Using Habitat Quality and Diversity Measures to Assess Conservation Priorities for Sites in the Ukrainian Carpathians

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Abstract The chapter investigates the possibilities and advantages of using habitat quality and diversity measures in the design of ecological networks in the Ukrainian Carpathians. It was shown that habitat diversity could be indicated by the measures of topographic variance. The latter correlate well with some characteristics connected with ecological as well as socioeconomic factors determining land suitability for conservation. The received measure of topographic variation correlates significantly with the abundance of rare and endangered plant species entered into the Ukrainian Red Book. The correlation of this abundance with the Normalized Difference Vegetation Index (NDVI) values is not as pronounced and is highly dependent on local conditions. An attempt was made to arrive at an integral measure of the appropriateness for assigning protected status, using easily obtained remote sensing and elevation data.

1 Introduction

The Carpathians are one of the largest mountain ranges in Europe, providing an essential habitat and refuge for many endangered species of plants and animals and Europe's largest area of virgin forests, and they constitute a major ecological, economic, cultural, recreational, and living environment in the heart of Europe, which is shared by numerous peoples and countries.

In the Ukraine, the Carpathians are the largest and highest mountain range, hosting a large part of the country's biodiversity, as well as providing indispensable ecosystem services and being an important area for local and regional tourism and recreation. Thus, the Carpathians are the priority area for conservation activities in Ukraine.

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Establishing a large ecological network and assigning protected status to substantial areas is a resource-consuming enterprise, involving large management costs and even more indirect costs of land use restrictions. Thus, the placement, zoning, and management of protected areas should be established upon sound scientific research regarding the aims of conservation and the best ways to achieve them. The conservation aims can be broadly divided into three groups: the conservation of rare, endangered, or valuable species (the realm of conservation biology); the conservation of valuable ecosystems functions (e.g., soil and water protection, and carbon retention capacity); and the protection of scenic landscapes and natural monuments for their aesthetic qualities and attractiveness for tourists and local people. Careful planning of the placement, zoning, and management of protected areas requires that reliable data on the occurrence and distribution of biodiversity data, as well as some other ecosystem properties determining the suitability of areas for conservation, are available. Because protected areas are characterized by restrictions placed on land utilization and certain kinds of economic and social activities that can burden society, the placement of such areas should be based on sound methodology, minimizing such a burden, while maximizing the aims of conservation. It is recognized, for example, that cheaper or less socially disruptive reserve networks are more likely to be implemented.

The Ukrainian Carpathians currently host a rather dense network of protected areas with various protection regimes, including the Carpathian Biosphere Reserve, the Gorgany Natural Reserve, several national nature parks and regional landscape parks, and scores of small, protected areas of local significance. The current state of the Ukrainian Carpathians protected areas network and its legal and organizational basis and functions have been briefly summarized by Deodatus and Protsenko (2010, Appendices 2, 3).

It is widely recognized that the present structure and management regime of this network is far from optimal and should be modified according to modern standards, approaches, and practices to be effectively integrated into the European ecological network (EECONET). For the last dozen years, several relevant legal acts have been passed, including two laws "On the State Program for the Development of the National Ecological Network in Ukraine for 2000–2015" (2000) and "On the Ecological Network of Ukraine" (2004). The topic became the subject of a number of scientific studies and projects, and a number of proposals, recommendations, and suggested schemes have been put forward (Sheliag-Sosonko 1999; Brusak et al. 2006; Deodatus and Protsenko 2010).

All of the proposed projects and schemes are heuristic and tentative, because an "ideal" scheme should take into consideration the exhaustive inventories of species habitats and ecological characteristics, as well as valuable ecosystems functions, natural monuments, and scenic landscapes. This can be a practically unfeasible task. However, methods could be developed that render more objectivity by explicitly accounting for the factors related to conservation aims. Remote sensed imagery could be used as a data source for the task, considering its accessibility and low costs, compared to field surveys. However, as species and processes can rarely be directly seen and measured, remote sensing is usually used to derive some quantitative measures related to ecological characteristics meaningful to conservation.

