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Determination of ecological significance based on geostatistical assessment: a case study from the Slovak Natura 2000 protected area

Research Article

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Abstract: The Sitno Natura 2000 Site covers an area of 935,56 hectares. The Sitno region is significant due to the number of rare and endangered species of plants, and as a result is considered a location of great importance to the maintenance of floral gene pools. The study area suffers human impacts in the form of tourism. The main purpose of this study is to the measure landscape elements, determine the ecological significance of habitats within the Sitno area, and from this data, organize the study area into conservation zones. The results of this landscape quantification are numerical values that can be used to interpret the quality of ongoing ecological processes within individual landscape types. Interpretation of this quantified data can be used to determine the ecological significance of landscapes in other study areas. This research examines the habitats of Natura 2000 Sites by a set of landscape metrics for habitat area, size, density, and shape, such as Number of patches (NP), Patch density (PD), Mean patch size (MPS), Patch size standard deviation (PSSD) and Mean shape index (MSI). The classification of land cover patches is based on the Annex Code system.

Keywords: nature and landscape conservation • ecological significance of landscapes • landscape metrics • quantification and interpretation of landscape metrics.

1. Introduction

Central and Eastern European countries have a long tradition of nature protection and conservation; in the late seventeenth century it had already become clear to the population that mining and industrial development caused severe environmental problems [22, 65]. In recent decades, new directions have been developed for EU ecological policy, mainly as a result of increased environmental and biodiversity awareness and, at the same time, a required increase in agricultural productivity and intensive utilization of arable lands [56]. This conflict induced the cre-

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ation and implementation of the Natura 2000 framework, which focus on the sustainable conservation of valuable landscapes, biodiversity and species richness [26]. The development of the Natura 2000 ecological network is now widely recognized as an important policy initiative to support the protection of critical sites, which are selected based on a set of standardized rules [38]. The standardization of the Natura 2000 framework across Europe has resulted in a high proportion of overlap with previous or current national protected area networks. For example, in Slovakia, the Natura 2000 sites cover 86% of existing protected areas. In comparison to other EU countries, Slovakia has the third highest rate of nature reservation, integrated environmental land-use, and resources management; in Slovakia, Natura 2000 sites cover about 29% of the terrestrial area, whereas the average Natura 2000 area for a EU country is 17.5% [11, 48]. The Natura 2000 framework requires action from both State and private organizations that contribute to environmental activities, including, among others, resources management, biodiversity conservation, land-use strategy, and development planning sectors [43]. The sustainability and effectiveness of the Natura 2000 system requires the balanced cooperation of land ownership, local community, and governance interests, as well as close inter-institutional development and cooperation [39, 45, 58].

This study aims to analyse landscape components (habitats) where human impacts are in form of tourism. The main purpose of this study is to measure and interpret habitats of the Sitno study area (Figure 1), which is under Natura 2000 Site protection. According to [16, 17, 19, 20, 36], it is possible to measure each habitat using landscape metrics, such as size, density, shape, edge, and diversity. The outputs from these landscape metrics can be used directly to indicate the quality of ongoing ecological processes at different levels in the region. Quantified land-cover patches also carry useful information about the state of landscape configuration and spatial composition [10, 61]. The landscape elements can be defined by geographic attributes, as well as through the ecological significance of each land-surface element. For the purpose of this study, 'landscape' is defined, based on [23], as a part of the Earth's surface where its components are perceived by humans. In accordance with [2], therefore, the landscape represents a biophysical unit — an aspect of the landscape determined by its natural components (geological and geomorphologic structure, soil, water, climate, flora and vegetation, and fauna). In contrast to the biophysical unit, the term 'landscape' describes elements defined not only by natural conditions, but also human influences. The natural, modified (cultivated), and artificial objects integrated in the landscape also have specific physiognomy [15, 54].

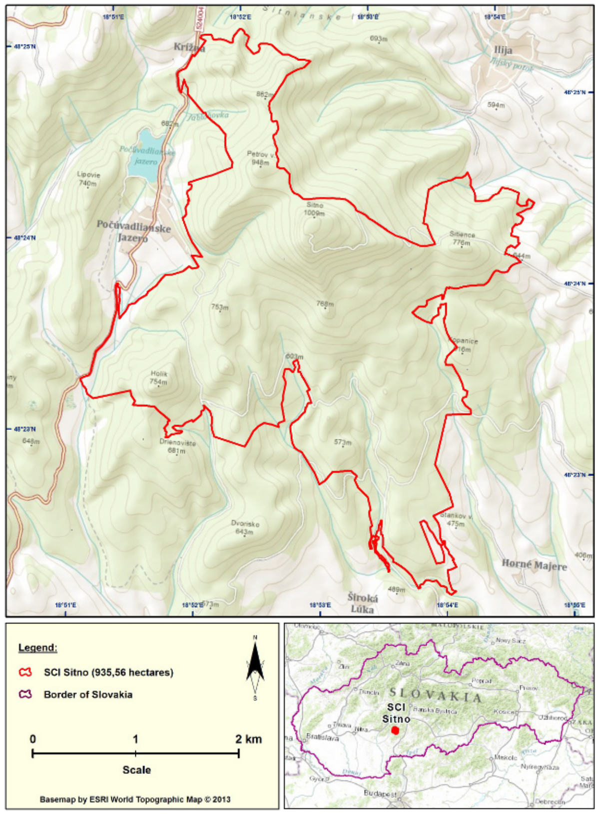

Figure 1. Topography of the study area.

According to [25], the ecological significance of an area results from the ecological processes operating in a landscape. The ecological significance is a purpose-built landscape characteristic that pointed on a degree of self-regulatory processes in landscape ecosystems. In this form self-regulatory processes means conditions for ecological stability and regeneration of genetic and natural resources of landscape ecosystems.

According to [24], ecological systems are shaped by evolution, and managed by natural selection, thereby forming their ecological significance. The factors that impinge on individuals within an environment can be arranged within a dominance hierarchy, with the physical characteristics of the environment providing the most restrictive constraints, as modification of local geochemical cycles or weather patterns are only made with difficulty and are energy intensive.

