

Potential of use of remote sensing data as additional management tool in Biosphere Reserve networks – a case study of Czech Biosphere Reserves

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Abstract

The main goal of UNESCO's Man and the Biosphere Programme (MAB) is to improve the relationship between people and the environment using biosphere reserves (BR), which can be perceived as comprehensive and collaborative tools for the sustainable management of landscapes and natural resources. The BRs must comprise natural landscapes and examples of the gradation of human environmental impact, allowing for the study and proposal of new approaches to sustainable development. To comply with this agenda, knowledge of the sites' physical characteristics and ecological status is a prerequisite. The availability of public remote sensing data and other readily available sources opens a new approach to periodic BR assessment, even in sites with limited scientific infrastructure. To test and simulate this approach, we spatially joined the BR border polygons with various open-access data sources to analyse the main physical characteristics of six Czech BRs. In the study, we focused on analysing the environmental characteristics of the sites with particular emphasis on the Ecological Stability Coefficient (ESC) as an indicator of conditions needed to improve the ecological stability of the landscapes. The ESC was calculated based on the formula used in the Czech Republic, utilizing the CORINE Land Cover (CLC) dataset. The results showed that five sites have natural and close-to-nature landscapes with a significant predominance of ecologically stable structures and low intensity of human use, and one site has a generally balanced landscape with preserved natural structures. The results suggest that most Czech BRs follow the positive trend in the ESC state, offering feedback to BR coordinators. In addition, the study confirmed sufficient feasibility of open access data (CLC and similar) for temporal assessment of BRs and their ecological stability, which is information required for the periodic review process and as an indicator for the implementation of BR functions. If adjusted to local conditions, the ESC based on the CLC could be considered an additional management tool in mountain biosphere reserves and the rest of the World Network of Biosphere Reserves.

Introduction

Sustainable development is a crucial concept that focuses on the harmonious combination of economic growth, social well-being and environmental protection. Agenda 2030 urged countries to be more active in addressing global challenges through sustainability (UN 2015). There are many ways to seek out strategies to balance sustainable human use and the protection of biodiversity in landscapes managed and used by people (Tobón et al. 2017; Kremen & Merenlender 2018).

One approach is the implementation of the biosphere reserve (BR) concept in landscape management. A key requirement is that each BR must include areas that have different levels of alteration due to human activities. The large-scale protected areas, for example the national parks, are compatible yet different from the BRs (Gregg 1989). While national parks are primarily designated in undisturbed natural areas, BRs encompass human populations as both key contributors and beneficiaries of their activities (Tangley 1988; Price 1996). In terms of national park designation, nature conservation is of the highest priority. At the same time, the BRs must equally fulfill the three main interconnected functions – conservation, development and logistical support for research and education (UNESCO 1996; UNESCO 2017; UNESCO 2022).

Based on their zoning, the BRs are designated so as to find such a balance (Paliwoda et al. 2021). The BR

concept has proved its value beyond protected areas and is increasingly embraced by various stakeholders to link biodiversity conservation and socio-economic development for human well-being (Ruoss 2013). The Man and the Biosphere Programme (MAB) requires the inclusion of areas affected by human activities in every BR so as to study the relationship between humans and their environment. One of the first examples of incorporating altered landscape was the Trebonsko (Trebno Basin) BR, partly changed by gravel mining (Jeník 1996). The BRs carry biological and cultural values, history, traditions and heritage, and they focus on using natural resources that people protect and develop. The significant contribution of the BRs to the issue of sustainable development is their ability to cooperate with other similarly oriented networks, e.g. the International Model Forest Network (Cupa & Madera 2019).

As a subject of scientific inquiry, the landscape, not just in BRs, continually prompts questions regarding methodologies and scientific approaches. Being a composite of multiple layers of time and space, the landscape surpasses simplistic, one-dimensional concepts due to its intricate and complex nature (Lapka & Gottlieb 2022). The ecological stability of a landscape is crucial for sustainable development. It involves maintaining and enhancing the resilience of ecosystems to support various life forms while also providing essential services to human societies (Peng et al.