The aims of this study concern the investigation of the possibilities of using two quantitative measures as indicators of proper conservation targets. The first measure is the Normalized Difference Vegetation Index (NDVI), easily determined and mapped using spectral reflectance measurements acquired in the red and near-infrared regions (Rouse et al. 1973). Values of NDVI could correlate with the Leaf Area Index, plant productivity, biomass, chlorophyll concentration in leaves, fractional vegetation cover, and some other ecosystem properties that together indicate the degree of presence and the current state of natural vegetation of the area (Glenn et al. 2008). Thus, NDVI could be regarded as indicative of the overall “naturalness” of the site conditions determined by the ecosystem’s status, primary production, the proportion of area covered by natural vegetation, etc.

The second measure pertains to the local habitat diversity, mostly determined by abiotic factors like soils, microclimate, hydrologic conditions, etc. The plant and animal habitats are characterized by the sets of indirect, direct, and resource environmental gradients (Austin and Smith 1989). This means that the increased diversity of abiotic factors in certain area leads to the increased amount of potential habitats, thereby contributing to its biodiversity. In areas of complex topography, topographic variables make efficient predictors of habitat characteristics, given the high spatial accuracy of modern digital elevation models (DEMs) (Guisan and Zimmermann 2000).

In this study, an attempt is made to derive these measures from freely available digital data and to test their suitability as indicators of conservation priority by comparing them to the data on rare and endangered species habitats. Some suggestions are made for the improvement of the existing protected areas network using these measures.

2 Study Area

The study area is located in the Ukrainian Carpathians together with parts of the adjacent foothills and plains. The Ukrainian Carpathians can be roughly divided into three parallel, relatively narrow belts extending from northwest to southeast. The northern macroslope of the range makes up the spruce belt, where secondary spruce forest stands dominate with admixtures of beech and fir. The highest axial part of the range consists of connected or isolated massifs, in their highest parts (starting from 1,500–1,600 m) covered with subalpine vegetation. The southern macroslope makes up the beech belt, where beech forests dominate. In the northern and southern foothills of the range, oak forests dominate with an admixture of beech and hornbeam, while Precarpathian and Transcarpathian plains are mostly arable lands with patches of broad-leaved forests. The detailed description of the natural conditions of the region can be found in Herenchuk (1968), which also contains its regionalization scheme cited below.

3 Materials and Methods

The source of elevation data was the processed SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model) version 4.1 (Jarvis et al. 2008), available online from the CGIAR Consortium for Spatial Information (http://srtm.csi.cgiar.org). These data with 3-arc second resolution are in decimal degrees based on World Geodetic System (WGS) 84. For the calculation of NDVI, the Landsat 7 ETM+ multiband image was used (NASA Landsat Program 2009) from the online USGS archive (http://glovis.usgs.gov). The data were acquired on October 13, 2009, and are available in the Universal Transverse Mercator (UTM) geographic coordinate system (zone 35). The multiband image consists of 8 band layers, of which bands 3 and 4 (both having 30 m resolution) were utilized in the study.

The SRTM DEM data were projected to the UTM coordinate system and resampled to 90 m spatial resolution. The Landsat layers were resampled to 90 m resolution, for better compatibility with the DEM and to facilitate further calculations.

The resampled DEM was used to obtain the three measures of habitat diversity:

1. the variance of elevation;
2. the variance of slope values;
3. The relief horizontal dissection and aquatic habitat richness measured by a local density of stream network.

Variances of elevation and slope values were measured in local windows by taking variance measures among values in local neighborhoods (e.g., 3×3 square around a central pixel). The local variance of elevation indicates mainly the diversity of microclimates (temperature, humidity, and precipitation values) and insolation regimes, while the variance in slope values indirectly indicates the complexity and diversity of geological structures and processes with diversity in soil edaphic and hydrologic properties. The third measure, the stream network density, was derived using the method described by Montgomery and Foufoula-Georgiou (1993), wherein the variable flow-accumulation area thresholds are calculated using slope value raised to a power.