Tourism has been observed as having an impact on land cover and land use (landscape changes) within the study area. Contemporary landscape changes, such as for tourism, are generated principally by human activity, and can be defined as any activity directed at manipulating the Earth's surface for individual or societal needs or wants [3, 40, 60, 64]. Urbanization, industrialization, and intensive agriculture often result in rapid landscape changes, as well as losses of ecological capacity, diversity, and scenic beauty, and damage to historically valuable cultural landscapes [2]. Problems related to rapid landscape change have been analysed for Europe by [42].

Sitno was selected as a study area due to the richness of its natural environment, and the current state of human impacts. The highest point the study area, Sitno Peak (1 009 m), is a very popular tourist (walking and climbing) destination. The area has been the focus of long-term discussion regarding the best use of its environment, and in the last 30 years has seen the building of extensive technical infrastructure for tourism and communications. Sitno is presently under high priority nature and landscape protection, but the environment is extensively used for multiple purposes, and land-use conflicts of interest are growing. Therefore, the area needs to be divided (zoned) for separate human-usage and conservancy purposes; here, we aim to use landscape ecological significance as a tool to zone the study area using the terms and principles of the Natura 2000 sites framework. This method is an objective approach to determine ecological values, presenting the results in an easily readable form to end-point customers, such as land owners, local communities, and state organizations.

2. Overview of the study area

The Sitno Natura 2000 Site covers an area of 935.56 hectares, and was declared a protected region in 1951 to protect the significant natural landmarks of the Štiavnica Mountains. The site is classified as part of the Štiavnica Mountains All geomorphological units of the Slovak Central Highlands Geomorphological area, of the Inner Western Carpathians Subprovince, of the Alpine–Himalayan System [34]. The study area contains very few affected or disturbed natural environments, and provides suitable living conditions for many species of rare flora and fauna. Sitno is protected under both the national (Slovak) and European conservation system (as a European Site of Community importance, or SCI). Geologically, the Sitno area sits over a cooled andesitic lava flow, with Sitno peak dominated by volcanic clinopyroxene andesite, which is characterized by its plate-cleavage, and which is more resistant to weathering than surrounding rock types [29].

The study area is relatively open, demonstrating no environmental borders with the surrounding Pannonian plain. As a result, several Pannonian species have reached their maximum height, or northernmost distribution limits in this area. At the same time, the northern side of Sitno has seen an invasion of typical Carpathian floral elements. Therefore, the area has a unique character combining forest, grassland, and rocky habitats, with [55] describing 11 habitats of European importance. According to [57], the Sitno vegetation is a submontane flora with thermophilic and mountain elements that interrelate, or rotate, depending on the environmental conditions. The species of highest stability in the Sitno flora are *Potentilla alba*, *Trifiolium alpestre*, *Trifolium montanum*, *Betonica officinalis*, *Helianthemum ovatum*, *Festuca pseododalmatica*, *Callamaagrostic arundinacea*, *Prunella grandiflora*. Of the supporting community types, dominant overgrown meadow taxa are *Geranium ganguineum*, *Carlina acaulis*, *Inula ensifolia*, *Inula hirta*, *Salvia pratensis*, *Galium verum*, *Anthericum ramosum*, and *Campanula persicifolia*, and prominent mountain elements include *Valeriana tripteris*, *Aruncus silvestris*, *Adoxa moschatelina*, *Cicaea alpina*, *Gymnadea conopsea*, and *Lilium martagon*. Perhaps, the most important flora is located on rocky sites, and includes species such as *Sempervivum montanum* subsp. *carpaticum*, and *Minartia hirsuta* subsp. *frutescens*. In this relatively small area, almost 300 different forms of roses are recorded, with the major types including *Rosa gallica*, *Rosa spiny*, *Rosa andegavensis*, and *Rosa glauca*. Furthermore, species such as *Pulsatilla grandis*, *Lilium martagon*, *Iris graminea*, *Cornus mas*, *Huperzia selago*, *Platanthera bifolia* and *Adenophera lilifolia* are typical in the area. The large number of rare and endangered plant species in the study area identifies Sitno as an important region for the maintenance of gene diversity.

The study area covers almost 260 m in elevation (from 750 to 1009 m), and can be divided into four forest vegetation zones. The most widespread vegetation zones are the oak–beech, and oak – nitrophilous beech forest types. On average, the forest ranges from 60 to 160 years in age, with the southern part of the study area characterized by natural forest having a distinctly primeval character. The varied species composition of the forests in the Sitno area makes this a unique ecosystem within the Carpathians. These forests are now afforded a high degree of protection and economic activity is strictly limited, although in the past, beech wood from surrounding forests was used in wooden charcoal production [6].

According to [14], these extensive forest complexes are a refuge for many animal species. In regards to the invertebrates, the area supports a considerable number of species, particularly molluscs, butterflies, and beetles. including *Lucanus cervus*, 11 species of *Carabus*, *Calosoma inquisitor*, 12 species of *Bombus*, and several species of the ant genus *Formica*. The reptilian inhabitants in the Sitno area include *Lacerta agilis*, *Anguis fragilis*, *Natrix natrix* and *Coronella austriaca*. Only a few amphibian species are known in the area due to a lack of aquatic habitats, but species recorded include *Bufo bufo*, *Rana temporaria* and *Salamandra salamandra*. The study area is characterized by large populations of roe and red deer, and *Lynx lynx*, *Felis silvesttris* and *Ursus arctos* are recorded sporadically.

Based the the studies of [68], the first ancient human impacts recognized in the Sitno area are settlements dated to the period of a Lusatian culture (1000 to 700 years BC), which consist of a Late Bronze Age, massive, fortified line built on the top of Sitno Hill. The remainder of the wall was constructed later, in the Middle Ages (around 13th century), and included massive walls and a castle. The entire fortress covers an area of approximately 16 hectares. Modern human impacts are in the form of tourism, dated to the second half of the 19th century. During this period, the first tourist clubs was founded, and tourist events were regularly organized at Sitno, introducing resort infrastructure to the area. Finally, a watchtower was built on top of Sitno Hill in 1727 [30].