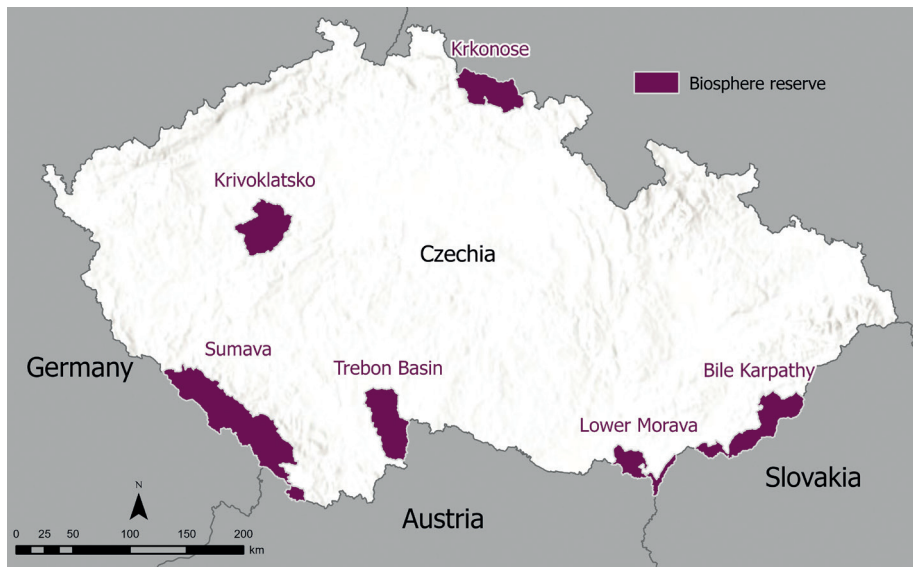


Figure 1 – Location of Czech biosphere reserves. Source: The Nature Conservation Agency of the Czech Republic

2021). A comprehensive understanding and assessment of the anthropogenic impacts on the environment is a prerequisite to maintaining its good ecological state (Vyleta 2019).

An essential component of ecological balance in landscapes is forests that serve as natural shields, mitigating the impacts of increasingly occurring severe weather patterns caused by climate change (Brockerhoff et al. 2017; Sallmannshofer et al. 2023; Moos et al. 2021). That is why we have emphasized the issue of forests as one of the environmental characteristics of the BRs. In addition, many BRs develop strategies to mitigate natural risks. Therefore, ecological stability in BRs is gaining importance in the context of natural disasters or their prevention (Pavlova et al. 2019).

Ecological stability in landscapes is assessed by using various methods to understand an ecosystem's resilience to changes. Diverse approaches can be used to evaluate landscape stability, including calculations of Ecological Stability Coefficients (ESC), soil erosion measurements and similar aspects (Nemetova et al. 2024). The methods must consider the context, management practices and specific landscape studied (Dujka & Kusbach 2023). The results can be used to balance human activities with ecosystem health because there is a strong relationship between landscape stability and land use (Prokopova et al. 2019). Various formulas quantify the ecological stability of landscapes. Specific research was performed by Novakova (1987), Löw (1984; 2003), Michal (1982; 1994), Lipsky

Table 1 – The area of individual sites, the year of designation, and mountain class. Source: USGS 2025*

Name of the biosphere reserve	Area (ha)	Year of designation	Mountain Class (MC) and Landform Class (LC)
Trebonsko (Trebon Basin)	68,747.7	1977	K3 LC: High Hills
Krivoklatsko	62,508.9	1977	K1 MC: Elevation = 300 m & Local (7 km radius) Elevation Range > 300 m K3 MC: Scattered Low Mountains and Low Mountains
Sumava	16,7586	1990	K1 MC: Elevation = 300 m & Local (7 km radius) Elevation Range > 300 m K3 MC: Low Mountains
Krkonose	54,969	1992	K1 MC: Elevation = 1000 m & Slope >= 5 degrees OR Elevation = 1000 m & Local (7 km radius) Elevation Range > 300 m K2 MC K3 MC: Low mountains and High Mountains
Bile Karpaty (White Carpathians)	74,701.8	1996	K1 MC: Elevation = 300 m & Local (7 km radius) Elevation Range > 300 m K3 MC: Scattered Low Mountains and Low Mountains
Dolni Morava (Lower Morava)	34,935.7	2003	K3 MC: Scattered Low Mountains and Low Mountains

* USGS Global Mountain Explorer platform works simultaneously with three scientific mountain classifications: K1 by Kapos (2000), K2 by Körner/GMBA (2011), and K3 by Karagulle et al. (2017). K1 is a physical geographic definition based on a combination of elevation, slope, and local elevation range (Kapos et al. 2000). K2 is an ecological classification that defines mountains according to terrain ruggedness and bioclimatic zones, especially the treeline and montane to alpine belts (Körner et al. 2011). K3 is a geomorphological classification using Hammond's landform types, combining slope, relative relief, and surface profile (Karagulle et al. 2017). USGS displays all three layers in parallel because each represents a different scientific perspective on what constitutes a "mountain," enabling comprehensive comparison across physical geography, ecology, and geomorphology.