The evaluation of these measures should take into account different scale domains in the landscape. Currently, the scaling problem is one of the most important in ecology (Alpin 2007). It is known from landscape and ecological studies that the reaction of different species to environmental conditions reveals itself on certain spatial scales, which could be designated as the spatial scales of certain species. Likewise, processes shaping the landscapes reveal themselves in different spatial scales; therefore, landscape management should comprise different scales, each one pertinent to a certain set of species (McGarrigal and Marks 1994). Wiens (1989) shows examples when changes in scale affect the size and even the sign of habitat relationships and interspecific associations, concluding that scaling issues are fundamental to all ecological investigations, as they are in other sciences (Wiens 1989). Processes determining and influencing most ecological factors also often show scale-dependency (Clark 1985; Levin 1992; Blöschl 1995). Margalef (1968) introduced the notion of a diversity spectrum, in which biological diversity is examined as a function of scale. These studies show that the values of criteria for determining the appropriateness of sites for assigning protected status should be estimated not only on a scale dictated by the size of the pixels of the raster image but also on a range of scales embracing the most important ecological processes and the living space of species selected as conservation targets.

This was achieved by the calculation of measures in a series of local neighborhoods with different window sizes, each being a triple of its predecessor: 270 × 270 m, 810 × 810 m, 2,430 × 2,430 m, and 7,290 × 7,290 m. While the sizes were arbitrarily chosen, the spectrum is meant to encompass the processes pertaining to the movement of the large part of vertebrate species. Then, the averages among all scale levels were used as values to be entered into the model.

To make some assessment of the validity of these criteria, correlational analysis was carried out using data on geographic distribution of the diversity of a set of plant species. While biodiversity is a rather complicated concept, the species count is often regarded as its surrogate (Purvis and Hector 2000). The hypothetical set of target species contained the vascular plant species included in the Ukrainian Red Book, the official registry of the rare and endangered species composed by the Ministry for Environmental Protection of the Ukraine, as prescribed and regulated by Ukrainian law (Ministry for Environmental Protection of Ukraine 1996). Most of the species in the Ukrainian Red Book are also listed in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species.

In whole, 92 species of the division *Angiospermae*, together with the 14 species of the group of lower vascular plants (divisions of *Pinophyta*, *Lycopodiophyta*, and *Pteridophyta*), were selected for analysis (106 species in total). These were plant species characteristic of the Ukrainian Carpathians, whose habitats are described in the Ukrainian Red Book in sufficient detail to be mapped. Then, the digital maps were produced with the delineations of the habitats of each of these species.

It should be noted that the habitat descriptions used were often pretty rough, so the produced habitat map is not assumed to be of high spatial accuracy. But in the absence of the detailed spatial species inventories, this approach is regarded to be the only feasible one and suitable enough to obtain the relative measures of biodiversity. After creating the digital habitat map layer, the habitats of different species were overlaid to obtain a map layer of species richness, which depicts the amount of species present in a certain place (Fig. 1). It shows that the highest values are characteristic of subalpine meadows on the highest areas of the region, while the beech belt of Transcarpathia has by far larger rare and endangered plant species richness than the northern spruce belt, foothills, and adjacent plains.

The correlation coefficients were calculated between species richness values, measures of habitat diversity and NDVI values determined in neighborhoods of

