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GEODIVERSITY AND LANDSCAPE SERVICES IN THE REGION OF OGULINSKO-PLAŠĆANSKA ZAVALA, CROATIA

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Abstract

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In terms of spatial planning and environment protection procedures in Croatia, geomorphological features as a component of geodiversity are mostly considered marginally. They are considered locally in the scope of certain operations such as urban development, mining, or activities that are being assessed in the environment impact assessment procedures or spatial and strategical planning. Regarding the protection and the planning processes connected with it, geomorphological features should be considered in the right scale and with all of its values and services that are being provided to the environment on a landscape scale. In this paper, geodiversity and its role in landscape evolution will be connected and explained with the example of subgeomorphological region Ogulinsko-plašćanska Zavala, in the mountainous Dinaric karst part of Croatia. As it has been a region with long human and nature interaction, and a region with preserved natural and seminatural landscapes, it is a suitable area for such an analysis. In order to properly assess the geomorphological features as one of the determinants of landscape, the basis for environment impact assessment procedures and spatial planning procedures, geoecological analysis of geodiversity and landscape services occurrence and spatial distribution is carried out.

Key words: landscape typology, geodiversity, relative relief assessment method.

Introduction

Landscape as a term can be defined in different ways that are dependent on the aspect of a study. In this study, landscape is analyzed from physical geography aspect. It is the closest to the definition of landscape as a physical space, part (at various scales) of the Earth's surface, which is shaped by natural conditions and formed by human influences to a different extent (Bastian et al., 2014). Natural basis of landscapes is determined by its primary structure. Primary landscape structure is defined by the abiotic elements of geosystems, for example, geology, relief, soil, water, and air. It is the primary basis for other landscape structures (Miklós et al., 2019). Collective term for overall diversity of landscapes, landforms, and processes that form and reshape them on the Earth's surface and in the lithosphere (that includes their features, relationships, and systems) is defined as *geodiversity*. Its elements are geological,

geomorphological, and pedological diversity (Gray, 2005; Serrano, Ruiz-Flaño, 2007; Gray, 2008, 2013; Gray et al., 2013; Brilha et al., 2018; Reynard, Brilha, 2018; Coratza et al., 2018; Zwolinski et al., 2018).

Landscape types are units that are relatively homogeneous in their composition. These are generic in nature since these may occur in different areas in different parts of the country and share broadly similar combinations of geology, topography, drainage, landforms, vegetation, historical land use, and settlement patterns (Swanwick, 2002).

Although it recognizes the importance of the landscape natural elements as a basis for spatial development, the spatial planning sector in Croatia does not currently sufficiently utilize geographical elements and holistic approaches such as ecosystem services and landscape services in the planning process (Marohnić-Kuzmanović et al., 2017). Recent concept is adapted to the strategic level of landscape planning and protection (Obad Šćitaroci et al., 2014). It provides good overview of the landscape state, as well as an overview of the methods and strategic guidelines used for landscape planning and protection. It does not sufficiently consider the primary structure of the landscape, which is not further elaborated on lower order components, while the secondary and tertiary landscape structures are elaborated in greater detail. An approach based on the cultural components of the landscape was emphasized and, unfortunately, did not go far from the landscape regionalization developed for spatial development by geographer I. Bralić in the mid 1990s (Bralić, 1999).

On the other side, the usual approach in the Croatian nature protection sector is based on the biological point of view or, rarely, ecosystem services approach. It recognizes habitat types (determined by vegetation areas) as basic spatial units, initially based on EUNIS habitat classification (EUNIS, 2019; HAOP, 2017). Besides positive aspects, one of the main problems with ecosystem services approach (or newer *Nature's Benefits to People* concept; Kadykalo et al., 2019) is the focus on the benefits for human society, economic framework or biodiversity, often not giving correct attention to the other ecosystems' components. Therefore, it can be used only as an additional method in landscape analysis (Birkhofer et al., 2015; Lele et al., 2013; Portman, 2013).

