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Validation and limitations of large-scale forest condition indicators – An example from Hungary

László Zoltán [a,b,*], Eszter Tanács [a,c], Tibor Standovár [a]

[a] Department of Plant Systematics, Ecology and Theoretical Biology, ELTE Eötvös Loránd University, Pázmány P. sétány 1/C, H-1117 Budapest, Hungary
[b] Doctoral School of Biology, Institute of Biology, ELTE Eötvös Loránd University, Pázmány P. sétány 1/C, H-1117 Budapest, Hungary
[c] Centre for Ecological Research, Institute of Ecology and Botany, 2-4 Alkotmány Str., H-2163 Vácrátót, Hungary

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A B S T R A C T

As the multi-scale study of biodiversity is extremely resource-intensive, proxy indicators taken from various databases are often used to answer questions on a larger spatial scale. Considering differences in the scale and methods, the application of such indicators (especially from different monitoring systems) requires careful consideration and standard methods of validation. In order to demonstrate this, we validated the results of the MAES-HU (National Ecosystem Assessment of Hungary) forest condition assessment (based on the Hungarian NFD – National Forestry Database) with thematically richer, finer-scale field data. We also examined the relationships of some MAES-HU indicators with other variables significant for nature conservation, not currently included in the NFD. We found the MAES-HU scoring was similar to the fine-scale score results in the case of tree species composition indicators, however, less so for structural indicators. The MAES-HU assessment uses the values of the NFD, averaged for forest management units, and thus tends to underestimate structural variety. This highlights a potential loss of important conservation-related information. During the examination of relationships with other indicators that are not included in the large-scale MAES-HU assessment, we found that the presence of large-diameter and old trees correlates with tree-related microhabitats and large standing deadwood, but no relationship was found for other investigated indicators (game pressure, further deadwood indicators). This highlights the need for integrating some key conservation indicators (presence of old and large trees, quantity and quality of standing and lying deadwood) into existing forest monitoring systems in order to optimise the resources dedicated to multipurpose data collection. Our study also highlights that applying indicators as proxies requires the full knowledge of monitoring methods and validated indicator-indicanda relationships.

1. Introduction

Biological diversity means "the variability among living organisms [...] which includes diversity within species, between species and ecosystems" (Secretariat of the Convention on Biological Diversity, 2005, p. 6). Since the Rio Earth Summit 1992, there has been a continuous increase in related research and numerous projects followed (Gao et al., 2015). One such program is the Natura 2000 network in Europe, which is the result of two frameworks: the Birds Directive (CD 79/409/EEC) and the Habitats Directive (CD 92/43/EEC). Since 1992, the Habitats Directive has aimed to achieve the favourable conservation status in sites of community importance. This includes the maintenance and restoration of habitats to prevent further biodiversity decline. In order to reach this goal, the member states have established a monitoring obligation since 1992. In 2004, another program was initiated to develop biodiversity indicators at the European level to monitor the status and trends of biodiversity ("Streamlining European Biodiversity Indicators" – SEBI). This initiative was linked to the global CBD (Convention on Biological Diversity). They have paid special attention to the need for detecting biodiversity indicators that are easy to communicate to policymakers and managers. The EU Biodiversity Strategy to 2020 required EU Member States to evaluate the ecosystems, their status, and services (European Commission, 2011). One of the goals of the Biodiversity Strategy until 2030 is to expand the knowledge and monitoring systems

Abbreviations: MAES-HU, National Ecosystem Assessment of Hungary; SCP, Swiss Contribution Project; NFD, National Forestry Database.

* Corresponding author at: Department of Plant Systematics, Ecology and Theoretical Biology, ELTE Eötvös Loránd University, Pázmány P. sétány 1/C, H-1117 Budapest, Hungary.

E-mail address: zoltan.laci93@gmail.com (L. Zoltán).

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related to biodiversity (European Commission, 2020). Despite a large number of significant initiatives, it is a question, whether the guidelines and proposed sets of indicators are appropriate and effective for monitoring the whole biodiversity.

Three main types of forest biodiversity indicators can be distinguished: compositional, structural, and functional (Larsson et al., 2001; Noss, 1990). Until the late 2000s, biodiversity was mostly expressed in compositional indicators related to species richness; structural and functional diversity received less attention (Feld et al., 2009; Winter et al., 2008). Since then, several studies have been published also on structural biodiversity indicators (e.g., Burrascano et al., 2013; Lombardi et al., 2015; Oettel & Lapin, 2021; etc.). However, it is still necessary to develop quantitative tools for monitoring the overall structural diversity of forests because the existing protocols can only be used for small geographical regions, specific forest types, and small databases (Storch et al., 2020). Functional indicators (e.g., nutrient cycling, disturbances, decomposition etc.) are the least used because their assessment is a complex task that may require laboratory work (Ćosović et al., 2020). There are currently plenty of monitoring data as well as biodiversity indicators in use, but these vary widely in time, space, scale, and sampling method (Feld et al., 2009).

To reduce resource needs, substitute indicators (proxies) can be used that indirectly describe the phenomena to be studied (e.g., the potential presence and diversity of saproxylic insects can be inferred from the presence of dead trees with certain parameters). Monitoring programs on environment, species, habitats, and land use at various scales provide numerous useful variables (Geijzendorffer & Roche, 2013), so indicator selection guidelines frequently recommend their use, especially for comprehensive reporting. Despite an apparent abundance of related data, only a few datasets are suitable for use in international reports, because taxonomically, spatially and temporally they are not sufficiently broad (Geijzendorffer et al., 2016). Nevertheless, the use of such proxy data is quite common (e.g., Maes et al., 2020; Kokkoris et al., 2018; Marín et al., 2021). Maes et al. (2020) derived indicators based on Natura 2000 conservation status of habitats. However, it was not taken into account that the methodology of Natura 2000 assessments differs radically from one Member State to another, and the protocols may even vary between reporting periods (Alberdi et al., 2019). Thus, the meaning of favourable conservation status may greatly differ between the Member States. In large-scale studies, the excessive simplification of indicators may occur due to the need to use already available data (Raudsepp-Hearne & Peterson, 2016), regardless of their characteristics. An example is an overrepresentation of bird species occurrence data for biodiversity assessments in the Global Biodiversity Outlook 4 (CBD, 2014), which distorts the comprehensiveness of the report (Geijzendorffer et al., 2016). Not all indicators and indicanda have a scientifically validated relationship, so their correlations still need to be studied (Gao et al., 2015; Oettel & Lapin, 2021).

The broadest and most comprehensive data on European forests comes from the NFI (National Forest Inventory) database of each country. Winter et al. (2008) suggested that forest biodiversity assessments should be based on these data. NFIs are good examples of utilising large-scale sectoral databases for conservation – they cover large areas, but they were created for forestry purposes and not for biodiversity assessments. Many attempts have been made to use NFI data either as biodiversity indicators or proxies (Chirici et al., 2011), although traditional NFI sampling methods are not necessarily suitable for examining total species richness. Still, they can be used to detect tree species richness and some tree-related dimensions: for example most of the indicators of the Forest Europe Initiative using NFI data for comprehensive reporting (FOREST EUROPE, 2020). Over time, new biodiversity variables (e.g., dead trees) have been integrated into NFI methodologies (Storch et al., 2020). They have started evolving into multi-purpose databases containing new data in multiple directions (Corona et al., 2011).

According to the EU Biodiversity Strategy to 2020, the ecosystem services of EU Member States should be mapped, and their condition should be assessed (European Commission, 2011). With the guidance of the EC Working Group on Mapping and Assessment of Ecosystems and their Services (MAES), several countries have started this work (Maes et al., 2020). Following the commitments of the EU Biodiversity Strategy to 2020, the Ecosystem Map of Hungary was completed in 2019, in accordance with the MAES principles (Tanács et al., 2021). The National Ecosystem Assessment of Hungary (MAES-HU) project (Vári et al., 2022) also included a condition assessment, where condition was interpreted similarly to ecosystem integrity (for details on the concept see Tanács et al., 2022). As the task required a wall-to-wall national-scale mapping, in most cases proxy variables were used to describe condition. In the case of forests they used compositional and structural data derived from the Hungarian NFD (National Forestry Database). Although the term "condition" is also widely associated with ecosystem health, variables related to the momentary vitality of vegetation (such as vegetation indices derived from remote sensing) were not included in the assessment at this stage. However, the chosen proxies indirectly refer to long-term ecosystem health since higher diversity means higher resistance to change (e.g., in mixed-species forests, the risk of major damage caused by natural disturbances such as pests or wind is lower – Felton et al., 2010).