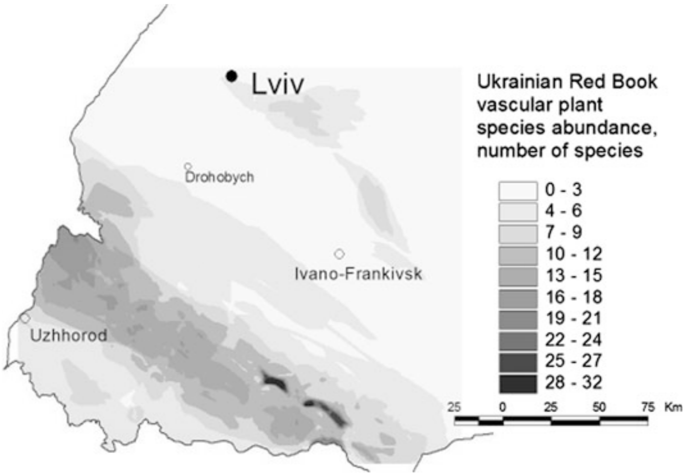

Fig. 1 The amount present of rare and endangered vascular plant species in the Ukrainian Carpathians as listed in the Ukrainian red book

different sizes. While the reliabilities of these coefficients were hard to strictly measure due to the presence of spatial autocorrelations (which complicates greatly the estimation of the degrees of freedom), the presence of the large and consistently repeated correlation coefficients suggests a strong possibility that an accurate relationship exists between values.

Lastly, an attempt was made to arrive at an integral measure of appropriateness to assigning protected status. To this aim, NDVI values over all the scale levels were standardized (subtracting the minimal value and then dividing by the maximum one) to 0–1 scale, and then the average values were calculated. The latter mean of the NDVI was averaged among scale spectrum. Similarly, the three measures of habitat diversity (the variances of elevation and slope values, and the stream network density), each averaged over four scale levels, were standardized to 0–1 scale and then summed to arrive at the integral measure of habitat diversity—the terrain variability index. At the last step, the averaged NDVI measures were multiplied by the integral measures of habitat diversity, to obtain the final assessment.

Finally, the correlation coefficients were calculated for the measures of terrain diversity and NDVI, and calculated for different neighborhood windows (corresponding to different spatial scales) and the observed rare and endangered vascular plant species count.

For the preparation and analysis of the data, several geographic information system (GIS) software products were used, including commercial ArcView and ArcGIS software packages by ESRI, and free and open ILWIS GIS software.

4 Results

Figure 2 illustrates the distribution of NDVI values calculated from the Landsat images, while Fig. 3 shows the terrain variability index arrived at by combining the values of the variance of elevation, the variance of slope values, and the local stream network density. These can be visually compared to Fig. 1, depicting the spatial density of habitats of the rare and endangered plant species.

As can be seen from Table 1, all correlations are positive, yet the correlations between species count and terrain diversity are substantially higher than the correlations between species count and NDVI values. All correlations appear to consistently increase with the spatial scale. The spatial pattern of correlations was also visually analyzed, showing strong negative correlations of species count and NDVI index in the highest mountain ranges with subalpine meadows, and characterized by low NDVI values except for the largest density of Red Book species. The highest positive correlations were characteristic of beech belt, while in spruce belt the correlations were insignificant. While the overall correlation is small, it is positive and steadily rises with the increase in spatial window, from 0.01 for 90 m to almost 0.1 for 7.29 km.

The correlation with terrain diversity turned out to be much higher: from 0.6 for the 90 m neighborhood to almost 0.73 for the 7.29 km neighborhood. It proves the hypothesis that terrain variability is a good indicator of the diversity of plant habitats. The spatial distribution of correlation values (Fig. 4) shows that the largest correlations are characteristic of highest axial massifs with the presence of subalpine associations; high correlation is also found in beech belt and in dissected Precarpathian plains, while the spruce belt again shows insignificant correlations.