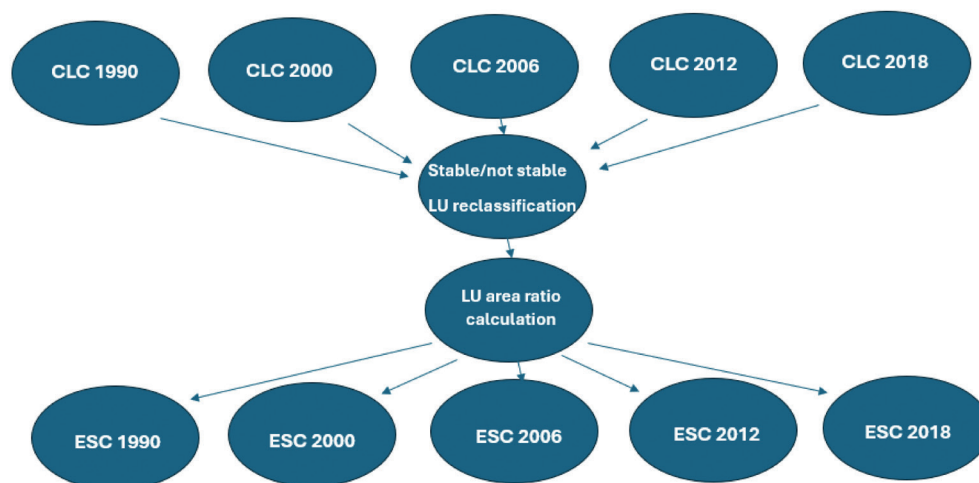


Figure 2 – A graphic framework model for incorporating the CLC (CORINE Land Cover) data and land use (LU) classification into the calculation of the ESC. (Ecological Stability Coefficient)

(2000) and Rehackova and Pauditsova (2007) in the regions of the Czech Republic and Slovakia. Landscapes are usually very diverse and often contain specific classes that are difficult and frequently impossible to incorporate into one of the habitat quality categories. Therefore, it is crucial to choose a coefficient that considers each element separately with an adequate value assigned (Bazik et al. 2014).

Addressing the issue of human influence on the environment begins with assessing landscape ecological stability, a complex process. This evaluation relies on various mathematical methods, starting with the identification of landscape elements and their classification into predefined categories (Ivan et al. 2014). While these categories may differ across methodologies, they generally share a similar perspective on the eco-stabilization value of landscape elements. The ESC was created and used in the Czech Republic and Slovakia for use in land consolidation (Ivan et al. 2013) or as a part of methodologies and guidelines for documenting territorial ecological stability systems at both regional and local levels, mainly to support state nature and landscape protection initiatives (Húsenicová et al. 1992; Izakovičová et al. 2000). The ESC serves as a key measure for the Czech Statistical Office, the central state administration authority, to assess territorial/landscape stability. It reflects the area's ability to endure external pressures while maintaining its ecological functions (Czech Statistical Office 2024). The ESC evaluates several factors, including landscape composition – the balance between natural and human-made elements within the environment; vegetation cover – the presence of forests, grasslands, water bodies and other natural ecosystems; degree of urbanization – the presence and extent of developed areas and their influence on ecological stability; and environmental resilience – the capacity of the landscape to withstand challenges such as pollution or climate shifts. Additionally, this indicator is used to evaluate environmental carrying capacity. A certain level of ecological sta-

bility is a prerequisite for landscape resilience and key principles of environmental sustainability.

Our study introduces a new approach by combining national ESC calculations with the international CORINE Land Cover (CLC) database for broader site assessment. Unlike traditional ESC calculations, which rely on precise but localized data, we prioritized widely accessible datasets that support large-scale analysis, benefiting stakeholders such as BR Coordinators and MAB Programme representatives.

The UNESCO member states must provide the border polygons projected in the WGS84 system (UNESCO 2022) and information about various site attributes (temperatures, precipitation, altitude, endangered species, etc.). Unfortunately, not all BRs have access to relevant site-specific data. Therefore, they are limited to open-access sources. This study aimed to test if the open-access remote sensing datasets, additional public sources and especially the CLC data used in simple ESC calculation can provide sufficient overall temporal assessment of the environmental characteristics that are required for the mandatory periodic review process and that can serve as an additional indicator of BR performance and as a support tool for BR coordinators.

Materials and methods

Study area

This analysis is focused on six Czech BRs that belong to the regional EuroMAB network. The total area of all Czech BRs is 463,449.1 ha, or 5.87 % of the Czech Republic's area (Figure 1).