3. Material and methods

The method of determining ecological significance is based on quantifying habitats and their patches; the results of this quantification process should be interpreted as a degree of ecological significance for each of the landscape elements. The basis of this methodology is the measurement of these landscape elements according to landscape metric principles, most of which are based on mathematical or statistical approaches measuring element area, perimeter, length, and shape. A wide scale of landscape metrics have been defined and used by many researchers [1, 18, 21, 36, 41, 44] and numerous additional metrics have been developed to measure and describe the composition and configuration of land-cover features [20, 37]. Therefore, since the 1990s, landscape metrics have been used extensively in landscape-pattern monitoring, assessment and planning [5, 31, 33, 50].

The most frequently used landscape metrics was selected for this study, specifically, identification of spatial composition and landscape configuration based on Total Area (TA), Class area (CA), Number of patches (NP), Patch density (PD), Mean patch size (MPS), Patch size standard deviation (PSSD) and Mean shape index (MSI). These metrics were selected as they have the potential to monitor the effects of ongoing ecological processes within a landscape ecosystem [19, 37, 62], and have applications in urban-landscape planning [32]. The metrics mentioned (Table 1) were used as predictor variables in the statistical analysis to examine the significance of each habitat patch, and of the whole landscape.

This study involved the identification of interactions among patches and how this influences the landscape pattern in form of ecological significance. These interactions are expressed by the aforementioned landscape metrics [10, 16, 17, 21, 33, 36, 62] in the following manner:

- **Total area (TA)** equals the total area of the landscape in hectares. This metric does not provide great interpretive value in regards to evaluating landscape structure, but is important in defining the landscape extent.
- **Class area (CA)** is a measure of landscape composition; specifically, how much of the landscape consists of one particular patch type.
- **Number of patches (NP)** of a particular habitat type may affect a variety of ecological processes.
- **Patch density (PD)** is a limited, but fundamental aspect of landscape structure, having the same basic utility as NP but expressing the number of patches on a per unit area basis, facilitating comparisons among landscapes of varying size. PD therefore equals the number of patches in the landscape divided by the total landscape area, multiplied by the unit area basis.
- **Mean patch size (MPS)** equals the area of each patch type within a landscape mosaic, and is perhaps the single most important and useful piece landscape metric, although the area comprised by each patch type (class) is equally important. As for the patch area, the range in MPS values are limited by the structure, the extent of the landscape, and the minimum patch size.
- **Patch size standard deviation (PSSD)** equals the square root of the sum of the squared deviations of each patch area from the mean patch size. This parameter should be interpreted in conjunction with MPS as the absolute variation is dependent on patch size. When PSSD = 0, all patches in the landscape are the same size, or there is only one patch of this class (i.e. there is no variability in patch size).
- **Mean shape index (MSI)** measures the average patch shape, and equals the sum of the patch perimeter divided by the square root of patch area

Table 1. Landscape metrics used for landscape element (land-cover patch) quantification.

Class area (CA) — the sum of the areas of all land-cover patches of a single class. Unit: hectares (ha).	$CA = \sum_{j=1}^{n} a_{ij}$
Total area (TA) — the area of all land-cover patches regardless of class. Unit: hectares (ha).	$TA = A$
Number of patches (NP) — the number of land-cover patches in each class.	$NP = n$
Patch density (PD) — the number of land-cover patches in a class divided by total landscape area of that class. Unit: number of patches per 100 hectares (ha).	$PD = \frac{n}{A}$ (100)
Mean patch size (MPS) — the sum of the areas of all land-cover patches in a class divided by the number of patches of the same class. Unit: hectares (ha).	$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n}$
Patch size standard deviation (PSSD) — size deviation of each land-cover patch in its own classes. Unit: hectares (ha).	$PSSD = \sqrt{\frac{\sum_{j=1}^{n}\left[a_{ij}\left(\frac{\sum_{j=1}^{n} a_{ij}}{n}\right)\right]^2}{n}}$
Mean shape index (MSI) — the average shape index of land-cover patches within a certain patch type.	$MSI = \frac{\sum_{j=1}^{n}\left(\frac{p_{ij}}{2\sqrt{\prod^{o} a_{ij}}}\right)}{n}$

Notation abbreviations:
j = 1 *n* patches
i = 1 *m* patch types (classes)
n number of patches of patch type *i*
m number of patch types (classes) present in the landscape
A total landscape area (hectares)
a_{ij} area (hectares) of patch *ij*
p_{ij} perimeter (metres) length of patch *ij*
P_i proportion of the landscape occupied by patch type (class) *i*

for each patch in the landscape. When MSI = 1, all patches in the landscape are circular (vector) or square (raster), with MSI increasing (without limit) as the patch shapes become more irregular.

Measurement of these metrics for the Sitno study area was undertaken in a digital environment, using the ESRI platform in conjunction with the GPL / GNU software product Patch Analyst.

3.1. Landscape element classification

Many concepts and definitions exist for habitats as a concept, a fact reflected in the wide range of regional, national, and European habitat and landscape element classification systems. The main European classifications are: CORINE Biotopes [4, 35], the Annex I of the Habitats Directive [13], and the EUNIS habitat classification [7], although the EUNIS habitat classification [7] and the Annex I of the Habitats Directive [13] are general considered central systems by European conservation agencies. These two latter systems are also used in the present program because they form the legal framework for habitat protection in Europe through their link with the Natura 2000 site scheme. [12] describes the development of these habitats, and their role in nature conservation policies. The expansion of the EU to cover the 27 current Member States has also led to the progressive refining of habitat definitions. These definitions have been used in the identification of the Natura 2000 sites, which in turn form the framework for nature conservation in Europe.

In this study, the classification of land-cover patches was based on the CORINE Land Cover 2000 (CLC2000), CORINE Biotopes, and EUNIS habitat classification schemes. These classification systems were directly applied according to the scale and accuracy of abstracted landscape elements in the study area; As such, the 1:10 000 reference scale was used primarily in this study, and the smallest landscape element identified had an area of 0.1 ha. The artificial surface area represents the data of self-mapping process in scale 1:10 000 with GPS and GNSS technologies.