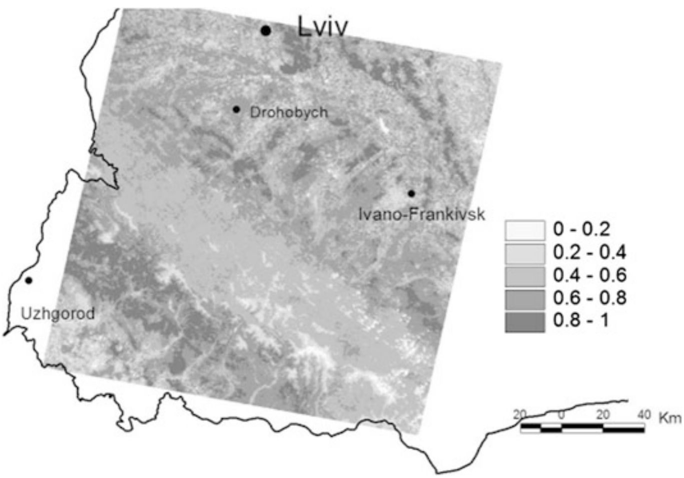

Fig. 2 The distribution of scale-averaged NDVI values in the Ukrainian Carpathians

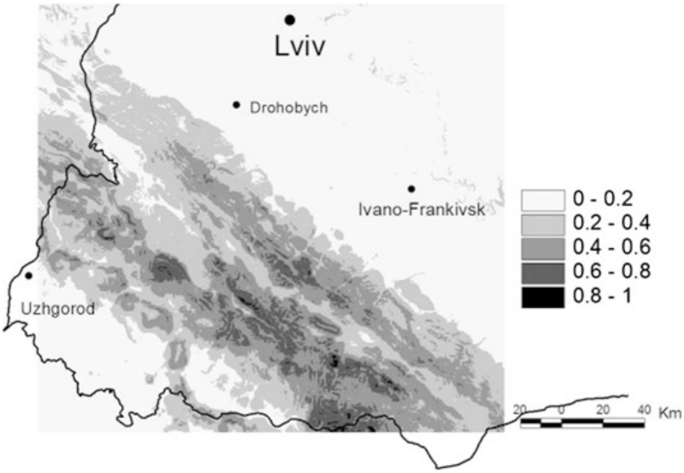

Fig. 3 The terrain variability (*TV*) index in the Ukrainian Carpathians

Table 1 The correlation coefficients between rare and endangered plant species count that were present and the NDVI and terrain diversity values in the Ukrainian Carpathians

Neighborhood (m)	NDVI	Terrain diversity
90	0.0187	–
270	0.0306	0.6032
810	0.0372	0.6154
2,430	0.0539	0.6790
7,290	0.0979	0.7275

It should be noted that the increases in correlation coefficients with the increases in the size of the averaging window could be an artifact, due to the fact that the plant habitats used to calculate the amount of species present (Fig. 1) were delineated with relatively low spatial precision.

The final stage of the research consisted of the combination of information on terrain diversity and NDVI and the creation of the map layer showing the integral values of appropriateness of sites for assigning a conservation status. The appropriateness is higher in mountains than on adjacent plains, while the highest values of the appropriateness index are observed on the south macroslope of the Polonyna range, characterized by the highly dissected relief with a big variance of altitudes and covered by rich beech and mixed forests. The second region considered among the most appropriate is the Vyhorlat-Hutyn low-mountain range made up of volcanic rocks. The third most appropriate region is the northern macroslope of the Skybovi Carpathians, made up of flysch rocks and covered with mixed forests.

The sites with the highest values of the appropriateness index lie mostly on both slopes of the transversal valley in the southwestern part of the Ukrainian Carpathians, known as the Perechyn-Lypha natural region (Fig. 5). Of all the administrative regions of Ukraine, the Transcarpathian region has by far the largest area of the sites most appropriate for assigning a protected status.