The first two BRs were designated in 1977. The latest Czech BR was approved in 2003 as an extension of an existing site designated in 1986 (Table 1).

Databases and Methodology

Many BRs worldwide lack adequate scientific infrastructure. Even though this is not the case in the Czech

Republic, to simulate this situation, we used open remotely sensed datasets to obtain primary data complemented by additional data derived from other public sources (e.g. the IUCN Red List), as these sources are available for all UNESCO member states. The software used to extrapolate all data is ArcGIS Pro ver. 3.1.0 (Environmental Systems Research Institute - ESRI). However, QGIS (Open Source Geospatial Foundation Project) can also be used, as it contains the same geoprocessing tools that were used to process the data in this study. The BR border polygons were spatially joined with the following databases for the analysis:

The AW3D (JAXA) World digital terrain model determined the average elevation. The Biogeographical Provinces of the World (Udvardy 1975) were used to analyse the spatial distribution of Czech BRs by biome and province type. The average temperatures are among the characteristics collected from the BRs during the nomination process and periodic reviews. The WorldClim 2 model (Fick & Hijmans 2017) was used for the analysis, offering spatially interpolated monthly climate data at approximately 1 km² resolution. The dataset includes information on temperature (minimum, maximum and average), precipitation, solar radiation, vapour pressure and wind speed. To determine the number of endangered species (excluding birds) in BRs, the IUCN Red List of Threatened Species, Version 2024-1, was used. Currently, the IUCN database's bird section does not allow species selection for the categories of vulnerable, endangered and critically endangered. Therefore, the bird species were excluded from the spatial evaluation. Data on protected areas were sourced from Protected Planet, the World Database on Protected Areas (WDPA) online platform, a collaborative effort between the IUCN and UNEP-WCMC. The Global Forest Change dataset (Hansen et al. 2013) was used to extrapolate forest loss and gain inside the borders of BRs in the period 2000–2020. The CLC dataset, monitoring the pan-European land cover inventory, with an update period of six years, was used to extrapolate the land cover changes within the BRs in the years 1990, 2000, 2006, 2012 and 2018 (Figure 2), providing input for ESC calculations. The updated CLC dataset for 2024 was not yet available when this article was written.

The ESC formula and the interpretation of its results used in the study were designed for the conditions of the Czech Republic. Therefore, there is a limit to potential transferability to the WNBR. In its original form, the group of environmentally stable areas includes forests, hop fields, vineyards, gardens, orchards, permanent grassland, pastures and water bodies. The group of environmentally unstable areas encompasses arable land, built-up areas and other use areas (Czech Statistical Office 2024). These categories do not fully adhere to the structure of CORINE Land Cover layers used as an input. Therefore, we divided the CLC classes into relatively stable and relatively unstable land cover categories (Table 2) based on the assumption

Table 2 – Distribution of CLC and cover classes according to their ecological stability.

Relatively stable areas
Agro-forestry areas
Bare rocks
Beaches, dunes, sands
Broad-leaved forest
Coastal lagoons
Coniferous forest
Estuaries
Fruit trees and berry plantations
Glaciers and perpetual snow
Green urban areas
Inland marshes
Intertidal flats
Land principally occupied by agriculture, with significant areas of natural vegetation
Mixed forest
Moors and heathland
Natural grasslands
Olive groves
Pastures
Peat bogs
Salines
Salt marshes
Sclerophyllous vegetation
Sea and ocean
Sparsely vegetated areas
Relatively unstable areas
Airports
Annual crops associated with permanent crops
Burnt areas
Complex cultivation patterns
Construction sites
Continuous urban fabric
Discontinuous urban fabric
Dump sites
Industrial or commercial units
Mineral extraction sites
Non-irrigated arable land
Permanently irrigated land
Port areas
Rice fields
Road and rail networks and associated land
Sports and leisure facilities

that ecological stability is defined as the ability of a given ecosystem to return to its original equilibrium state after disturbance (Ives & Carpenter 2007; Levin et al. 2009) and the intrinsic ability to maintain ecological functions despite disturbance (Turner et al. 1993).

As mentioned above, ecological stability analysis is based on the ESC indicator used by the Czech Statistical Office, one of the state administration authorities, to assess territorial/landscape stability and the environment's carrying capacity (Czech Statistical Office 2024). The ESC formula is defined as the ratio of relatively environmentally stable areas to relatively unstable ones:

$$\text{ESC} = \frac{\text{total of relatively stable areas}}{\text{total of relatively unstable areas}}$$

Table 3 – Interpretation of the Ecological Stability Coefficient (ESC).