As an alternative to the concept of ecosystem units and ecosystem services, the concept of landscape units and *landscape services* (or functions) in landscape analysis is much more applicable due to the more holistic perspective. Termorshuizen and Opdam (2009) stressed the role of landscapes as "spatial human-ecological systems that deliver a wide range of *functions*, that are or can be valued by humans for economic, sociocultural, and ecological reasons". Developing the landscape services approach, Bastian et al. (2014) provided a wider look at the geographical space and its components. Due to the features and modifiers that shape *landscape types*, they are more appropriate spatial units than ecosystems in spatial planning and environment protection. Landscape services are defined similar to ecosystem services, but represent upgrade due to the more holistic perspective. They also account for the contributions of landscapes to human well-being (Bastian et al., 2014), but are also applicable to other landscape/ecosystem elements. Landscape services are mostly classified in three themes: provisioning, regulation and socio-cultural (Vallés-Planells et al., 2014).

As abiotic nature is greatly taking part in landscape types, one aim of this paper is to analyze spatial distribution and features of geodiversity, and its role in landscape typology. The

other aim is to analyze primary landscape structure and to examine possibilities of landscape services' quantification with the use of relative relief assessment method. For this study provisioning, socio-cultural and regulation services were selected. This approach is focused on the integration of primary landscape structure or physical geographical aspect in combination with values of landscape through utilitarian value, which also includes some indicators of biodiversity. This kind of approach could bring new insights about landscape structure and values besides the usual approach of land cover characteristics analysis (Pătru-Stupariu et al., 2017; Zaušková, 2014; Mkrtchian, 2013).

Study area

Study area of Ogulinsko-plašćanska Zavala (Fig. 1) covers 300.24 km^2 and it is a part of the Mountainous Croatia in Dinaric karst mountain belt (Bognar, 2001; Bognar et al., 2012). It was named after two main settlements – Ogulin and Plaški. It is tectonically relatively low-

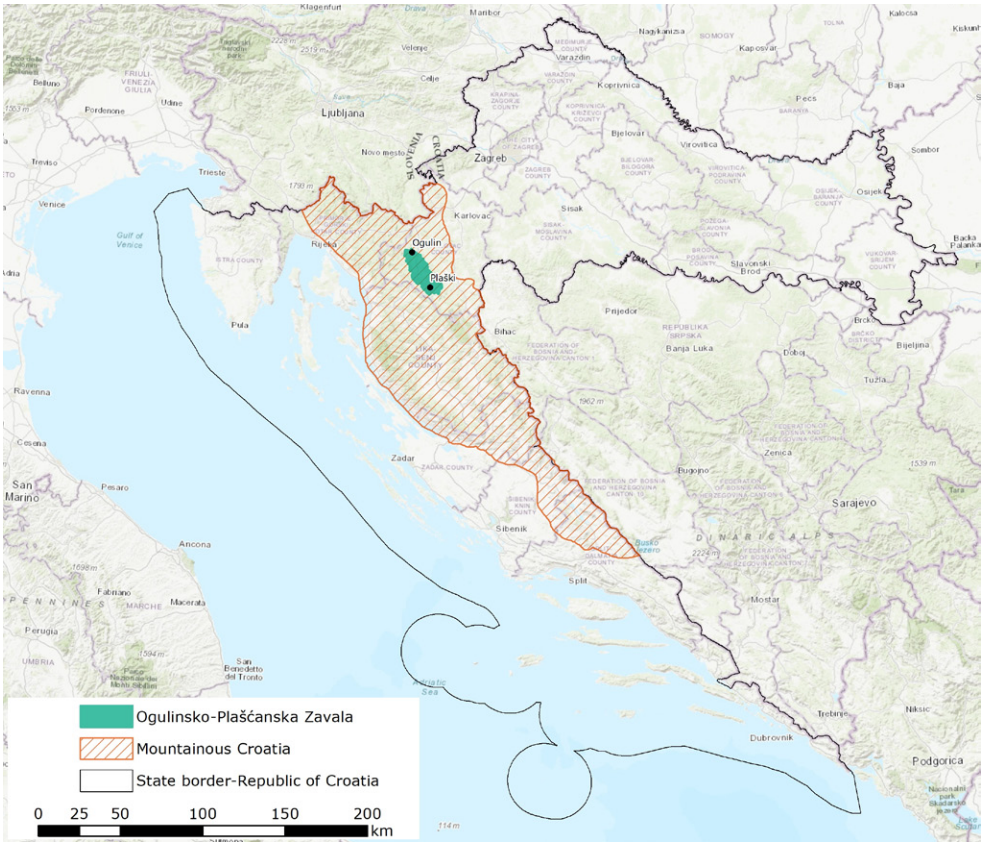


Fig. 1. Location of study area.

ered depression of Dinaric direction (Bočić et al., 2016) modelled by various geomorphological processes.