Data for the study's agricultural areas was collected by

the GEF (Global environmental fund) project 'Mapping of grassland vegetation in Slovakia'. Data from this process was provided at 1:25 000, with the geometry accuracy (to 1:5000 scale) and database records (to 1:10 000 scale) of each patch within this category updated using data from the State Nature Conservancy of the Slovak Republic organization. Forest and semi-natural areas are represented in a scale of 1 : 10 000. This spatial information are based on Forest Care Program of the study area.
These data were collected by the Slovak national forestry authority. The only part of this dataset with potential data accuracy issues is the attribute table, where 5–10% error is expected. Each database record is classified under EUNIS categorization, updated by the Natura 2000 and Corine Land Cover 2000 codes [7–9].

3.2. Ecological significance

Using the landscape metrics discussed above, it is possible to interpret each habitat and its patches with a view to assessing the quality of ongoing ecological processes. This interpretation can be used to assign each habitat a degree of ecological significance, based on the following levels [25]:

1 — Very significant land-cover patches
2 — Significant land-cover patches
3 — Moderately significant land-cover patches
4 — Almost insignificant land-cover patches
5 — Insignificant land-cover patches

The quality of ecological processes in the landscape also increases at higher levels of ecological significance.
According to [28], the first step in this interpretative process is to assign a level of ecological significance (S_A) for every habitat, based on the operation of ecological processes in the landscape. The next step modifies S_A by the percentage proportion ($P_{\%}$) of each habitat metrics (NP, PD, MPS, PSSD and MSI) in comparison to the total number obtained for that metric, based on the following scale:

0–20% = ecological significance remains constant; **S_A the same value**
21–40% = ecological significance is **S_A plus one degrees**
41–60% = ecological significance is **S_A plus two degrees**
61–80% = ecological significance is **S_A plus three degrees**
81–100% = ecological significance is **S_A plus four degrees**

The result of this modification is the partial ecological significance (S_B). The final ecological significance S_C for habitats is formed by match average of values S_B. Therefore, the determination of ecological significance for a region can be summarized by the following steps [28]:

1. Assign a S_A value to each patch, class, and landscape: i.e. S_{AP} — Patches; S_{AC} — Classes; S_{AL} — Landscape.
2. Calculate the Percentage proportion ($P_{\%}$) of each patch's metric value in relation to the total landscape value: i.e. $P_{\%\,of\,P/L}$ — NP of patches, classes and landscape; $P_{\%\,of\,P/L}$ — PD of patches, classes and landscape; $P_{\%\,of\,P/L}$ — MPS of patches, classes and landscape; $P_{\%\,of\,P/L}$ — **PSSD** of patches, classes and landscape; $P_{\%\,of\,P/L}$ — **MSI** of patches, classes and landscape.
3. Assign values S_B based on the modification of S_A in accordance with calculated $P_{\%}$ figures: i.e. S_{BP} — Patches; S_{BC} — Classes; S_{BL} — Landscape.
4. Generate final S_C values as a match average of values S_B for each patch, class and landscape.

4. Results

The main result for this work is determination of the ecological significance of the Sitno Natura 2000 Site. The ecological significance of landscape elements at this site are represented by numerical values (degrees), which can be used to interpret the quality of ongoing ecological processes in the landscape. Based on the calculated degrees of ecological significance it is then possible to zone the protected area, objectively dividing the study area into different regions of separate nature-conservation and landscape-usage regimes. This process should be an objective and ecological approach that also respects sustainable human development.

4.1. Landscape elements of the study area

Landscapes in the study area are divided into three base categories: 1. 'Artificial surfaces', which show evidence of human impact; 2. 'Agricultural areas', including arable land; and 3. 'Forests and semi-natural areas'. These three categories are further divided into 19 subcategories (Table 2; Figure 2). The subcategories are defined in accordance with the referenced scale and the methodological concept of habitat classification.
The study area is dominated (91.81% TA) by 'Forests and semi-natural areas'. As shown in Table 2, the most commonly representated landscape elements within the study area are '*Asperulo–Fagetum* beech forests' (9130), which occupy 52.64% of the total area (TA) of the Sitno site. The total number of patches (NP) in the study area was 105. The PD values show the distribution and concentration of patches within the landscape, with an overall total of

Table 2. Identity and size (area) of habitats represented within the Sitno Nature 2000 Site.

CORINE land cover type		ANNEX		EUNIS	Class Area (CA)	
Code	Description	Code	Description		ha	%
1. Artificial surfaces					**13.98**	**1.49**
1.1.2	Discontinuous urban fabric	X (1.1.2)	X	X	1.86	0.20
1.2.2	Road and rail networks and associated land	X (1.2.2)	X	X	12.12	1.29
2. Agricultural area					**53.32**	**5.69**
2.3.1	Pastures	6510	Lowland hay meadows	E2.22	30.79	3.29
		X (2.3.1)	Large *Carex* beds	C3.26 (D5.21)	0.34	0.04
		6410	*Molinia* meadows on calcareous, peaty, or clayey slit laden soils	E3.51	2.54	0.27
		6110*	Middle European pioneer swards	E1.11 (E1.29)	1.54	0.16
		6210	Arid subcontinental steppic grasslands	E1.22 (E1.23) E1.28)	2.74	0.29
		6240*	Sub-Pannonic steppic grasslands	E1.2 (E1.29)	13.89	1.48
		6230*	Mat-grass swards	E1.71 (E4.31)	1.48	0.16
3. Forests and semi-natural areas					**868.25**	**92.81**
3.1.1	Broad-leaved forest	X (3.1.1)	Oak–hornbeam forests	G1.A16	2.44	0.26
		91G0*	Pannonic woods with *Quercus petraea & Carpinus betululus*	A1.A16	231.29	24.72
		91H0*	Pannonian woods with *Quercus pubescens*	41.7374	10.67	1.14
		91M0	Pannonian–Balkanic turkey oak – sessile oak forests	G1.76	22.55	2.41
		9180*	*Tilio–Acerion* forest on slopes, screes, and ravines	G1.B5	92.49	9.89
3.1.3	Mixed forest	9130	*Asperulo–Fagetum* beech forests	G1.63	492.44	52.64
3.2.4	Transitional woodland shrub	40A0*	Continental deciduous thickets	F3.24	5.69	0.61
		X (3.2.4)	Temperate thickets and scrub	F3.1	6.84	0.73
3.3.2	Bare rocks	8150	Medio-European upland siliceous screes	H2.32 (H2.5)	0.29	0.03
		8220	Siliceous rocky slopes with chasmophytic vegetation	H3.11	3.55	0.38
Total area (TA) / hectares (ha)					**935.56**	**100%**