ESC	Interpretation
< 0.10	territory with maximum disturbance of natural structures; basic ecological functions must be intensively and permanently replaced by technical interventions
0.10 < ESC < 0.30	area with above-average use, with a clear disturbance of natural structures; basic ecological functions must be replaced by technical interventions permanently
0.30 < ESC < 1.00	in intensively used areas, mainly by agricultural production, the weakening of self-regulatory processes in ecosystems causes considerable ecological instability and requires high inputs of additional energy
1.00 < ESC < 3.00	a generally balanced landscape in which technical buildings are relatively in harmony with the preserved natural structures, resulting in a lower need for energy and material inputs
> 3.00	natural and close-to-nature landscape with a significant predominance of ecologically stable structures and low intensity of human use of the landscape

The results of ESC calculations are interpreted according to their value (Table 3). ESC is a dimensionless figure. Any value exceeding 3 suggests stable landscapes reflecting an area's high eco-stabilization potential. The weakness of this methodology is that it does not sort into groups the areas with ESC values above 3, even though some can reach a value close to 100 in cases of dominant natural conditions. However, a high ESC is sufficient to gain situational awareness.

Results

Spatial distribution of Czech BRs in the context of protected areas

Five out of six Czech BRs are entirely covered by some form of large-scale protected area (National Park or Protected Landscape Area). Only 13 870.6 ha are located outside protected areas (Table 4), relevant to only one site – the Lower Morava BR.

Biogeographical distribution of Czech BRs

According to the Classification of the Biogeographical Provinces of the World (Udvardy 1975), four of the studied BRs are located in the Mixed Mountain Biome and the Temperate Forest and Woodland Biome (Table 5 and Figure 3).

Main environmental characteristics of Czech biosphere reserves

The terrain of the Czech Republic is very diverse. Two major mountain ranges (the Krkonose Mountains and the Sumava Mountains) and a network of highlands and lowlands shape much of the country's landscape. The Snezka (altitude of 1,602 m asl) – the highest peak in the entire country, is located in the Krkonose BR. The average elevation across the country is about 400 m (World Map Guide 2024). The precipitation and temperature data can provide a valuable baseline for evaluating the changes related to climate change (Table 5). The WorldClim 2 model enables tracking these variations if necessary.

Table 4 – Comparison of protected areas and Biosphere Reserves in the Czech Republic (Source: the authors).

Total area (ha)	7,884,180.00
PA area (ha)	1,732,154.43
PA (%)	21.97
BR area (ha)	461,066.14
BR (%)	5.85
BR area outside PA (ha)	13,870.60

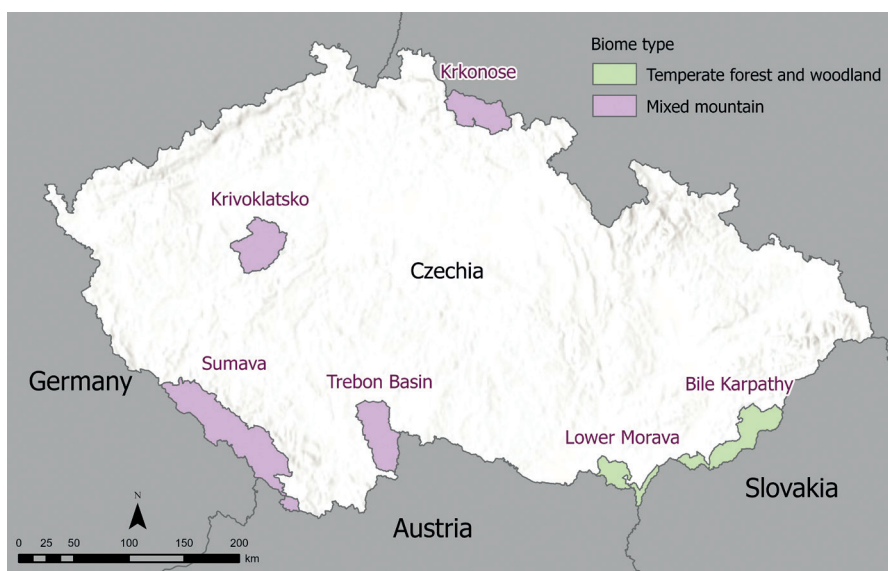


Figure 3 – Spatial distribution of Czech BRs within the biomes (Udvardy 1975).

Table 5 – Biogeographical distribution (Udvardy 1975), number of Vulnerable (VU), Endangered (EN) and Critically Endangered (CR) species of the IUCN Red List of Threatened Species (excluding bird species) (IUCN 2024), elevation and temperatures (AW3D and WorldClim 2) and precipitation in Czech BRs (WorldClim 2) in Czech Biosphere Reserves (BR).