The spatial distribution and alteration of limestones and dolomites resulted in local differences in geomorphological processes and landscape properties (Fig. 2). Two main morphogenetic relief types determine the landscape: karst and fluviokarst. The karst was developed in areas built of Cretaceous limestones. It is characterized by dynamic landscape of sharper contours due to the steeper slopes and higher relative relief values. There are forest landscapes on thin soils and bare rocky surface in the mountains. The manmade grasslands are characteristic for karst plateaus. The diagnostic landscape elements are numerous karst phenomena: closed depressions on the surface (dolines and uvalas), subterranean phenomena (caves and shafts) and predominantly underground karst water circulation. Fluviokarst is a morphogenetic relief type typical for the dolomite and contact karst zones where relief developed by the combination of karst, fluvial and slope processes. There are also karst phenomena (dolines, caves, poljes, and blind valleys with ponors), underground water circulation, but also better developed surface stream network with often thicker fluvial deposits important for agriculture. This is the area of mosaic cultural and semi-

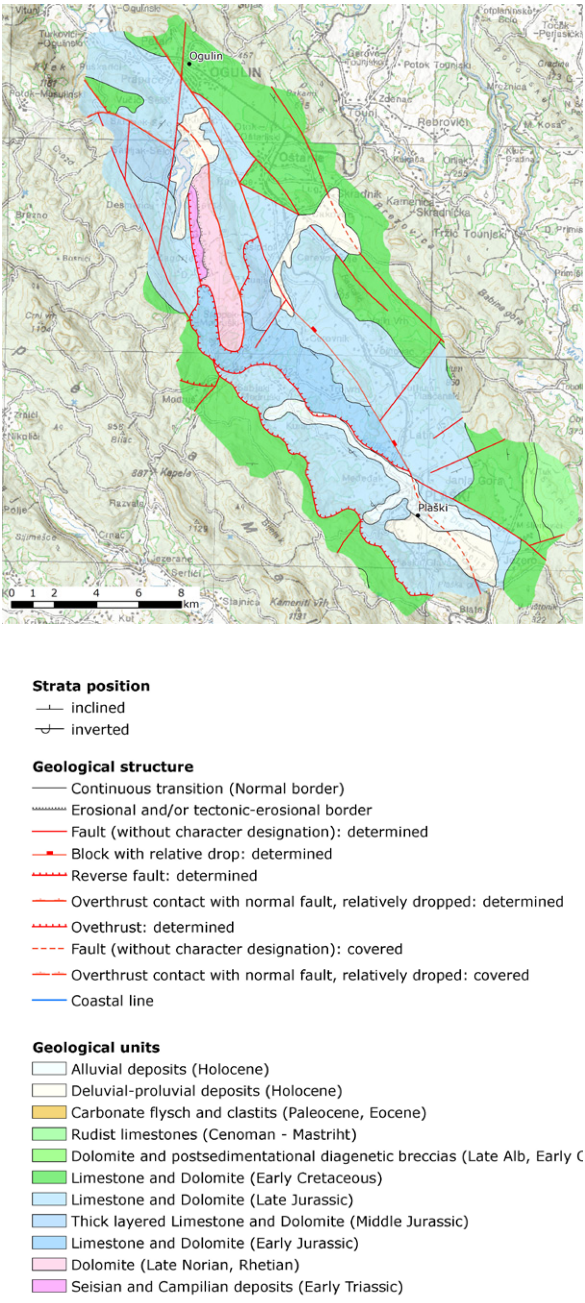


Fig. 2. Geological map of study area (after Velić, Vlahović, 2009).

natural landscapes with settlements, arable lands and forest patches. Valleys and karst poljes bottoms are covered with the younger Holocene alluvial and slope deposits.