The NFD is a spatially explicit database of Hungarian forests, used for forest management planning. It describes forest stands similarly to NFIs, but rather than sampling in points, it comprises a wall-to-wall map of the country's forests. Its main objective is to monitor forest attributes necessary to forestry administration, such as forest composition, structure, and management-related variables (Kolozs & Szepesi, 2010). It also serves similar functions as NFIs – storing data of the main attributes of Hungarian forests. Most reports on the forests of Hungary are based on this database. The MAES-HU assessment used it because of its spatially explicit nature and (nearly) wall-to-wall coverage of all (cc. 2 million hectares) Hungarian forests. The spatial units of the NFD are subcompartments with variable size, which can nevertheless be interpreted in a hectare scale.

Between 2014 and 2016, a field survey was carried out in some forests of the northern mountainous regions of Hungary (Swiss Contribution Project – SCP – Standovár et al., 2016), which aimed to provide more coherent and detailed data on the involved forests than the already existing databases (including the NFD).

National-scale evaluations often rely on indicators derived from large-scale databases, without validation with other, possibly fine-scale ones. Our study aim was to validate a large-scale forest condition assessment database with a fine-scale one, by applying the methodology developed for MAES-HU on a finer-scale field database (SCP). We also examined whether the chosen proxies correlate with some other, well established variables, not directly present in the NFD. Therefore, our study provides a measure of the uncertainty introduced by using only large-scale databases in similar assessments.

2. Methods

2.1. Study areas

The study areas are located in 3 mountainous regions of North-Hungary: Börzsöny Mts., Mátra Mts., and Aggtelek Mts. (Fig. 1). Table 1 summarises their abiotic, climatic and biotic properties.

2.2. Data

2.2.1. National Forestry database (NFD)

The NFD is a spatial database, updated annually. Field sampling is repeated every ten years, which includes data on forests and management activities from all forested parts of the country. The NFD contains data about subcompartments (approximately 600,000 pieces nationally). These are spatial units of forest management with variable sizes,

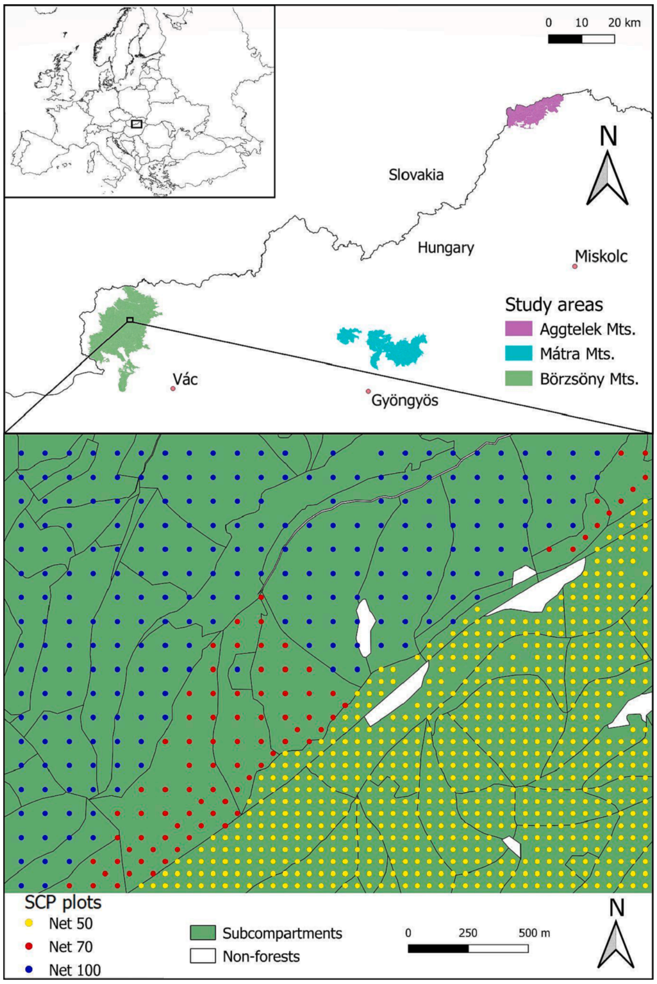

Fig. 1. The three study areas (upper map) presented with examples of subcompartments and SCP (Swiss Contribution Project) sampling points at different grid densities (lower map).

delimited based on their environmental, habitat and administrative characteristics. The sampling methodology within the subcompartments is not precisely defined. Data collection can be considered a type of census (Kolozs & Szepesi, 2010). The surveyors consider the subcompartments as whole sampling units. They walk within each subcompartment and provide comprehensive average data to describe it. The most important variables of the NFD and their technical details are presented in Table 2 and Supplement 1. It is important to note that although the NFD is considered here as a large-scale database, it has a finer spatial resolution than the km^2 scale used by many large-scale monitoring systems, e.g., NFIs (Tomppo et al., 2010).

2.2.2. Systematic field data collection (SCP)

Field data collection took place in some forests of Hungary within the framework of the project "Multipurpose assessment serving forest biodiversity conservation in the Carpathian region of Hungary" – SCP. The survey took place within two national parks and one landscape protection area, all of them part of the Natura 2000 network. During the 2014–2016 vegetation periods 50,000 ha were surveyed at almost 60,000 sampling points. The SCP survey used a 50 m grid in strictly protected forest reserves and a 70 or 100 m grid in commercial forests in the interests of proper resource allocation. This means a sampling density of 1, 2 or 4 points/ha (Fig. 1). The protocol used three sampling units. A plot is a circular sampling unit of 500 m^2 from which most variables are derived. A subplot is a smaller circular unit with an area of 30 m^2 that coincides with the centre of the plot. The route is the area which can be seen along a straight path between two plots. During the sampling, the surveyors collected data on many variables. The variables relevant to the present study are highlighted in Table 2 and 3. The catalogue and the definitions of the tree-related microhabitats (TreMs) is listed in Supplement 3. The SCP survey was the first of this type to be conducted in Hungary. Although useful for supporting nature conservation management planning in specific areas, it cannot be used for nationwide monitoring due to its human and financial resource requirements. However, it can be applied to effectively test the reliability of other databases in its sampling areas.

2.3. Data analysis

2.3.1. MAES-HU national condition assessment for forest ecosystems

The MAES-HU ecosystem types played an important role in the condition assessment. This ecosystem type classification originates from the Ecosystem Map of Hungary (Tanács et al., 2021). During this classification the NFD was the main source of information for the forests (Supplement 1), so the mapping was done on a subcompartment level. It was based on the mixture ratio of tree species and, to a lesser extent, climate and hydrology. Classification rules were assigned to each ecosystem type, and all subcompartments in the country were classified.

The applied indicators, rules and scoring system of the MAES-HU condition assessment can be found in Supplement 2 in detail. For the condition assessment a total of 15 indicators were created based on NFD data (Tanács et al., 2022). Different thresholds were established for each of the variables, based on expert opinion. Indicator scores were awarded based on these thresholds (scores range 1–3 for indicators on the ordinal scale; and 0–1 for binary indicators). Different indicator sets were applied for plantations and native forests. Habitat-dependent indicators were scored in relation to reference levels considered ideal for the ecosystem types included in the Ecosystem Map of Hungary. The scores were aggregated by addition to "Forest composition score" and "Forest structure score". The "Summed score" was used for the final rating, obtained by weighting the "Forest composition score" by 1.5 (1). This value was simplified to a 5-point scale resulting in the final, "Simplified score" (Table 4). As a result, each subcompartment can be characterised by a single value.