BR	Biome type	Number of VU, EN, CR species (IUCN Red List of Threatened Species)	Max. elevation (m asl)	Temperature (°C)			Precipitation (mm)		
				Annual average	Max. in the warmest month	Min. in the coldest month	Annual avg.	Avg. in the driest month	Avg. in the wettest month
Krkonoše	Mixed mountain	18	853.1	5.0	18.6	−6.8	689.4	34.8	90.8
Krivoklátsko	Mixed mountain	17	412.1	7.9	22.7	−4.4	597.6	30.7	81.1
Sumava	Mixed mountain	33	905.2	5.6	19.2	−6.0	1163.7	70.1	134.8
Třebonsko	Mixed mountain	20	454.4	7.8	23.0	−4.9	635.0	32.3	88.0
Bílé Karpaty	Temperate forest and woodland	26	442.2	7.7	22.8	−5.2	723.7	36.1	97.9
Dolní Morava	Temperate forest and woodland	23	194.0	9.7	25.5	−3.6	598.4	28.6	84.3

The number of vulnerable, endangered and critically endangered species in BRs

In addition to other criteria, the BRs should be significant for biological diversity conservation (Table 5). It must be emphasized that biodiversity cannot be evaluated only by the number of endangered species. Despite that, the MAB collects data on red-listed species. Therefore, we included the analysis of the number of vulnerable (VU), endangered (EN) and critically endangered (CR) species according to the IUCN Red List of Threatened Species (excluding birds) available in the IUCN database.

Forest change in Czech biosphere reserves

Between 2000 and 2022, the forests in some Czech BRs experienced a loss due to various events (Table 6). These events were mainly linked to global climate change and included pests, disease outbreaks or extended periods of drought.

ESC – Ecological Stability Coefficient

The results summarize the development of the ESC in individual BRs between 1990 and 2018. The trend reflects the comparison of the ESC in 2006, when all the sites were already designated, to the situation in 2018, when the latest data originated (Table 7 and Figure 4).

Discussion

Remote sensing data (and other digital databases) are widely used in the evaluation of protected areas, while in the case of BRs, they still need more implementation. Despite that, a similar approach to characterizing ecosystem functioning and functional diversity was implemented, for example, by Cazorla et al. (2023) in the case of the Sierra Nevada BR (Spain), utilizing Ecosystem Functional Type (EFT) classes and their changes and presenting new dataset based on the temporal dynamics of the Enhanced Vegetation Index (EVI) data from the MODIS sensor (MOD13Q1.006). The EFT approach provided insights into conservation priorities, ecosystem reactions to environmental changes and estimating the provision of ecosystem services or model species distribution. This approach is more precise than the one used in this study, requiring more specific data. As many BRs do not have access to specialized datasets, we tried to work with open sources to obtain information usable for assessing and providing situational awareness within the World Network of BRs (WNBR).

The ESC calculation for temporal BR evaluation seems more frequent and was applied, for example, by Olah and Boltižiar (2009) in the case of four Slovak BRs. They used a different formula, $ESC = (\sum p_i \cdot k_i) \cdot p^{-1}$, where p_i is an area of land use form; k_i is the ecological significance of land use

Table 6 – Forest loss and gain in Czech BRs (Global Forest Watch – Copernicus).

BR	Forest loss 2000–2022		Forest gain 2000–2012		Forest loss 2000–2012	
	ha	% of BR area	ha	% of BR area	ha	% of BR area
Bílé Karpaty	3,701.9	5.0	923.5	1.2	1,493.9	2.0
Krivoklátsko	3,959.3	6.3	1,144.2	1.8	1,634.1	2.6
Krkonoše	2,780.7	5.1	3,181.1	5.8	924.5	1.7
Dolní Morava	1,967.9	5.6	351.2	1.0	1,183.5	3.4
Sumava	17,603.1	10.5	4,095.6	2.4	11,384.5	6.8
Třebonsko	4,047.2	5.9	1,545.5	2.2	1,939.7	2.8

Note: The data are based on a 12-year period (2000–2012) due to the limited availability of extrapolated forest growth data derived from satellite imagery. Forest increment data are available for that period because a forest needs a certain period of growth (more than 10 years) to be analysable from satellite data. This contrasts with forest loss, which is visible immediately and can be analysed continuously.

Table 7 – Ecological Stability Coefficient (ESC) according to CORINE Land Cover classes (+ positive trend, – negative trend).