The simultaneous occurrence of typical karst phenomena with big karst springs (Zagorska Mrežnica, Bistrac, Zagorska Peć, Rupečica) and surface hydrological network typical for non-karst areas are a result of geological conditions (Bahun, 1970). The largest stream Dobra is a losing fluviokarst river that flows into the research area from the NW. A losing river is a stream in karst in which water infiltrates underground because the groundwater table is below the bottom of the stream channel (Bonacci, Andrić, 2010a). River Dobra receives water from the well karstified area of the Velika Kapela Mt. Its valley developed along the part of an upper impounding zone, along the contact zone of well-karstified limestones, and less permeable dolomites that act as a hydrogeological barrier for karst drainage, causing specific valley geomorphology, hydrology, the occurrence of numerous springs and small streams contributing Dobra River from the SW (Bahun, 1968, 1970; Bonacci, Andrić, 2010b; Žganec, 2012). Dobra is also the sinking river with ponor developed at the contact between Jurassic dolomite zone and Cretaceous limestone zone. Ponor is located at the border of Ogulinsko polje in the city of Ogulin and continues in the 16.4 km long cave system Đula-Medvedica (Kuhta, Novosel, 2001). The springs, streams and valleys were important factors of settlement development and contribute to the landscape diversity of the area. The valleys attracted population with fertile soil and they were the cores of landscape transformation from mostly forests and wetlands to agricultural landscape.

Material and methods

To proceed the qualitative-quantitative assessment of landscape services and geodiversity, the most common geoecological method in Republic of Croatia, *relative relief assessment* method, was chosen. Its aim is to assess values of the landscape or any other spatial unit for certain landscape evaluation, economic activity or nature protection tasks (Bognar, 1990; Bognar, Bognar, 2010; Buzjak, 2008; Mamut, 2010a,b). A qualitative characterization of geodiversity consists of elements' analysis and explanation on assigned values. This qualitative approach includes proposals that are based on expert views. Geodiversity values are labelled or rated but always in a non-numerical form and tend to be highly subjective (Pereira, Pereira, 2010). Following geospatial methods were performed in ESRI ArcMap 10.3.

Delineation of study area was done on the ridge and thalweg map extracted from DEM (10 x10 m) with Spatial Analyst extension. The borderline is extracted from continuous ridges surrounding hypsometrically lower area.

Delineation of landscape types and subtypes was made based on primary and secondary criteria. Primary criterion is relative relief (Lozić, 1995). It was calculated from DEM (Focal statistics) and classified into 6 classes of which the first three are distinctive for *planated relief*, and the last three for *dissected relief*. With this first level of delineation, some of the borders were too generalized, therefore additional steps have been taken. On the northern and southern part of the study area, the boundary between two landscape types was set on elevation contour 320 m, similar to Bahun (1970). Subtypes were afterwards delineated by continuous ridges and thalwegs, which are visible structural borderlines between landforms. First level of delineation produced two *macrolandscape* types: *dissected relief* and *planated relief macro-landscape types*. Major difference between them are the overall geomorphological processes, which are influencing energy fluxes between natural processes and human activities, and those are denudation and accumulation in different proportions. The second level, *subtypes*, were defined by their location in study area (boundary or central), size (micro, meso or macro), landform type and morphogenetic features (karstic, fluviokarstic, and karst polje as a polygenetic landform type). Third level of landscape typology delineation was done between landscape subtypes, which are different and divided in morphologic and morphometric aspect. *Micro-types* are named after the names of settlements, peaks or landforms.

With the use of relative relief evaluation method provisioning, regulation and socio-cultural landscape services were also assessed. Input data were generated from DEM, topographic map 1:25k and geological map 1:100k, Non-Forest Terrestrial Habitat Map of Republic of Croatia (Bardi et al., 2016), and cave archive of the Speleological Section of Croatian

T a b l e 1. Landscape services valorization table.