Table 1
The properties of the study area in each mountain region (Mts.). Abiotic, climatic and biotic parameters are shown along with the number of subcompartments and SCP (Swiss Contribution Project) plots belonging to the three study areas. The vegetation types follow the Natura 2000 classifications. *Nagy (2007) **Bartholy & Pongrácz (2011) ***Székely (1964) ****Újvárosy (1998)

Region	Bedrock	Mean elevation (highest peak)	Avg. annual temperature and rainfall	Vegetation type(Natura 2000 habitat code)	Study area (ha)	Subcompartments (No.)	SCP plots (No.)
Börzsöny Mts.	andesite	400 m (939 m)	7.5–9°C*; 600–850 mm**	*Pannonian-Balkanic turkey oak – sessile oak forests (91M0); Pannonic woods with Quercus petraea and Carpinus betulus (91G0); Asperulo-Fagetum beech forests (9130)*	27,516	3,945	33,476
Mátra Mts.	andesite, rhyolite tuff	400 m (1014 m)	7–9°C; 550–800 mm***		12,066	1,506	12,870
Aggtelek Mts.	limestone	380 m (605 m)	8.5–9°C; 650–700 mm****		7,629	1,009	10,984

Table 2
The differences in measurements between NFD (National Forestry Database) and SCP (Swiss Contribution Project). *Cohort means an aggregation of tree individuals that differ in some dimension (different cohorts might belong to the same species but differ in age or diameter category). For more details see Supplement 1 and 3.

	National Forestry Database (NFD)	SCP (Swiss Contribution Project)
Sampling	Full coverage	Systematic grid (50, 70, 100 m resolution)
Sampling unit	Subcompartment	Plot, subplot, route
Sampling unit size	Various, Avg = 6.9 ha (SD = 5.5 ha)	500 m^2 (plot), 30 m^2 (subplot), stand (route)
Forest composition	Avg. mixture ratio of tree species per canopy layer per subcompartment	Cover categories per DBH classes per tree species per plot
Forest structure	Avg. DBH per cohorts*	
	DBH > 10 cm and height > 1.5 m	DBH > 0 cm and height > 2.5 m
	Avg. age per cohorts*	–
	Shrub layer is characterised by one of 5 categories from an ordinal scale	Shrub layer is characterised by one of 5 cover categories from an ordinal scale in the subplot

Table 3
Sampling method and rules for relevant SCP (Swiss Contribution Project) variables related to the present research. The complete list can be found in Standovár et al. (2016).

Sampling unit	Variable-group	Variable	Details
Route		Presence of outstanding trees	Alive / dead / both; DBH > 50 cm
Route		Presence of invasive tree species	Presence of *Robinia pseudoacacia, Fraxinus pennsylvanica, Ailanthus altissima, Padus serotina, Quercus rubra* or *Acer negundo* at least in seedling stage
Plot	Stand	Canopy closure	Closure of trees above 2.5 m with 5% precision
Plot	Stand	Tree species composition in diameter classes	Cover in broad categories (0–5%, 6–20%, 21–50%, 51–100%), in diameter classes (DBH = 0–8, 9–20, 21–35, 36–50, >50 cm) above 2.5 m, per species
Plot	Dead trees	No. of standing dead trees	In diameter classes (DBH = 9–20, 21–50, >50 cm), above 2.5 m
Plot	Dead trees	Lying deadwood	FWD (DBH = 0–8 cm) and CWD (DBH = 8 < cm) diameter and quantity (m^3 classes) in 9 categories
Plot	Microhabitats and disturbances	No. of TreMs	Presence of 9 type of TreMs; details in Supplement 3
Plot	Microhabitats and disturbances	Severity of soil disturbance	Ordinal scale (0–1%, 2–5%, 6–20%, 21–50%, 50%<)
Plot	Microhabitats and disturbances	Type of soil disturbance	Wheel, game, skidding trail
Subplot	Regeneration	Presence of adventive tree species	Presence of adventive regeneration outside the subplot
Subplot	Regeneration	Cover of high-, and low regeneration layers	Cover in ordinal scale (0–1%, 2–5%, 6–20%, 21–50%, 50%<) above 0.5 m and between 0.5 m and 2.5 m height trees
Subplot	Regeneration	Regeneration tree species	List of regeneration tree species
Subplot	Regeneration	Browsing	Characterised by one of 4 categories (unbrowsed, slightly-, heavily browsed, bonsai-like)

Table 4
The final scores of the MAES-HU (National Ecosystem Assessment of Hungary) forest condition assessment on a 5-point scale.

Summed score	Simplified score
1–13	1 (least favourable)
14–17	2
18–21	3
22–25	4
26<	5 (most favourable)

$$\textit{Summed score} = 1.5 \times \textit{Forest composition score} + \textit{Forest structure score} \tag{1}$$

2.3.2. The utilised SCP plots

There are open forests or grasslands under afforestation that are not considered forests by the NFD, so MAES-HU lacked suitable data to handle these. SCP data from these areas were excluded from further analyses. In some subcompartments there is no actual forest stand due to recent felling or natural disturbances. For some of our analysis, SCP plots and subcompartments without forest stands were ignored. The resulting sample numbers and study areas can be seen in Table 1. The average number of SCP sample plots per analysed subcompartments are 6.3 (min.: 1, max.: 90).

2.3.3. Validation of the MAES-HU national forest condition map using data from the SCP fine-scale field survey

To find out whether the NFD can be considered a suitable data source for the national forest condition assessment of MAES-HU, we applied the MAES-HU scoring protocol to the SCP data. In order to do this, we created the same set of indicators from SCP (as far as possible) as in MAES-HU and then compared them in the study area covered by both projects (Fig. 1). Due to the differences in the raw data (Table 2), it was impossible to use exactly the same protocol. If a MAES-HU variable was not included in the SCP, multiple indirect indicator variants were designed and calculated, and the most similar results were retained (Supplement 4).

Because the NFD is based on subcompartments and the SCP on systematic sampling (Fig. 1), we needed to aggregate the SCP data to the subcompartment level. The timing and method of aggregation can affect the results, so it is worth analysing two versions: (i) applying the MAES-HU scores to the SCP plots, then aggregating (averaging) scores at subcompartment level – "Plot level scoring"; (ii) aggregation (averaging) of raw SCP data to subcompartment level and applying the MAES-HU scoring to the aggregated data – "Subcompartment level scoring" (Fig. 2). The calculation of each MAES-HU condition indicator from the SCP plot data is available from Supplement 4.

The "Plot-level scoring" was established by applying the ecosystem type classification of the Ecosystem Map of Hungary to the SCP data. Some minor changes were needed in the classification algorithm in order