Biosphere Reserve name	Year of designation	ESC					Trend 2006–2018
		1990	2000	2006	2012	2018	
Bile Karpaty	1996	2,05961	3,21316	4,09125	4,54818	4,51856	+
Krivoklatsko	1977	2,53394	2,94699	3,06936	3,43299	3,42624	+
Krkonoše	1992	8,63252	24,4112	24,8815	18,1074	17,728	–
Dolní Morava	2003	1,19481	1,28032	1,41765	1,48262	1,52481	+
Šumava	1990	14,5937	66,1693	74,3012	94,7681	95,5761	+
Třebensko	1977	2,47493	3,43419	3,57178	4,4188	4,47866	+

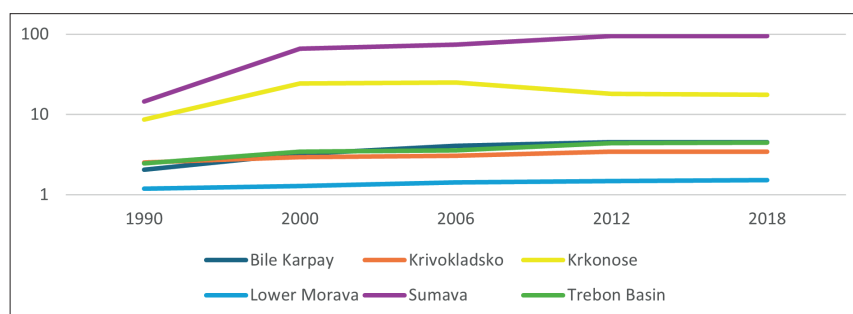


Figure 4 – Trend in the evolution of Ecological Stability Coefficient values in landscapes of Czech Biosphere Reserves between 1990–2018.

form; and p is the total area (Miklos 1986). The input data was based on conventional historical and current maps and aerial orthophotographs processed in GIS. The results were more accurate than our study but required more detailed input data. Despite different methods, ESC calculation was validated as an instrument for assessing BRs, which our study confirmed. In any case, it should not imply that the low-scoring BRs have inappropriate management, and the high-scoring sites have immaculate management, as more precise data are always needed for responsible evaluation. An on-site survey must verify the indicated problems. For example, the negative trend in the development of ESC in the Krkonoše BR, presented in this study, was caused by a combination of planned timber harvest, mugo pine (*Pinus mugo*) control measures to mitigate inappropriate planting in the past and mainly necessary forestry measures called for by bark beetle (*Ips typographus*) outbreak. However, despite the trend, the local survey confirmed that the site maintains a very high ESC status and that all the implemented measures are closely monitored and reviewed.

Alternative indicators of stability, such as the Normalized Difference Vegetation Index (NDVI) or Land Use / Land Cover (LULC) changes, have been considered. However, their effect is significantly influenced by local aspects. NDVI changes are strongly affected by regional climate, and LULC varies in the importance of habitat types in the local context. Modern technologies in remote sensing such as the Sentinel satellite system, LIDAR, machine learning and AI-based classification, or multispectral images with very high resolution such as WorldView III, World View Legion, SkySat and others as well as analysis of radar satellite data are providing very accurate assessments of environmental aspects or indicators of ecological

stability at the local level. However, adopting these technologies for a global methodological procedure brings high demands to the processing team, which is often not within the capabilities of BR management. Such a sophisticated approach will also necessarily introduce high variability in the interpretation of the outputs, resulting in their mutual incomparability.

Generally, the use of remote sensing data in larger sections of the WNBR may bring several challenges. One is related to the need for more current data on borders in digital form in BRs in less developed countries. This issue is currently being resolved through the generation of the UNESCO Biodiversity Portal. Another issue may involve the need for more information to be provided by the states to the CLC datasets. Another area for consideration is that there needs to be a universal methodology to assess the stability of land uses according to their influence on the ecological stability of the landscapes. A topic for future discussion is remote sensing data sources, an alternative to CLC, which are utilized in various parts of the world. Additional challenges stem from the technical limits of the CLC. For example, there is the issue of the generalization of data used by the CLC. The CLC implements images provided by Landsat with 30 m pixels. Should the ESC be used as a precise indicator of BR performance or as a tool for the BR managers to improve decision-making? More accurate databases based on orthophotos or images acquired by unmanned aerial vehicles must be employed. Regarding not only BRs, the ecological stability of landscapes is fundamental to balancing human needs and the environment's capacity to provide resources and services sustainably. The more information is available, the higher the quality of the landscape management measures implemented, and the actions proposed.