Services	Service name	Indicator	Categories	Points
Provisioning services (100)	Freshwater (50)	Springs Kernel density (25)	0-1	8.4
			1-2	16.7
			2-3.85	25
		Drainage network density (25)	0.1-1	8.4
			1-2	16.7
			2-3.6	25
	Construction material (50)	Carbonates (50)	Presence	50
Regulation services (100)	Rock cycle (33.3)	Fault density (6.6)	0-0.3	8.4
			0.3-0.6	16.7
			0.6-1	25
		Dolines Kernel density (6.6)	0-20	0.825
			20-40	1.625
			40-60	2.45
			60-80	3.3
			80-100	4.125
			100-120	4.95
			120-140	5.775
			140-160	6.6
		Springs Kernel density (6.6)	0-1	2.2
			1-2	4.4
			2-3.85	6.6
		Caves (6.6)	Presence	6.6
		Ponors (6.6)	Presence	6.6
	Water regulation (33.3)	Karst polje (16.65)	Presence	16.65
		Drainage network (16.65)	Presence	16.65
	Conserving biodiversity (33.3)	Naturalness of vegetation (16.65)	Presence	16.65
		Caves (16.65)	Presence	16.65
Socio-cultural services (100)	Aesthetic values (50)	Vertical relief dissection (7.14)	0-5	1.4
			5-100	2.8
			100-300	4.2
			300-500	5.7
			500-800	7.14
		Naturalness of vegetation (7.14)	Presence	7.14
		Caves (7.14)	Presence	7.14
		Ponors (7.14)	Presence	7.14
		Dolines Kernel density (7.14)	0-20	0.89
			20-40	1.8
			40-60	2.69
			60-80	3.58
			80-100	4.47
			100-120	5.36
			120-140	6.25
			140-160	7.14
		Springs Kernel density (7.14)	0-1	2.9
			1-2	4.7
			2-3.85	7.14
	Recreation (50)	Naturalness of vegetation (12.5)	Presence	12.5
		Caves (12.5)	Presence	12.5
		Drainage network density (12.5)	0.1-1	4.16
			1-2	8.34
			2-3.6	12.5
		Protected areas (12.5)	Presence	12.5

Mountaineering Society "Željezničar", Zagreb. First step in landscape services assessment was inventory of specified features (Table 1). Criteria determination and scoring was done in MS Excel, and afterwards applied in ESRI ArcMap 10.3. Final landscape services assessment was proceeded with Spatial Analyst tools (Reclassify and Cell Statistics). In Table 1, three types of landscape services and their belonging indicators are listed together with their descriptions.

Geodiversity assessment was proceeded in order to quantify the occurrence of geodiversity elements. As perquisite, digital geomorphological analysis and geomorphological phenomena inventory was done. After that, vectorization and geostatistical analysis of collected data and determination of assessment criteria for geodiversity was performed. Criteria determination and scoring was done in MS Excel, and applied in ESRI ArcMap 10.3. Final geodiversity assessment was proceeded with Spatial Analyst tools (Reclassify and Cell Statistics). Criteria for geodiversity assessment was intrinsic value.

Results and discussion

Landscape typology was done according to the primary landscape structure. It consists of morphogenetic relief types with similar morphometric characteristics and assemblages of landforms. Delineation product is 2 macro-landscape types, 6 subtypes, and 13 micro-types (Fig. 3).

