HU mapping process was characterised by the involvement of experts from various fields [66], and the results thus reflect the experiences and perceptions of several stakeholder groups. However, it did not expressly include capturing stakeholder views and needs, which would have allowed the direct inclusion of demand in the analysis. This is one of the potential directions for further development of this national-scale work.

We demonstrated a simple use of networks to effectively visualise the interrelations of the examined service and condition indicators. This is a particularly efficient way to convey complex information, especially to a non-expert audience [120], an important aspect of policy-driven applications. The use of network theory in ecosystem services assessments is not yet widespread [11]. Recent developments and applications mainly involve using social-ecological network analysis [121–123]. Adding socio-economic components has the potential of shedding light on more complex causal relations [124,125], which should be the next step in utilising the MAES-HU results for better mainstreaming biodiversity in decision-making and land management in Hungary.

4.4. Ecosystem Services Bundles in Hungary

We have identified and mapped six bundles of ecosystem services using k-means cluster analysis. The results strongly support the findings from the other methods and help further refine our understanding of multifunctionality patterns. The obtained groups mainly reflect major ecosystem types and the related provisioning services. This is most apparent in the case of the food provisioning bundle (Bundle 1), with its obvious overlap with agricultural areas and deficient capacities for other services. In a similar analysis for Germany, the obtained bundles were also identified with (mainly) provisioning services [29]. The bundle dominated by grasslands (Bundle 2) is shown to provide some of the examined services at an outstanding level, especially pollination, but there seems to be no particular service among the examined twelve in which wetlands would excel. Most of the latter fell in the mixed category (Bundle 4); those that were classified as part of Bundle 2 are mainly wet grasslands. This again indicates that the chosen set of services and the lack of detailed information on certain ecosystem types affected the results.

The effects of topography also appear in the bundles, mainly due to the differences in the capacity of the examined hydrological services. Some of these were rated much higher in steeper, more mountainous areas. Their effect is most pronounced in the division of native forests into lowland and mountain categories.

Although ecosystem condition indicators were not used as input, bundles comprising predominantly native forests (Bundles 3 and 5) and non-native tree plantations (Bundle 6) were also separated by the algorithm. The latter is clearly designed for one provisioning service, wood production [126], although not as exclusively as croplands; tree plantations also show relatively higher values for a few other (especially climate-related regulating) services. However, they are characterised by less favourable condition (both in terms of composition and structure—see Figure S1) and a reduced ability to retain and support biodiversity [110,127,128]. While both are generally considered as 'forests', stakeholders tend to acknowledge the difference: forests with native species were found to be considered superior to (coniferous) monocultures in providing a range of regulating and cultural services in both Germany and Ireland [112,129].

5. Conclusions

The work presented in this paper is the first step in integrating results from the national mapping and assessment of ecosystem services in Hungary (MAES-HU). We explored relationships at the capacity level of the ecosystem services cascade and identified six ecosystem service bundles mainly aligned with major ecosystem types and topography. We found distinct patterns of ecosystem service multifunctionality and positive correlations with indicators of forest ecosystem condition. Despite data limitations and relying solely on existing databases, complex work was carried out, also adding to the identification of the most severe data gaps concerning certain ecosystem types (grasslands, wetlands) and services. Reliable information is an absolute necessity if the integrated ecosystem services assessments are to fulfil their role in providing new insights and effectively advising land use and conservation-related decision-making. In the future, we consider it important to include demand and socio-economic drivers to understand better the patterns and causal relationships of both ecosystem services and condition and their drivers. Only with the consideration of these relationships will it be possible to develop real, working plans for conservation and biodiversity. With this work, Hungary has not only fulfilled the requirements of the Biodiversity Strategy for 2020 to "map and assess its ecosystems, their state and services" but also contributes towards operationalising methodologies for multi-faceted ecosystem services synthesis at the national level. The results can also be operationalised towards fulfilling the requirements of the Biodiversity Strategy for 2030.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15118489/s1, Table S1: Spearman's rho correlation coefficients between the ecosystem services and condition indicators for the entire examined area of Hungary; Table S2: Spearman's rho correlation coefficients between the ecosystem services and condition indicators for all the forests; Table S3: Spearman's rho correlation coefficients between the ecosystem services and condition indicators for the forests of hilly and mountainous regions; Table S4: Spearman's rho correlation coefficients between the ecosystem services and condition indicators for the lowland forests; Figure S1: The area ratio of the forest condition categories within native forests and non-native plantations.

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