The article is not primarily focused on suggesting practical measures for improved decision-making by BR managers. Our work aims, above all, to highlight the use of the ESC based on the CLC as a tool to identify potentially problematic areas and initiate remediation processes if necessary. The practical applications must be completed individually, and the experience gained can be a topic for additional studies.

Despite its limitations, the ESC, in its current form, can be used to support management decisions regarding human activities within BRs. In terms of BRs, the majority of human activities occur in the transition area, partly in the buffer zones and seldom in core areas. A negative trend in ESC may signal potential problems, and subsequent analysis of input data can help explain which unstable areas are increasing in size and why. The proposed follow-up management decisions can be more targeted in terms of measures to be taken and stakeholders with whom to cooperate.

Conclusion

Protected areas overlap with five out of six Czech BRs entirely. The reason is that they were designated before the Seville Strategy for BRs (UNESCO 1996), which clearly distinguished BRs from protected areas, was fully adopted. This situation is different from the present trend in BR designation. Currently, the BRs within the majority of the respective UNESCO member states do not entirely coincide with protected areas, which is perceived as positively affecting the ability of the sites to fulfill their main functions equally, as well as the aptitude of governance structures to be more inclusive in terms of stakeholder participation. In addition, the territorial extension outside protected areas contributes to a better public understanding of the BR concept and improved differentiation from protected areas.

According to our analysis, the Czech BRs' composition meets the MAB criteria in terms of including diverse biomes and ecosystems, significance for biodiversity and potential for exploring approaches to sustainable management of natural resources in various conditions. These prerequisites are based on the requirements prescribed by the Statutory Framework for BRs. The question is whether the new challenges caused, for example, by global climate change can be currently fully addressed or whether new criteria are needed for establishing and transforming BRs, encompassing natural and human relationships and values as proposed by Stoll-Kleemann and O'Riordan (2018).

Our study introduces a novel approach by integrating national ESC calculations with the international CLC database for comprehensive site assessment. Traditionally, ESC calculations rely on alternative base data, which, while potentially more precise, are often localized and unsuitable for broader applications, such as BR networks. To enable large-scale assessments, we opted for datasets that encompass extensive areas and

are widely accessible – ensuring broader usability for various stakeholders, including BR Coordinators and representatives of national and international MAB Programmes – and that have been tested on Czech BRs.

The reliability or accuracy of the ESC indicator depends on the data source. The ESC assessment in this study was based on calculations that work with rather general datasets of the CLC. Therefore, the results can provide only a comprehensive overview of individual sites and the MAB networks if used on a larger scale. In the Czech Republic, where the ESC is widely used, the Czech Statistical Office produces the input data with only medium accuracy. The data is derived from the land types listed in the Land Register, which has limited accuracy. If there is a GIS register of land available, then the calculations of the ESC are relatively accurate. However, our approach can be used for preliminary surveys to identify areas where the issue of ecological stability might need special attention.

A positive feature of CLC use is the repeatability of the study, which results from regular updates of the CLC every six years. Periodic updates can facilitate long-term observations of changes, and the iteration can be reflected in the compulsory BR Periodic Review process, with a 10-year update period.

The ESC calculations have limitations in data availability, essential variables and land cover classes. Despite that, the BR coordinators can use the basic ESC calculation to manage and plan sustainable development measures if the variables and input data are adjusted to local conditions. General characteristics and calculated ESC suggest that all Czech BRs have favorable conditions for maintaining or improving ecological stability. Five Czech BRs have natural and close-to-nature landscapes with a significant predominance of ecologically stable structures and low intensity of human use. One site has a generally balanced landscape with preserved natural structures.

The forest cover changes signal the need for additional research as five Czech BRs experienced more significant forest loss than forest gain between 2000 and 2012. As the BRs are perceived as *living laboratories of sustainable development*, their forests offer unique opportunities for transforming new information into recommendations for forest management measures (Madera et al. 2011). The analysis of forest loss and gain can be used as an indicator by the BR coordinators to adapt specific forest management measures, including expedited reforestation.

The analysis of information about the essential characteristics of Czech BRs using the remote sensing data can indicate a possible approach to raising situational awareness on a larger scale as a basis for creating common strategies at the BR networks and improving networking between the BRs. The analysis can add to sound decision-making in BR management and upgrade MAB Programme coordination, even without using special access databases. In addition, the analysis results can provide new momentum for generating

topics for applied research, where every BR can be a platform for scientists to work together with practitioners. Other fields that might benefit include sustainable economic activities like agriculture, forestry and tourism without degrading the environment; climate change mitigation through carbon sequestration; and urban planning promoting green infrastructure or the prevention of the impacts of natural disasters by planning natural barriers against floods, landslides and other hazards.

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