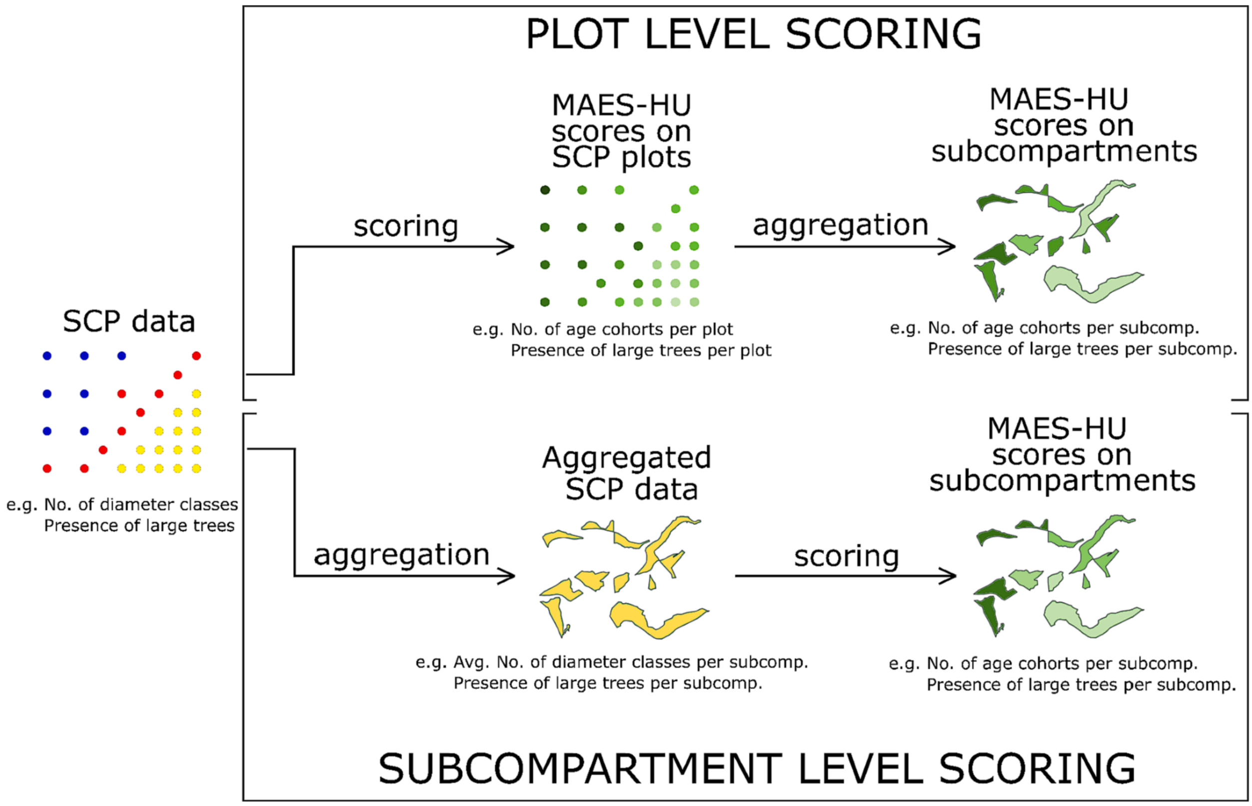

Fig. 2. Two ways of applying the MAES-HU (National Ecosystem Services Assessment of Hungary) scoring system on the SCP (Swiss Contribution Project) data. In the case of the "Plot level scoring", each SCP plot was scored individually according to the MAES-HU criteria, followed by aggregation. In the case of the "Subcompartment level scoring", the SCP data were first aggregated (averaged or added) to the subcompartment level and the MAES-HU scoring was applied to these results. In both cases, we obtained subcompartment level assessment like in the original MAES-HU, which can be further compared with the results of the MAES-HU.

for it to give correct results with the SCP survey data. Changes to the original set of rules can be found in Supplement 5. With these minor changes, the MAES-HU ecosystem type classification was completed for each SCP plot. For the "Subcompartment level scoring" the plots classified as regeneration areas were excluded from the analysis. For further details (indicator score rounding during aggregation, scoring of plantations) see Supplement 6. The "Plot- and Subcompartment-level scoring" results were compared with the MAES-HU results by subtracting the MAES-HU scores from the SCP scores for each indicator. The differences were plotted for the individual indicators. Paired-Wilcoxon tests were performed to detect statistical differences between the MAES-HU scores and the two types of SCP scores. The tests were performed on all condition indicators and scores.

2.3.4. Relationships of the MAES-HU indicators with other indicator groups of conservation importance

So far, we have examined the relationship of the MAES-HU scores with the same set of indicators, using similar data from two different scales. Here we examine the correlations of the MAES-HU scores to certain variables, which are not included in the MAES-HU indicator set. These variables are considered important for conservation, but were omitted from the MAES-HU assessment because they are missing from the NFD. By exploring the correlations, we searched for variables of conservation importance in the SCP dataset (Supplement 3) which can be indirectly detected through the MAES-HU scoring. The examined variables are listed in Table 5.

2.3.4.1. Relationship of the SCP indicators with MAES-HU scores. We analysed the relationship of all the variables in Table 5 with the MAES-HU scores. Spearman rank correlation was used. The comparisons were performed at the SCP plot level: the MAES-HU scores and the ecosystem type classification of the subcompartments were extracted for each SCP plot. If we had done the opposite (aggregated the data of the SCP plots to the subcompartment level), the outliers that could be important for conservation would probably have been lost during the procedure.

2.3.4.2. Relationship of the SCP indicators with individual MAES-HU indicators. As the SCP dataset has finer resolution than the MAES-HU data, we had the opportunity to study the relationships among some of their individual indicators, which we consider important for nature conservation. The MAES-HU indicators of old and large trees indirectly assume the presence of habitat trees in the subcompartment, as once they occur, there is a chance of finding more than just one individual. Some of these trees (or parts of them) may even be dead, therefore several tree-related microhabitats (TreMs) are expected to be present in the habitat trees. For all these reasons, based on the SCP data, we examined the relationship between the presence of TreMs, standing dead trees with DBH = 21–50 cm and DBH > 50 cm with the mentioned MAES-HU indicators (Table 3). This required the aggregation of SCP data at the subcompartment level. The number of TreMs and the standing dead trees by diameter class were aggregated according to their presence/absence in subcompartments. As these variables may also occur in regeneration areas, these subcompartments classified as such in MAES-HU were also included in these studies. We compared the distribution of these variables between the groups of binary MAES-HU indicators using Wilcoxon tests.

All analyses were performed using The R Base Package (version 4.0.4 – R Core Team, 2022).

Table 5
Further indicators of conservation importance examined in relation with the MAES-HU (National Ecosystem Assessment of Hungary) forest condition scores. The NFD (National Forestry Database) serving as the basis for the MAES-HU forest condition evaluation, does not contain such information. The variables from the SCP (Swiss Contribution Project) and their usage can be seen in the third column.

Indicator group	Indicator based on SCP	Meaning and calculation of the indicator	Compared with the following MAES-HU scores	Compared with the following MAES-HU indicator scores
Dead trees	DBH = 21–50 cm	No. of standing dead trees with DBH = 21–50 cm in the plot	Structure score; Summed score; Simplified score	Old trees presence; Large trees presence
	DBH > 50 cm	No. of standing dead trees with DBH > 50 cm in the plot		
	CWD	Qualitative and quantitative attributes of FWD and CWD (fine and coarse woody debris with below and above DBH = 8 cm) in the plot, based on the SCP ordinal scale		–
Invasive trees	Invasive tree species along the route	Presence of invasive tree species along the route (0/1), with unified species list congruent to MAES-HU	Composition score; Summed score; Simplified score	
	Invasive tree species in plot	Presence of non-native and invasive tree species in the plot (0/1)		
Microhabitats	Tree-related microhabitats (TreMs)	No. of TreM types in the plot, according to the SCP list	Structure score; Summed score; Simplified score	Old trees presence; Large trees presence
Game pressure	Game presence	In case of heavily or more severely browsed regeneration layer and the presence of game caused soil disturbance (0/1)		–

3. Results

3.1. Validation of the MAES-HU national condition assessment based on detailed field data

All the tested scores showed differences between the MAES-HU and SCP scores ($p < 0.001$) (Fig. 3). These originate from the differences between the scores of the individual indicators. The results of the paired Wilcoxon tests underlined that there was a significant difference (in most cases $p < 0.001$) between the MAES-HU and SCP scores for all indicators (Supplement 7). During the comparison of individual indicators, the "Subcompartment level scoring" almost always had a larger deviation from the MAES-HU scores than the "Plot level scoring".

In the case of "Forest composition score" the match between the MAES-HU and SCP data is visually striking. However, the SCP-based "Subcompartment level scoring" and the "Plot level scoring" showed slight differences compared to the MAES-HU: most of the subcompartments earned the same score during the "Plot level scoring" and earned 1 point more in the case of "Subcompartment level scoring" (Fig. 3).

The "Forest structure score" showed a poor match between the MAES-HU and the SCP evaluations. In most cases, the scores based on SCP data are 5 points higher. This is partly explained by the differences between the individual MAES-HU and SCP indicators (Supplement 7).

The "Summed score" also showed an inadequate match between the MAES-HU and SCP scores (Fig. 3). The results of the "Plot level scoring" showed a more acceptable match between the two, because the SCP received 2–6 points more than MAES-HU. In the case of the "Subcompartment level scoring" the SCP received 3–8 points more than MAES-HU.