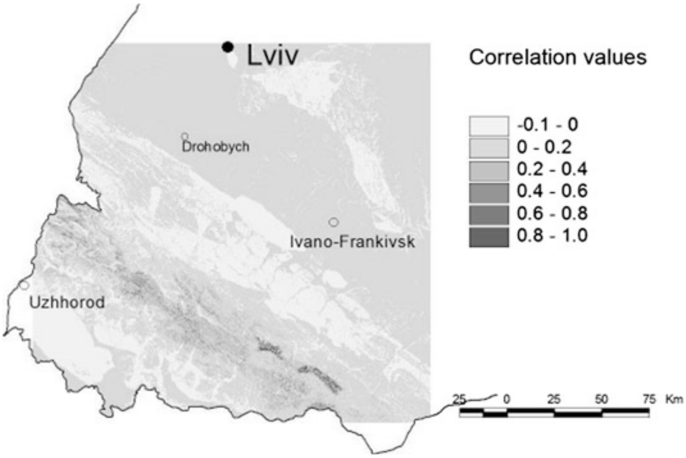

Fig. 4 Correlations between the amount of rare and endangered vascular plant species (Fig. 1) and the terrain variability (Fig. 3) in the Ukrainian Carpathians

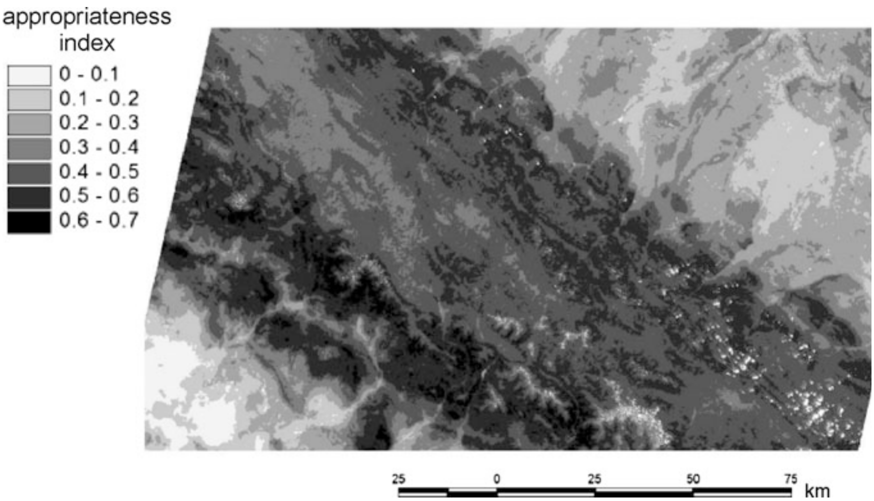

Fig. 5 The most appropriate sites for nature-conservation activities (shown in *black*) in the Ukrainian Carpathians

5 Discussion

There are a number of studies of relations between NDVI values and various ecosystem parameters and properties. Bawa et al. (2002) studying in the Western Ghats, India, found a positive correlation between mean NDVI and tree species diversity for different vegetation types, concluding that satellite imagery can identify broad patterns of tree species diversity in tropical forests. Oindo et al. (2000), examining the relationship between NDVI and bird species richness in Kenya, revealed a strong positive correlation between species richness and maximum average NDVI. As many species require for successive survival and reproduction the existence of continuous areas of certain minimal extent with favorable environmental conditions, not only the local values of NDVI but also the presence of sufficiently large areas with high NDVI values can be of importance. As Danell et al. (1996) showed in their research, the larger and more homogeneous the area of forest coverage in a boreal section, the more mammalian herbivore species coexist there.

To explain such findings, Skidmore et al. (2003) suggested the productivity hypothesis, predicting that when resources are abundant and reliable, species become more specialized, allowing more species per unit area.

NDVI can be a viable indicator for the assessment of the appropriateness for assigning protected status for the sites, due to the fact that much of the animals prefer undisturbed areas of natural vegetation with sufficient extent, low disturbance factors like noise, and sufficiently high primary ecosystem production, which all are pretty well correlated with NDVI.

NDVI value can also relate to the ability of an ecosystem to fix carbon, thus contributing to carbon's withdrawal from the atmosphere and alleviating its harmful influence on the global climate. Prince (1991), Running et al. (2004) showed that NDVI has been related to net primary production at broad spatial scales. Frank and Karn (2003) concluded that NDVI has the potential for predicting carbon flux in semiarid grasslands and shrublands. Glenn et al. (2008) compared NDVI with another image-derived indices in their ability to indicate carbon flux values in various ecosystems.