X Not represented in this classification scheme

* Priority habitat for Slovakia

11.22 patches per 1000 ha. This is a very small value, indicating large, compact patches. Based on the Number of categories and sub-categories, and NP, PD, CA and TA (Table 2 and 3) values obtained for the Sitno region, it can be stated that study area is not fragmented at wide range by human impact.

From the NP and patch area values, we can calculate the Mean patch size (MPS). The MPS values obtained (Table 3) indicate that the 'Artificial surfaces' category has patches of very small mean size (2.21 ha). On the other hand, patches of the 'Forest and semi-natural areas' category occupy a large portion of the landscape and are categorized by large NP and MPS values. The most significant patch values are obtained for the '*Tilio–Acerion* forest of slopes, screes and ravines' (9180*) habitats, where MPS is 13.21 ha and CA is 92.49 ha. As a comparison, the 'Pannonic woods with *Quercus petraea & Carpinus betululus*' (91G0*) habitat has a CA almost 3 times larger than that of the 9180* habitats. Furthermore, each patch of habitat 9180* is large in size, and the landscape metrics indicate it forms a compact biotope, features which are not typical for Slovakian environments. This habitat is generally considered endangered due to its small scale and fragmented appearance. In comparison, the 91G0* habi-

Table 3. Quantification of habitat types by landscape metrics.

LCC Code	ANNEX Code	NP^1	NP^2	PD^1	PD^2	MPS^1	MPS^2	PSSD^1	PSSD^2	MSI^1	MSI^2
Artificial surfaces	X	**11**	**10.48**	**1.18**	**10.48**	**2.21**	**2.49**	**2.09**	**1.97**	**10.2**	**25.62**
1.1.2	X (1.1.2)	4	3.81	0.43	3.81	0.47	0.53	0.29	0.27	1.34	3.37
1.2.2	X (1.2.2)	7	6.67	0.75	6.67	1.73	1.96	1.80	1.70	8.86	22.25
Agricultural areas	X	**33**	**31.43**	**3.53**	**31.43**	**9.05**	**10.27**	**5.16**	**4.87**	**11.71**	**29.45**
2.3.1	6510	15	14.29	1.60	14.29	2.05	2.33	1.89	1.79	1.70	4.27
	X (2.3.1)	1	0.95	0.11	0.95	0.34	0.39	0.00	0.00	2.15	5.40
	6410	5	4.76	0.53	4.76	0.51	0.58	0.45	0.42	1.40	3.51
	6110*	3	2.86	0.32	2.86	0.51	0.58	0.31	0.29	1.46	3.68
	6210	4	3.81	0.43	3.81	0.69	0.78	0.67	0.63	1.41	3.55
	6240*	4	3.81	0.43	3.81	3.47	3.94	1.84	1.74	1.96	4.93
	6230*	1	0.95	0.11	0.95	1.48	1.67	0.00	0.00	1.63	4.11
Forests and semi-natural areas	X	**61**	**58.08**	**6.52**	**58.11**	**76.85**	**87.22**	**98.48**	**93.15**	**17.88**	**44.91**
3.1.1	X (3.1.1)	2	1.90	0.21	1.91	1.22	1.38	0.91	0.86	1.77	4.44
	91G0*	18	17.14	1.92	17.15	12.85	14.58	30.96	29.28	1.88	4.72
	91H0*	5	4.76	0.53	4.76	2.13	2.42	2.67	2.53	1.33	3.33
	91M0	4	3.81	0.43	3.81	5.64	6.40	3.24	3.07	1.61	4.06
	9180*	7	6.67	0.75	6.67	13.21	15.00	21.15	20.01	1.78	4.47
3.1.3	9130	14	13.33	1.50	1334	35.17	39.92	37.07	35.06	1.90	4.77
3.2.4	40A0*	4	3.81	0.43	3.81	1.42	1.61	0.52	0.49	1.58	3.96
	X (3.2.4)	5	4.76	0.53	4.76	1.37	1.55	1.96	1.86	1.91	4.81
3.3.2	8150	1	0.95	0.11	0.95	0.29	0.33	0.00	0.00	1.60	4.03
	8220	1	0.95	0.11	0.95	3.55	4.03	0.00	0.00	2.52	6.32
Total landscape value		**105.00**	**100.00**	**11.22**	**100.00**	**88.11**	**100.00**	**105.72**	**100.00**	**39.80**	**100.00**

Legend:

NP^1 Number of patches
NP^2 % NP of total metric value
PD^1 Patch density / 100 ha
PD^2 % PD of total metric value
MPS^1 Mean patch size (in ha)
MPS^2 % MPS of total metric value
PSSD^1 Patch size standard deviation (in ha)
PSSD^2 % PSSD of total metric value
MSI^1 Mean size index
MSI^2 % MSI of total metric value

tats have MPS, CA and NP values that indicate small sizes for some patches within the habitat.