Comparing the MAES-HU and SCP scores on the "Simplified score" refines the results. The aggregation of the "Summed score" values to a 5-point scale somewhat buffered the differences. Overall, a moderate match can be detected here because + 1 point were the most common in the case of SCP compared to the MAES-HU assessments (in this case, the maximum score is 5).

Supplement 7 summarises how the three types of scores (the original MAES-HU scores and the results of the MAES-HU scoring applied to the more detailed SCP data with two different aggregation methods) differ in the subcompartments for each indicator.

3.2. MAES-HU relationships with other indicator groups of conservation importance

3.2.1. Relationships of the SCP indicators with MAES-HU scores

The invasive tree species (SCP data), which were recorded along the route between plots, showed the strongest correlation with all the MAES-HU scores. The correlation of the invasive tree species frequency along the route with each of the "Forest composition score", the "Summed score" and the "Simplified score" all showed the same statistical result ($r_s = -0.22$; $p < 0.001$). These species occurred in areas with lower scores and were less likely to be present in areas with higher scores (negative r_s-values). A similar relation can also be seen in the case of the non-native regeneration layer recorded in the plot ($r_s = -0.20$; $p < 0.001$) (Fig. 4). All correlations examined here were significant, even though the r_s-values were not conspicuously high.

Regarding the distribution of DBH = 21–50 cm standing dead trees (SCP data), the correlations with the "Forest structure score" ($r_s = 0.04$; $p < 0.001$), the "Summed score" ($r_s = 0.01$; $p < 0.01$) and the "Simplified score" ($r_s = 0.01$; $p < 0.05$) all showed significant relationships. However, as reflected by the very low r_s values, the frequency of these trees showed a very similar distribution across all MAES-HU scores. As a result, we consider that differences in this indicator are not well reflected by the MAES-HU scores (Fig. 5).

Very few DBH > 50 cm standing dead trees were found in the study areas. High values of "Forest structure score" were found in plots with an elevated frequency of large-sized deadwood (Fig. 5). In the case of the

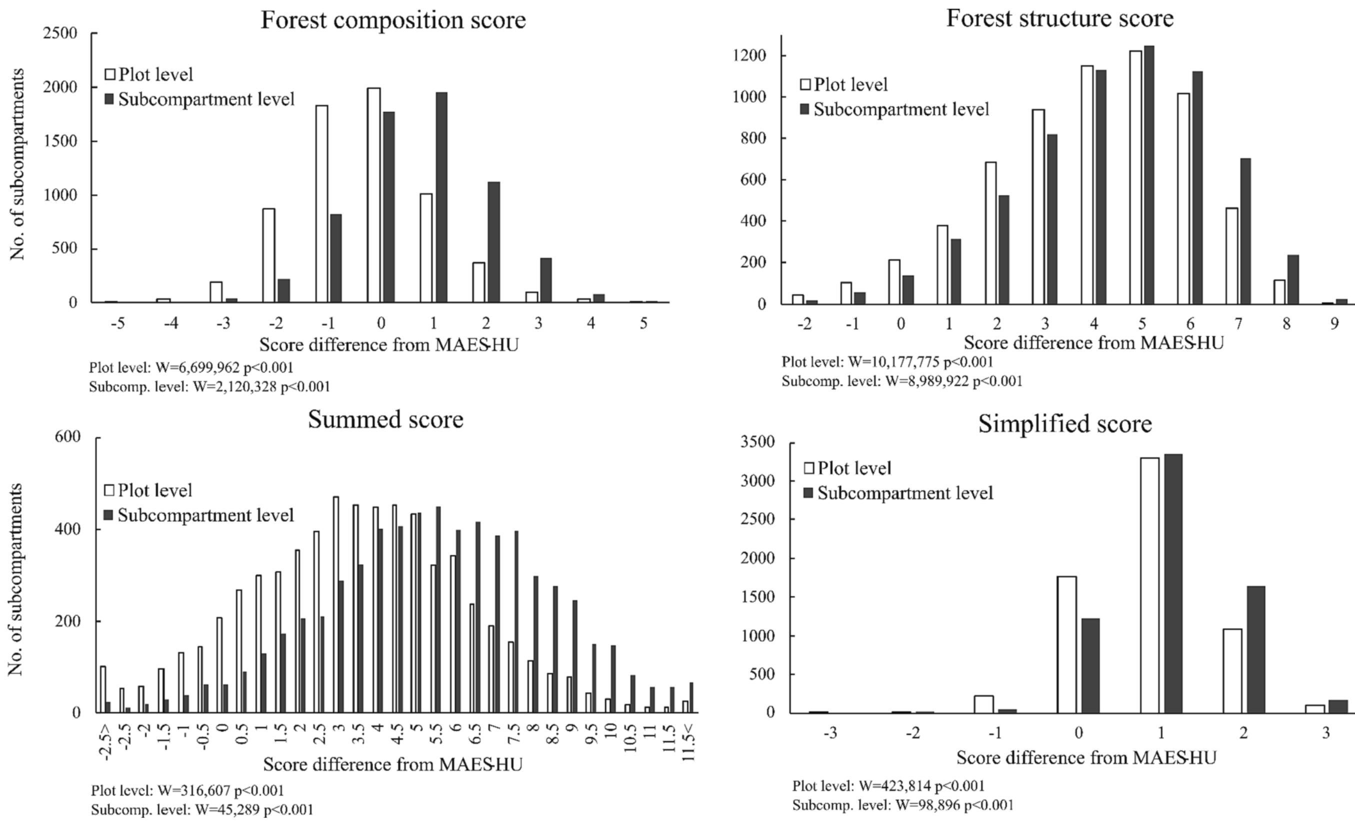

Fig. 3. The differences of the tested scores between SCP (Swiss Contribution Project) and MAES-HU (National Ecosystem Services Assessment of Hungary). The x axis shows the SCP score difference to the MAES-HU. The white bars represent the "Plot level scoring" and the gray bars the "Subcompartment level scoring". Plantations and native forests were not treated separately. The results of the Wilcoxon-tests between the 2 types of SCP-based calculations and the MAES-HU scores are shown under each diagram.

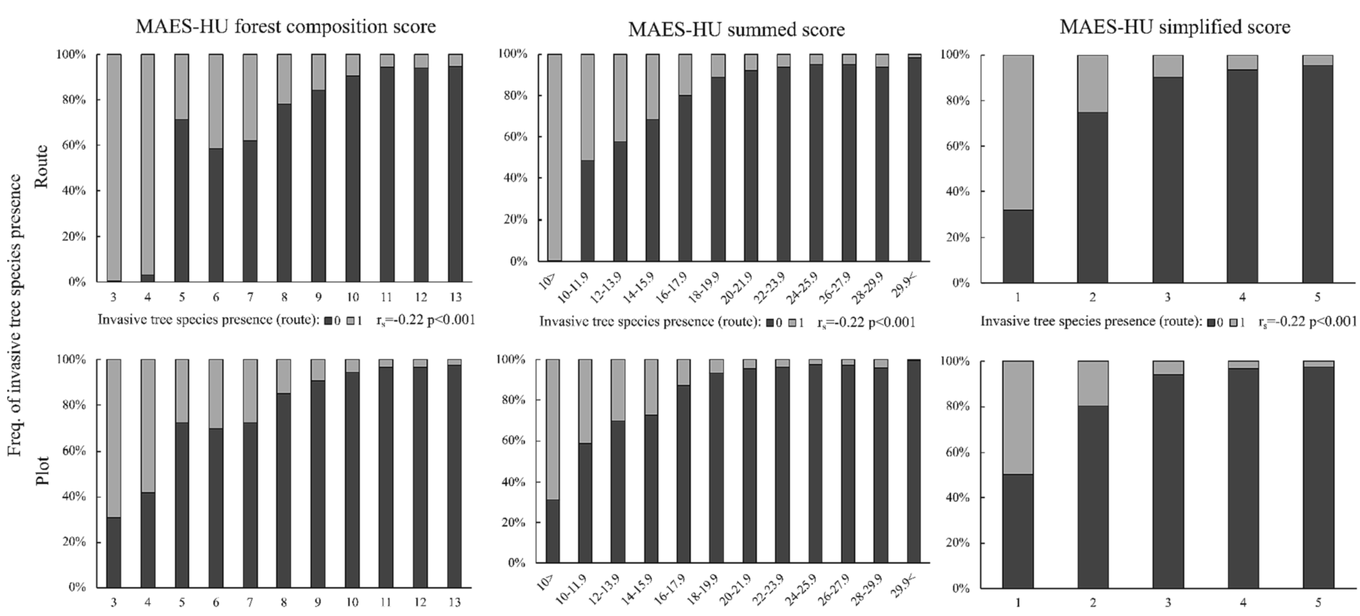

Fig. 4. Relationships of MAES-HU (National Ecosystem Assessment of Hungary) scores ("Forest composition score"; "Summed score"; "Simplified score") with some indicators from the SCP (Swiss Contribution Project) survey. The Spearman rank correlations between the plotted variables are shown under each diagram.