There are also a number of studies proving the relationships between the measures of terrain variability and the measures of biodiversity. By analyzing floristic data Hofer et al. (2008) discovered that the standard deviation of altitude explained a high proportion of the variation in γ diversity—the total species richness over an area (linear regression model, R2 = 0.63)—concluding that terrain variability at a landscape scale has strong effects on niche or microsite diversity and is an appropriate estimator of relative species richness in landscapes that are topographically heterogeneous and gradient dominated. Tang et al. (2006) used the elevation range (i.e., the difference between the highest and the lowest elevation) as a surrogate of habitat heterogeneity and found positive relationships between elevation range and the densities of plant genera and mammal species.

Habitat heterogeneity has long been shown to influence species diversity of birds (MacArthur 1964; Pianka 1966; Karr and Roth 1971). Richerson and Lum (1980) showed that in California topographic heterogeneity measured as a standard deviation of elevations in an area explains 19 % of the total flora diversity, ranking as the second highest contribution among all environment predictors after the rainfall values. Thus, they claimed that topographic heterogeneity has a strong effect on patterns of the total flora and most subdivisions. Owen (1989) found a significant relationship between variance in elevation and species richness for reptilian taxons.

These findings can be explained by the heterogeneity hypothesis stating that diverse ecosystems support richer assemblages of biological species compared with simple ecosystems (Podolsky 1994).

It should be noted that in case of future environmental changes and disturbances, like widely expected ubiquitous climate changes, areas with diverse abiotic environments could provide more shelter and refugia for species challenged by unfavorable conditions. For instance, in mountainous areas species facing a warmer and drier climate than that to which they have evolved could just shift their habitats several hundred meters upwards, while on plains they would have to migrate hundreds and thousands kilometers for a relatively short time span, which can be highly problematic.

Areas with a high level of terrain dissection are often at the same time harder for infrastructure development, construction activities, and less suitable for intensive agriculture. This makes the withdrawal of these areas from most economic activities for conservation purposes to be less burdensome for society.

The combining of these two criteria allowed for an assessment of the appropriateness of sites for assigning a conservation status, based on the values of NDVI and terrain variability integrated among several scales (see Fig. 5). This integral assessment can in turn be compared with the existing network of protected areas, to identify potential gaps in the latter. It can be inferred that, while most protected areas are situated in the northeastern part of the Ukrainian Carpathians, the ecosystems of its southwestern part (the Transcarpathian region) are greatly underrepresented in the existing network.

The proposed methodology, however, should be regarded as tentative, as it can be improved by elaborating the criteria of habitat diversity and richness, as well as the rules of their aggregation, to better meet the aims of nature conservation. More reliable estimates of the relations between habitat properties and species richness can be obtained by utilizing detailed field inventories of species, which is very labor- and time-consuming, yet an important task.

6 Conclusions

The assessment and mapping of the appropriateness for assigning protected status can be improved by making use of some easily mapped indicators of ecosystem properties defining their suitability for conservation. The terrain variability index calculated in a GIS from freely available DEMs were shown to correlate significantly with the diversity of rare and endangered vascular plant species. This correlation, however, differs spatially and with the scale of analysis. NDVI, calculated from multispectral spatial imagery, showed a lower correlation with rare plant species occurrences, yet it can also be indicative for conservation suitability assessment due to its connections with potential animal habitats, carbon-fixing capacity, and socioeconomic considerations involving the costs of conservation.

It should be noted that the beech forest belt shows significantly higher correlation values between rare plant species occurrences, topographical variability and NDVI indices, while in the spruce belt where most forests are secondary and are often in discord with the abiotic environment conditions, this correlation is nearly absent.

The output of this proposed methodology for the assessment and mapping of the appropriateness for assigning protected status can be used by conservation planners to help improve the existing protected areas network, inform the selection of new conservation areas for minimal cost, and facilitate the exploration of trade-offs between conservation and socioeconomic objectives.

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