The Patch size standard deviation (PSSD) metric is focused on the size difference among patches in the landscape (Table 3). A value of PSSD close to zero indicates patches of the same size, which in turn indicates uniform patch structure created by human impact or human landscape planning. The following habitats have the biggest deviation sizes: '*Asperulo–Fagetum* beech forests' (9130), 'Pannonic woods with *Quercus petraea* & *Carpinus betulus*' (91G0*), and '*Tilio–Acerion* forest of slopes, screes and ravines' (9180*). Combined with the previous interpretation of habitat 9180*, we can conclude that natural processes dominate within these habitat types. However, this value needs to be interpreted in conjunction with other metrics; an example can be seen for habitat 91G0*, whose values of MPS, CA, NP and PSSD indicate small patch sizes, and at the same time, differing sizes between patches of this habitat type. This result should be interpreted as reflecting human impacts due to

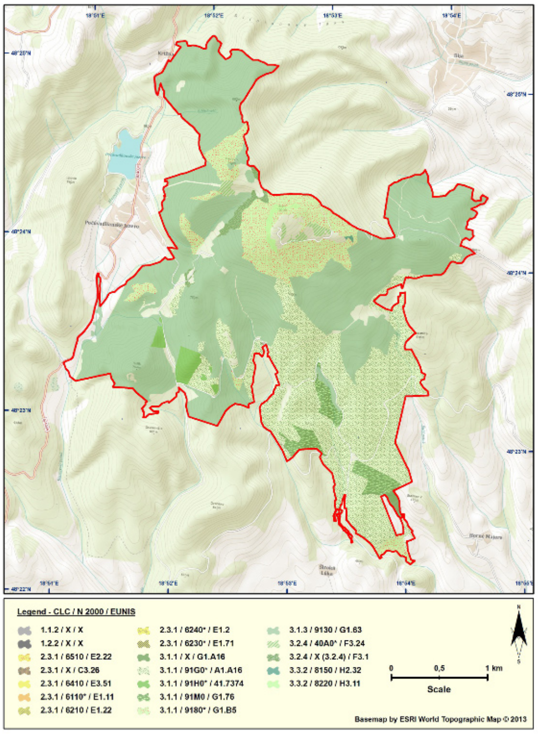

Figure 2. Nature 2000 site and EUNIS habitat classification for the study area.

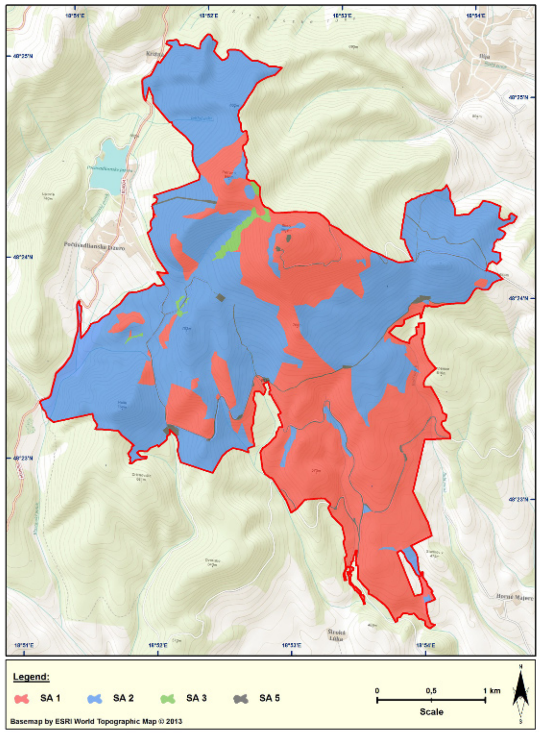

Figure 3. Baseline ecological significance values for the study area.

forestry, which is common in Slovakia. As a result, habitat 91G0* is threatened by forestry mismanagement, particularly the dimensions of intensive use and expansion of the invasive *Acacia*. For these reasons, this is considered a highly endangered habitat. No human impact in the form of tourism was detected within any of the habitats in the Sitno Natura 2000 site.

Finally, the Mean size index (MSI) can be used to indicate patch shape of particular habitats (Table 3), with the value of this index increasing with increasing irregularity of the patch shape. Patches with low values have circular shapes, and imply small amounts of human impact. For best results, this metric should be interpreted in combination with the NP and CA/TA values. Artificial surfaces have the most significant range of NP and CA/TA values, and Agricultural areas have very high CA/TA values. These results indicate the human impact inherent in these landscape categories, namely agricultural and historical settlements, and tourism.

4.2. Ecological significance of study area

Calculations of the ecological significance of landscape elements in the Sitno area are based on the methodology outlined above. Table 4 and Figure 3 illustrate the starting values (S_A) of each habitat. This is a baseline value of the ecological significance, with degrees assigned according to [25]. The study area as a whole has an ecological significance of degree 3. Modification (S_B) of this starting value was then calculated according to the:

- Landscape metrics for each habitat type, and their percentage proportion to that metric total value.
- Scale degree as the factor of accuracy.

The final ecological significance (S_C) value is assessed as a mathematical average using partial ecological significance (Figure 4). Overall, the study area has a S_C of degree 3, although values can also be determined for the main habitat categories represented in the study area. 'Artificial surfaces' occupy only 1.49% TA and have a S_C of degree 5. 'Agricultural areas' occupy 5.69% TA and have a S_C value of degree 2. Finally, 'Forests and semi-natural areas' occupy 92.81% TA and also have a S_C of degree 2. These values form the background data for division of the study area into zones, with specific nature and landscape conservation regimes assigned to each zone accordingly.

4.3. Zonation of the study area

Natura 2000 sites are designed, based on specific ecological and biogeographical criteria, to meet specific conser-

Table 4. Ecological significance of habitat types in the study area.