"Summed score", the plots richest in DBH > 50 cm dead trees received at least 30 points, and in the "Simplified score", the maximum points were given. Most of the plots that had 1 or more large standing dead tree(s) got the best final rating. There are only a few of these plots, but large dead trees are more likely to be present in forests with a high "Forest structure score". Probably due to the very low number of such trees, the correlation is very weak (although significant) ($r_s = 0.04$; $p < 0.001$).

In the case of the CWD scale (SCP data), the correlation with the

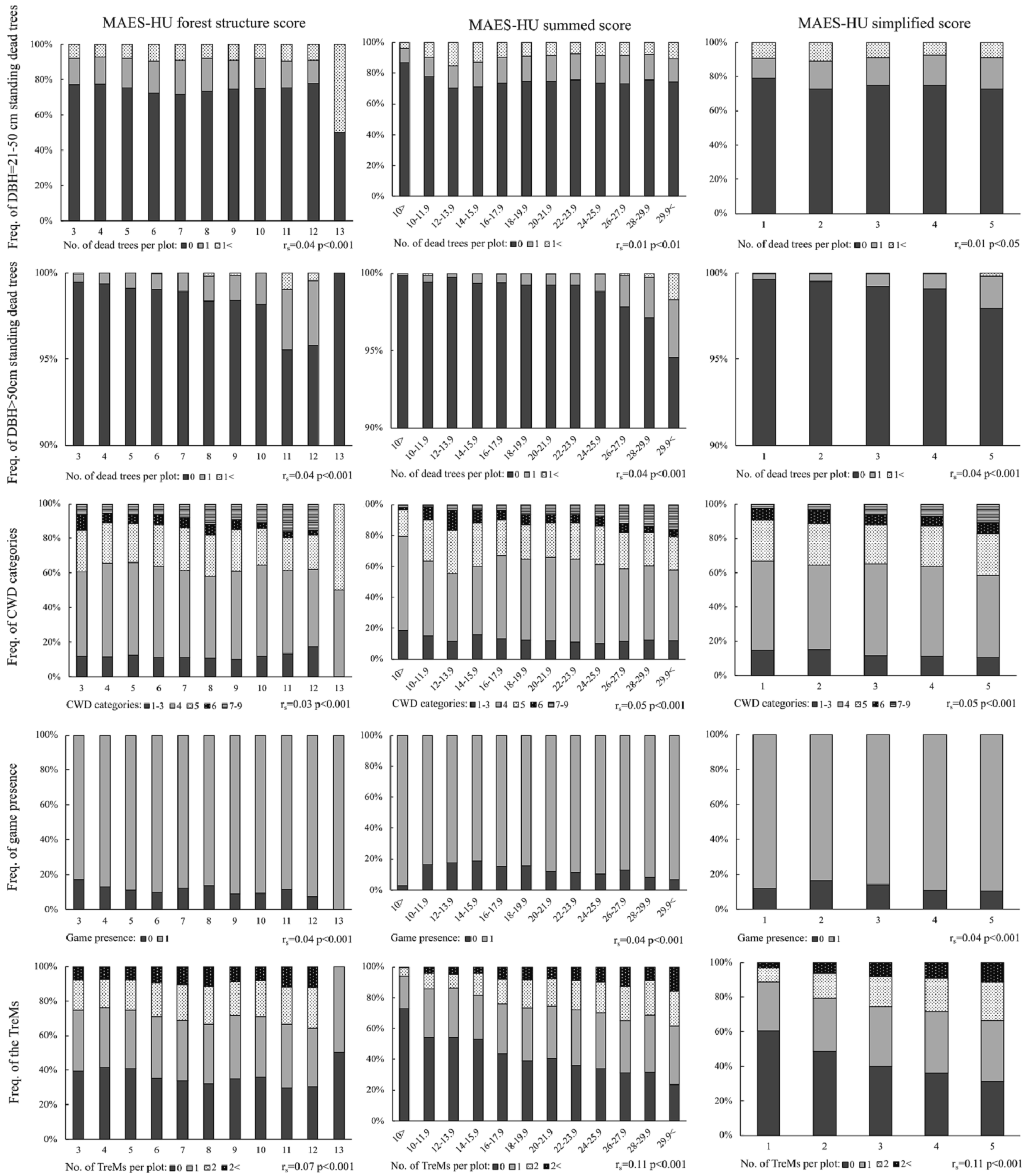

Fig. 5. Relationships of MAES-HU (National Ecosystem Assessment of Hungary) scores ("Forest structure score"; "Summed score"; "Simplified score") with some indicators from the SCP (Swiss Contribution Project) survey. The Spearman rank correlations between the plotted variables are shown under each diagram.

"Forest structure score" ($r_s = 0.03$; $p < 0.001$), the "Summed score" ($r_s = 0.05$; $p < 0.001$) and the "Simplified score" ($r_s = 0.05$; $p < 0.001$) all showed very weak relationships (Fig. 5). A similar result can be observed for game pressure ($r_s = 0.04$; $p < 0.001$). The frequency of the CWD categories and the presence of the game pressure showed a very consistent distribution across all MAES-HU scores. Intensive game pressure and forest management with consistently low level of deadwood retention is a widespread phenomenon in the study areas.

The number of TreMs also showed a very weak positive correlation with "Forest structure score" ($r_s = 0.07$; $p < 0.001$), the "Summed score"

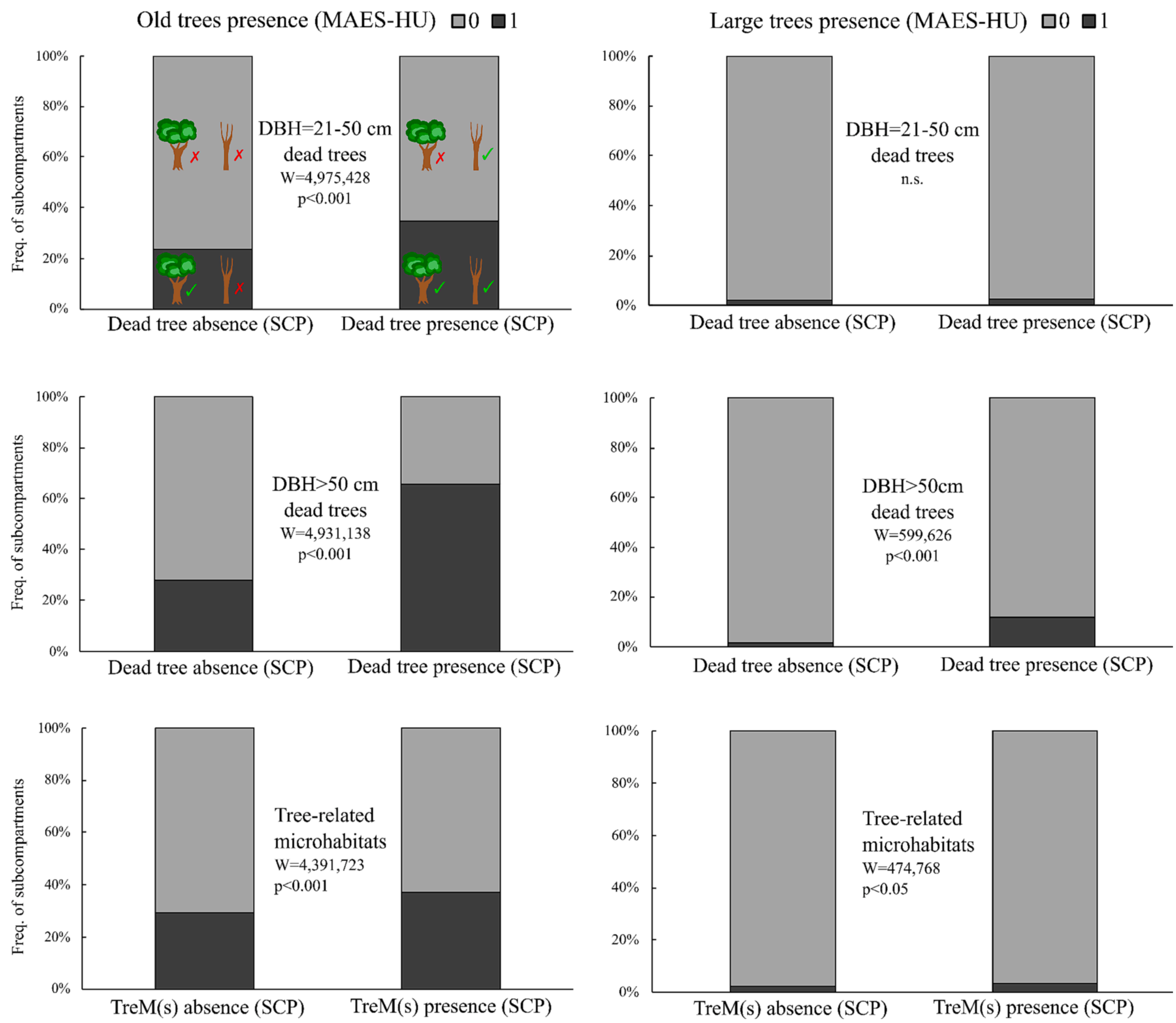

Fig. 6. The behaviour of more direct SCP (Swiss Contribution Project) biodiversity indicators (presence of standing dead trees with different DBH-categories and presence of tree-related microhabitats) in relation to the MAES-HU (National Ecosystem Assessment of Hungary) indicators (presence of old and large trees). The first diagram shows a visual example based on each combination of presence/absence of the tested values. The same interpretation can be applied to the other charts. The results of the Wilcoxon tests between the plotted variables are also shown.

($r_s = 0.11$; $p < 0.001$) and the “Simplified score” ($r_s = 0.11$; $p < 0.001$). Visually the “Summed score” and the “Simplified score” show a clearer trend: the higher their value, the higher number of TreMs occurred in the plot (Fig. 5).

3.2.2. *Relationships of SCP indicators with individual MAES-HU condition indicators*

The presence of dead trees with DBH = 21–50 cm (SCP data) showed a significant difference only in relation to the MAES-HU indicator “Presence of old trees” ($p < 0.001$) (Fig. 6). Dead trees in this DBH group were more likely to occur in subcompartments where there were at least some 100 year-old trees.

The presence of TreMs and standing dead trees with DBH > 50 cm (SCP data) showed a significant positive relationship with the MAES-HU indicators presence of both old (100 yrs. <) ($p < 0.001$ in both cases) and large (DBH > 50 cm) trees (TreMs: $p < 0.001$; dead trees: $p < 0.05$) (Fig. 6). If old and large trees are present in the subcompartment, they are likely to provide several types of TreMs, and dead trees with similar parameters are more likely to be found among them.

4. Discussion

4.1. *Validation of the MAES-HU condition assessment with SCP data*

As the study area of the SCP is limited, reliable data is only available for a part of the country. However, national condition assessments need to be based on databases with a national coverage in order to be consistent across the whole country. Our results serve to show the strengths and weaknesses of the national MAES-HU condition assessment, which was based on a less detailed and less reliable but spatially more extensive database, the NFD.

The NFD-based MAES-HU scores showed a varying correspondence with the scores based on SCP field data. In the case of indicators related to the forest composition, the MAES-HU reproduced the patterns of the finer resolution field data with reasonable accuracy. There are some differences in the proportion and number of native admixing tree species: in some cases, more of these have been registered in the SCP surveys than in the NFD. The NFD is specifically Hungarian, however, it is in many respects similar to NFIs, which are in use in many European countries. Related errors in the NFIs are usually caused by misidentifying and overlooking some individuals (Traub & Wüest, 2020), which can also be observed to a small extent in the Hungarian NFD. The SCP survey can be considered more reliable due to its strict quality assurance system (Standovár et al., 2016).

For the forest structure indicators, the MAES-HU and the SCP results differed from each other: MAES-HU underestimated the scores. The low correspondence may be due to the fact that in the NFD cohorts of different sizes are only recorded if they differ in size considerably and attain a minimum mixing ratio (Supplement 1), whereas in the SCP, all 5 DBH-classes present were described regardless of abundance. These differences are exacerbated by the lack of age variables in the SCP, which were consequently estimated based on diameter classes (Supplement 7). Thus the differences are multiplicated in the "Forest structure score" (Fig. 3). This result draws attention to the fact that valuable conservation information may be lost due to strong simplifications in large-scale monitoring methodologies which was concluded similarly by Corona et al. (2011). If data is available, we suggest the exploration of the relationships between fine-scale small-extent data and large-scale large-extent data. As we showed, with the validation of the fine-scale data we could find the best indicator(-combinations) in the large-scale database to predict diversity as well as the most important data gaps. The need for this kind of analysis is widespread. For example, Eigenbrod et al. (2010) showed that proxies can provide poor estimates of ecosystem services, and Lüscher et al. (2017) validated a biodiversity assessment tool with field data in farmlands.

The differences between the compositional and structural scores are also determined by the MAES-HU methodology. In several cases, the composition indicators were based on ratios, so single trees within an SCP plot had a minor effect on the composition score. Rare species are listed in the NFD (Supplement 1), and thus the difference between the SCP and the MAES-HU was small. On the other hand, most structural indicators take into account presence; a single tree could modify the indicator value of the entire subcompartment. Due to the nature of a more detailed, systematic survey, the SCP captures rarer dimensions better. The comparison method itself may also have contributed to the large differences in the structure scores. At the aggregation step, the presence / absence-type structural variables were rounded upwards, so the presence of e.g., a certain DBH-class in a single SCP plot would mean presence for the whole subcompartment (Supplement 6). This could have further magnified the differences.

According to our results, it matters a lot, in which step of the process we aggregate the data (Fig. 3, Supplement 7). This was particularly true when assessing admixing species; on an SCP plot basis, they received lower scores than when the proportions were aggregated to the entire subcompartment. This may be the result of the "Subcompartment level scoring" being more similar to the NFD data collection method: species composition data are averaged to subcompartments. Apart from that, the "Plot level scoring" seemed generally more reliable, because most of the comparisons showed smaller differences to the MAES-HU. In this aggregation method, the scores were averaged, which seems to mean less bias in the final result. In similar situations, we recommend aggregating scores instead of the indicator values, since the range of values is smaller, the information is therefore less distorted. Our results supported the suggestions of other authors that the careful selection of appropriate aggregation methods is important (Jakobsson et al., 2021), as these also influence the results.

We agree with Failing and Gregory (2003), who stated that different sets of indicators should be used to monitor biodiversity and make decisions. However, due to the national scale and the need for full coverage, the set of applicable variables is limited (trade-off between variable set and spatial coverage). The robust indicators of MAES-HU can adequately show changes in the condition at the national level on a large scale: e.g., a decline in the proportion of admixed species is worrying because of the increasing risk of pathogen outbreaks (Felton et al., 2010). But it is clear that the databases created for forest management and the condition assessments derived from these are of limited use when planning local conservation efforts (and should be supported by additional information). However, due to certain considerations (e.g., cost-effectiveness or the otherwise legitimate need to make the broadest possible use of existing databases), the idea to use these may arise.