LCC Code	ANNEX Code	S_A	NP		PD		MPS		PSSD		MSI		S_C
			$P_\%$	S_B	$P_\%$	S_B	$P_\%$	S_B	$P_\%$	S_B	$P_\%$	S_B	
Artificial surfaces	X	5	5		5		5		5		5		5
1.1.2	X (1.1.2)	5	3.81	5	3.81	5	0.53	5	0.27	5	3.37	5	5
1.2.2	X (1.2.2)	5	6.67	5	6.67	5	1.96	5	1.70	5	22.21	5	5
Agricultural areas	X	2	2		2		2		2		2		2
2.3.1	6510	2	14.2	2	14.2	2	2.33	2	1.79	2	4.27	2	2
	X (2.3.1)	3	0.95	3	0.95	3	0.39	3	0.00	3	5.40	3	3
	6410	2	4.76	2	4.76	2	0.58	2	0.42	2	3.51	2	2
	6110*	1	2.86	1	2.86	1	0.58	1	0.29	1	3.68	1	1
	6210	2	3.81	2	3.81	2	0.78	2	0.63	2	3.55	2	2
	6240*	1	3.81	1	3.81	1	3.94	1	1.74	1	4.93	1	1
	6230*	1	0.95	1	0.95	1	1.67	1	0.00	1	4.11	1	1
Forests and semi-natural areas	X	2	2		2		2		2		2		2
3.1.1	X (3.1.1)	2	1.90	2	1.91	2	1.38	2	0.86	2	4.44	2	2
	91G0*	1	17.1	1	17.15	1	14.58	1	29.28	2	4.72	1	2
	91H0*	1	4.76	1	4.76	1	2.42	1	2.53	1	3.33	1	1
	91M0	1	3.81	1	3.81	1	6.40	1	3.07	1	4.06	1	1
	9180*	1	6.67	1	6.67	1	15.00	1	20.01	2	4.47	1	2
3.1.3	9130	2	13.3	2	13.3	2	39.92	3	35.06	4	4.77	2	4
3.2.4	40A0*	1	3.81	1	3.81	1	1.61	1	0.49	1	3.96	1	1
	X (3.2.4)	3	4.76	3	4.76	3	1.55	3	1.86	3	4.81	3	3
3.3.2	8150	2	0.95	2	0.95	2	0.33	2	0.00	2	4.03	2	2
	8220	2	0.95	2	0.95	2	4.03	2	0.00	2	6.32	2	2
Total landscape value		3	3		3		3		3		3		3

Legend:

S_ABaseline values of ecological significance

S_BAssigned values of ecological significance, by proportional degree

S_CDetermined values of ecological significance for each habitat, by average

$P_\%$Percentage proportional to values for total landscape area

NP Number of patches

PD Patch density

MPS Mean patch size

PSSD Patch size standard deviation

MSI Mean shape index

vation objectives achievable through appropriate conservation measures. They are also designed to provide a wide range of provisioning, regulating, and other socio-cultural ecosystem services [27].

The Sitno Natura 2000 Site is a protected area where human impacts are detected, though not to a large degree. The final ecological significance (S_C) of this study area was calculated as falling into the same range as the initial level (S_A). Based on this situation, we may conclude that human impact does not impede natural processes, naturalness, and self-regulatory processes within habitats of the Sitno region.

On this basis, a spatial organization (zonation) of the study area was attempted based on S_C values and the partial ecological interpretation of landscape metrics (Figure 5). Each part of the study area is assigned to one of three zone, each characterized by a different conservation regime. These three zones are described and defined as aspects of the protected area as a whole, especially diversity, originality, ecosystem extent, human actions, and human land-use types. The first zone, 'zone A', represents the 'silent' zone; i.e. the area with the most stringent level of protection. On the other hand, 'zone B' can be considered an area under limited protection, and 'zone

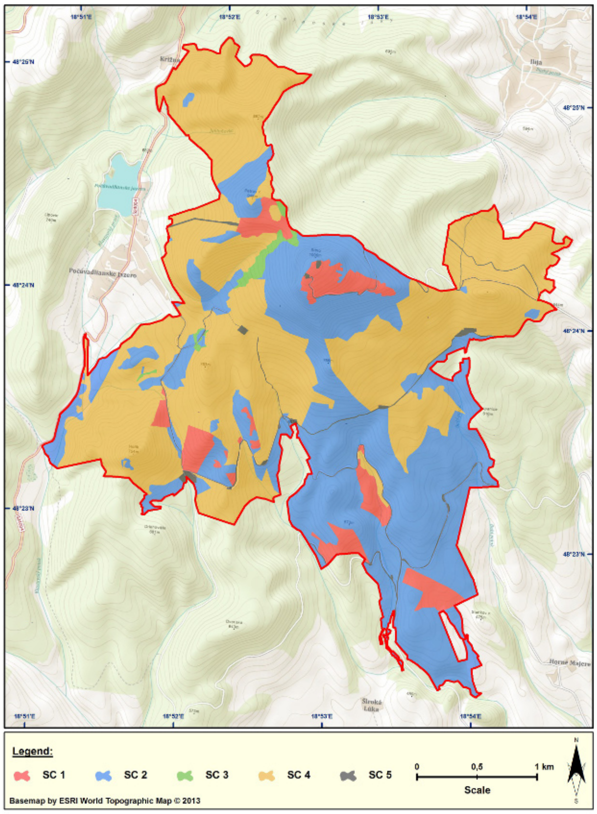

Figure 4. Final ecological significance values determined for the study area.

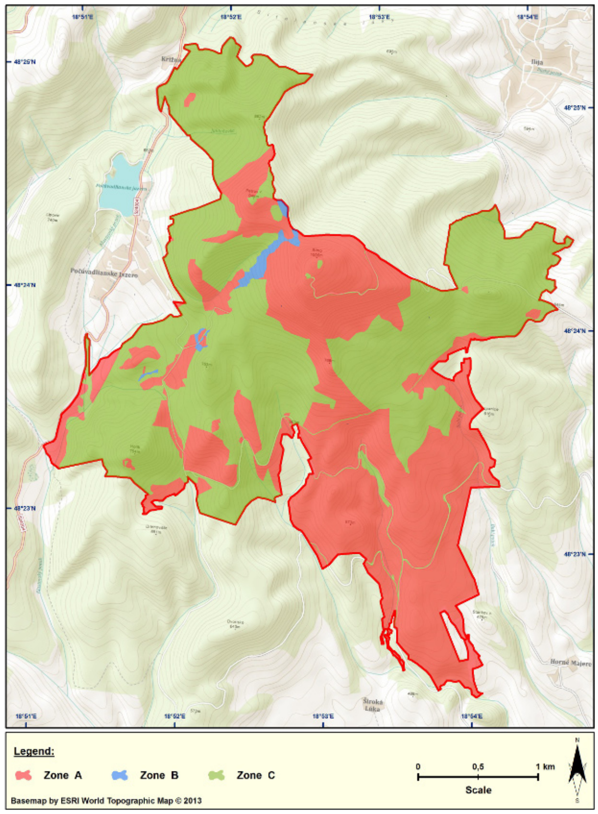

Figure 5. Study area divided into conservation and land use zones.