4.2. Indicator evaluation

4.2.1. Forest composition and structure

Compositional indicators are the most commonly used for biodiversity assessments in forests (Feld et al., 2009; Winter et al., 2008). According to our results, these can be utilised with high certainty on several scales, because both the SCP and NFD methodologies are suitable for thoroughly assessing this type of information. The compositional indicators can also indirectly provide information about the condition of the regeneration layer (e.g., if there are invasive canopy trees, these species could propagate themselves in the regeneration layer). However, the SCP data showed that they have already appeared in the regeneration layer in many places where there are no invasive canopy trees. Based on our results and the proven validity of the indicators of forest composition (Ampoorter et al., 2020), we recommend the use of this group of indicators for reports.

There are many kinds of forest structure indicators, based on different criteria, methodologies and sets of variables (Ćosović et al., 2020). Due to different methodologies and sampling intensities, the results may differ significantly, as can be seen from our case study. The scoring discrepancies resulting from the methodological differences of the individual condition indicators appeared in the aggregated scores, thus significantly influencing our results. Despite our results, we still recommend the use of structural indicators, as they convey important information, but it is crucial to pay special attention to the limitations of individual methodologies.

4.2.2. Non-native tree species

The non-native and invasive regeneration SCP variables correlated well with all tested MAES-HU scores (Fig. 4). In the presence of such regeneration, a lower "Forest composition score" was assessed for each SCP plot. Both MAES-HU and SCP were able to classify non-native and invasive stands well. Because most invasive trees have a good dispersion potential, the regeneration also appears in higher density around mother trees. Due to the combination of these factors, we managed to show the strongest positive relationship between these indicators and the tested MAES-HU scores. This is useful for harmonisation efforts, as such data are easy to access and also frequently used (Kovac et al., 2020). As a consequence they often play an important role in biodiversity assessments, therefore, we also recommend their use.

4.2.3. Dead trees

The presence of dead trees is a prerequisite for the presence of saproxylic insects. The strength of the relationship between them shows a strong biome and location dependency which affects their suitability to detect the diversity of saproxylic species (Lassauce et al., 2011). The location dependency could arise from the discontinuous presence of suitable habitats through time. Thus in certain areas additional indicators need to be integrated for an assessment.

From the deadwood indicators, only the presence of DBH $>$ 50 cm standing dead trees showed a good relationship with the "Summed score" and the "Simplified score" (Fig. 5). The scoring system of MAES-HU is able to detect them indirectly. Despite the same statistical result as the others, there is no clearly outlined trend with the "Structure score". These plots were most often given high scores for the forest composition, thereby compensating for the lower structural score, resulting in a good match with the "Summed score". The NFIs of many countries register standing dead trees and they are working to harmonise them (Woodall et al., 2009), so it would be essential to map at least large standing dead trees in the Hungarian NFD as well.

The presence of large standing dead trees is more likely in all cases if there are old and large trees in the subcompartment (Fig. 6). In these subcompartments the last forestry intervention happened a long time ago, or the managers specifically protect older and (partially) dead groups of trees. The further preservation and protection of these patches must play an important role in Natura 2000 management plans. A similar pattern was described by Andersson and Östlund (2004) in Norrbotten County, Sweden, where older trees typically appeared aggregated due to forest management.

The CWD scale is a complex indicator, as it simultaneously shows information on the diameter conditions and quantity of lying deadwood (Standovár et al., 2016). Combining the individual groups and treating them as one, we can see that there is no meaningful correlation compared to the MAES-HU scoring (Fig. 5). Plots with 4–6 CWD values are the most common and occur almost equally at all scoring values. This means a CWD of 3–20 m^3 / ha, which corresponds to the national values of the Hungarian commercial forests (0–44 m^3 / ha, average 11 m^3 / ha) (Bölöni & Ódor, 2014).

As neither the standing dead trees in the lower diameter classes nor the CWD categories showed a correlation with the MAES-HU scores, we do not think that these variables can be replaced by any of the examined indicators. Our results reaffirm what we have already suggested in our previous work (Bartha et al., 2009): it would be worthwhile to introduce some new, easy-to-add variables to the Hungarian NFD, which also contain information about these important components (e.g., presence of old and large living or dead trees in the subcompartment). Although these variables are frequently used, there are some boreal countries where the NFIs do not include them yet (Ćosović et al., 2020). Recording the amount of dead wood in the Scandinavian NFIs would be very informative, as Lassauce et al. (2011) showed a strong correlation with them and the saproxylic species richness of boreal forests. It would be particularly important to assess the deadwood-related indicators, as their standardisation also plays a role in most international harmonisation efforts (Chirici et al., 2012; Winter et al., 2008).

4.2.4. Tree-related microhabitats (TreMs)

TreMs are frequently used multi-taxon biodiversity indicators (Asbeck et al., 2021; Larrieu et al., 2018). Previous studies have shown that older trees are more likely to have TreMs (Paillet et al., 2017). The higher scores of many structural indicators suggest the presence of older trees directly (large and old trees) or indirectly (large difference between lowest and highest cohort age, presence of many diameter classes and age cohorts). According to our results, the presence of large and old trees is weakly associated with the diversity of TreMs, and thus with the formation of habitat trees (Fig. 6). This may be the result of the coarse resolution of the TreM typology we used, or the plot-based sampling which could overlook unique microhabitats (Burrascano et al., 2021). We have found the strongest correlation between the diversity of TreMs and the tested MAES-HU scores (Fig. 5). However, we consider it important to emphasise that in the case of a similar additive evaluation system, it is always worth examining the individual components separately. Thus, we highlight the importance of large and old trees, as described by Gossner et al. (2014). The monitoring methodology of TreMs, despite their importance, has not yet been generally harmonised (Kovac et al., 2020), however proposals have been made for harmonised typology and guidelines for their standardised recording (Larrieu et al., 2018). Based on our results, TreMs can be detected indirectly in several ways, so monitoring programs don't necessarily need to be supplemented with this group of indicators.

4.2.5. Game pressure

Game pressure was a combined variable (Table 5). As game pressure is uniformly high in the sampling areas, very weak correlations were found with the MAES-HU scores (Fig. 5). A program to monitor the impacts of wild game had started in Hungary independently of the NFD (so the significance of the impact has already been acknowledged), but it was terminated due to lack of resources. However, as this is a significant conservation indicator, the inclusion of additional proxies for this purpose seems justified for a full condition assessment. Demonstrating game impact (and other disturbances) is also a problem at the level of international reports, as efforts to harmonise this family of indicators are still pending (Kovac et al., 2020). Due to the lack of elaboration and harmonisation efforts of these indicators, they might not be easy to integrate into monitoring programs, however it would be necessary in the future.

5. Conclusions

In our case study we validated a large-scale database (NFD) with a fine-scale one (SCP) by comparing a forest condition assessment (MAES-HU) applied to both. We have shown that large-scale analyses can provide useful information within certain limits. We illustrated that a database primarily serving the needs of forest managers provides a range of biologically relevant variables reliably (species composition indicators). In contrast, additional information is needed for some other (structural) variables. Based on our results, the MAES-HU assessment which uses data from the NFD, tends to underestimate structural variety. Therefore we conclude structural indicators should be selected with special care, and it is important to be fully aware of the methodology of the data used as a proxy.

Certain information not directly included in large-scale databases (in our case, large standing dead trees and TreMs) can be detected indirectly; in other cases (other deadwood indicators, game pressure) important conservation information could be obtained by minimally supplementing the already existing large-scale monitoring protocols. Specifically, in the case of the Hungarian NFD, adding the number of old and large living or dead trees and some CWD indicators to the monitoring method would be beneficial for conservation-related reporting. Other national forestry databases (e.g., NFIs) should be overviewed for similar data gaps in order to make them suitable for satisfying the ever-growing need for up-to-date information on the condition of the forests. The additional variables should be integrated by taking international harmonisation proposals into account. We recognize that changing a methodology used for decades is not a straightforward task, but it would be worthwhile to make efforts to obtain information on important biodiversity variables.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2023.110539.

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