C′ is an area considered suitable for sustainable human development.

5. Discussion

The Sitno study area has here been characterized using spatial configuration and landscape composition metrics, which are seen to directly reflect ecological processes. According to the calculated values of these landscape metrics, it was possible to identify the quality of ongoing ecological processes within the landscape. Qualification of these processes is based on using the landscape metrics to identify the landscape's ecological significance, which in turn represents natural ecosystem operations.

Many case studies have been reported and published of this topic, with most of this work focussed on a geographical approach to identifying landscape changes. Published research papers, including on Natura 2000 sites, mostly refer to areas as a whole; e.g. to aesthetically pleasing, tourist-attracting landscapes. However, the main focus of the Natura 2000 system is to select, as primary targets of natural conservation, natural and semi-natural habitat types and areas containing endangered species of European significance. These tasks are covered by the European Habitats Directive 92/43/EEC and Birds Directive 79/409/EEC. On the other hand, this type of conservation relies on operations within these natural and semi-natural ecosystems, and on land-use types, as many of these valuable habitats would be lost or reduced in size if the areas were converted to intensive usage. That being said, there are no published studies focussing not only on a geographic approach to this problem, but also on an ecological approach based on interpretation of landscape operations.

Ecological significance of a region can be assessed by the application of a methodological framework that determines the degree of natural processes operating within an ecosystems. This method can be used as an integrative tool for nature and landscape conservancy. In the scope of the current work, we proposed a zonation of the protected study area for use in land-use and conservation planning (Figure 5). This was attempted as it was recognized that without objective interpretation, it is diffult to determine and describe how a protected area should be used in reality. The key tool of this ecological significance method is quantification using landscape metrics, although there is still some argument about how these landscape metrics should be interpreted. In recent decades, studies have focused on the problems of scale relations [31, 49, 53, 63, 66, 67], source data accuracy [51, 52], and the ecological implications of landscape metrics [31, 33, 59]. In contrast, the current application of landscape metrics for nature and landscape conservation studies should be based on an interdisciplinary approach; i.e. by integrating these considerations. Using a geographical approach based on spatial interpretation, only the landscape composition status can be adequately assessed, and the spatial configuration of each landscape element remains unresolved. On the other side, using a geographical approach makes it possible to use wide range of Earth-surface observation tools, such as remote sensing and modern online visualization services. These technologies offers a quick and easy way to measure and categorize landscapes (such as other Natura 2000 Sites around the European Union), and would provide the input data for landscape quantification using landscape metrics, from which it would be possible to determine qualitative landscape aspects through an ecological approach.

As demonstrated here, landscape elements, such as habitats, experience serious impacts as a result of anthropogenic land-use pressures, which cause habitat fragmentation or even direct destruction. These detrimental processes in specific habitats can be detected through landscape quantification (by landscape metrics) and qualification (by ecological significance). The results of this quantification and qualification can then be visualized in a spatial manner using cartographic means; e.g. maps. For the successful implementation of the Natura 2000 scheme, it has been recommended that regional conservation objectives and human development needs on the landscape are also determined in this way. Issues arising from the intersection of conservation objectives and human impacts can be better identified through processes establishing land-use zones for a protected area.

This study presents a methodology to use landscape metrics in solving a case-study problem specific to the Sitno area; that is, identifying regions within the Natura 2000 protected areas that can be used for sustainable development. The chosen methodology combines both ecological and geographical approaches to landscape research. The geographical approach is based on the habitat quantification for the preserved landscapes, based on the principles of landscape metrics. The ecological approach is based on interpreting the relationships between habitats and ongoing ecological processes within these landscape. The combined approach is focused predominantly on identifying landscape fragmentation and interpreting this fragmentation for selected habitat types; e.g. 9180* or 91G0*. This ecological interpretation has been performed in accordance to the following research works [10, 16, 17, 19, 20, 36, 61].

The interpretation process used here is partially based on an existing methodology for ecological carrying capacity [25]. This latter methodology was designed on the basis of research focused on Landscape Ecological Planning (LANDEP) [46, 47]. No research papers to date have extended the research base for the LANDEP methodology, and this methodology does not provide objective explanations and criticisms for the assignation of initial ecological significance (S_A). Despite this, the level of the ecological significance for the Sitno area was modified (to S_B and $P_{\%}$) through the means of applied mathematical and ecological interpretation, and using knowledge of specific ecological functions within the landscape. The methodology chosen was an experiment designed to objectively determine the levels of ecological significance for all habitats within the study area.

6. Conclusion

This work determined the ecological significance of Sitno Natura 2000 Site. Patch quantification pointed on result of human influencing on ecological processes within landscape ecosystems. This interpretative process examines land-cover patches using a set of landscape metrics for the area, size, density, and shape (NP, PD, MPS, PSSD and MSI) of habitats. Together, the output values express spatial processes in the landscape, such as perforation, dissection, fragmentation, shrinkage or attrition.

The final ecological significance (S_C) obtained for the study area — the Sitno Natura 2000 Site — is degree 3, which means that the area is represented by moderately significant land-cover patches or habitats. This final significance value was found to be the same as the initial significance level. Based on the ecological significance values of particular habitats, the study area has been divided into three zones, with each requiring a specific level of conservation. These zones and the S_C values of habitats were then retroactively compared to historical and cultural human development in this area, which started as early as the 1th century BC. Theoretically, this long period of intense human impact on the local environment should have completely destroyed the natural environment, but the Sitno area instead shows a natural ecosystem in rather good condition and habitats whose ecological processes are functioning well. Human impacts are only observed over a small part of the region, not more than 1.50% of the total area of the Sitno Natura 2000 Site. This conservation of Sitno ecosystems can be explained by three factors — firstly, the low population density within the study area, when compared to other EU areas; secondly, the historically responsible usage of the area by the local population; and thirdly, the high resilience of landscape elements to human impact.

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