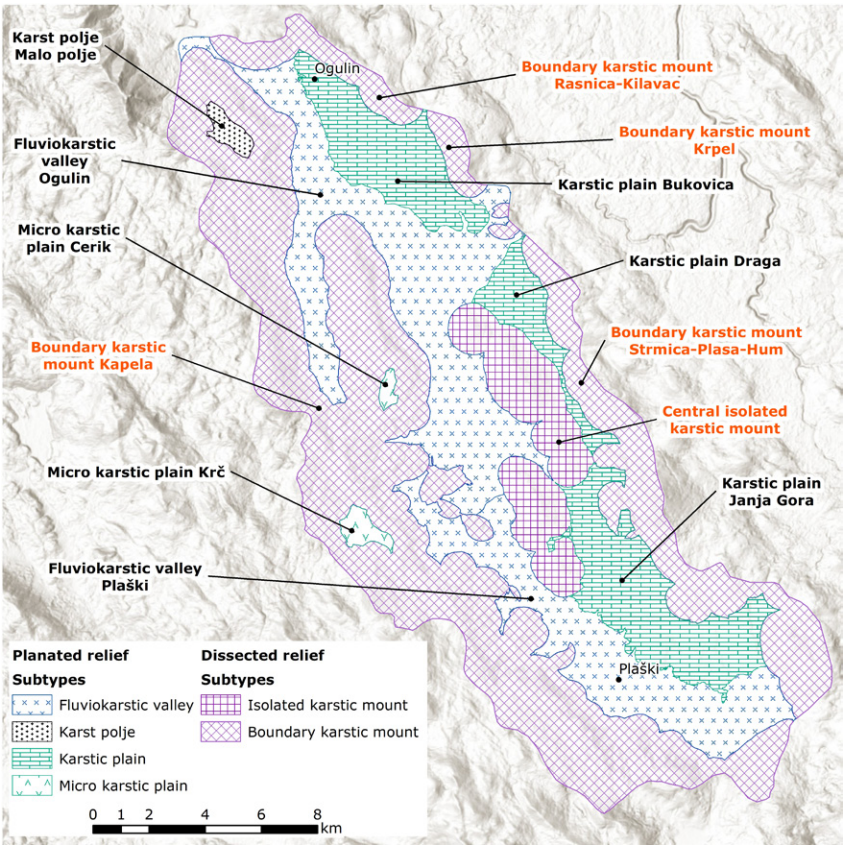


Fig. 3. Landscape typology.

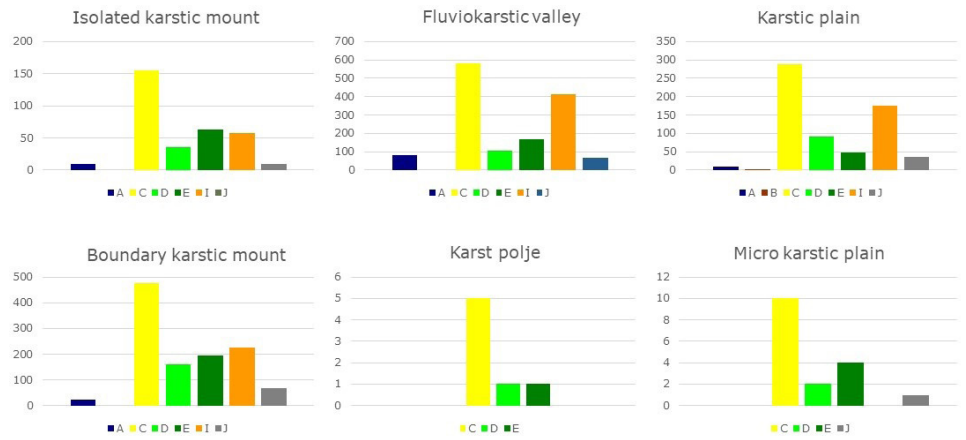


Fig. 4. Number of habitat types per landscape subtype.
Notes: A – Terrestrial surface waters and marshy habitats, B – Terrestrial areas without vegetation or poorly covered with vegetation, C – Grasslands, meadows, peat bogs and high grasses, D – Shrubs, E – Forest, I – Cultivated non-forest areas, weeds and ruderal vegetation, J – Built and industrial habitats.

Delineated landscape subtypes have some common characteristics regarding the habitat composition, which is closely connected to the land cover and abiotic components of environment. Natural habitat is a unique functional unit of terrestrial or water ecosystem determined by geographic, biotic, and abiotic features, independent regardless of whether it is natural or seminatural. All equivalent habitats are one habitat type (Croatian Nature Protection Act, Official Gazette of RC, No. 15/18, 14/19, Zagreb). Habitat types map is a good starting point for landscape analysis, its naturalness and changes measured by fragmentation (Bočić et al., 2018). Good indicator of landscape fragmentation is the number of habitat types patches in one landscape subtype and their ratio. In geographical term, landscape fragmentation is the division of larger homogeneous entities into smaller entities of different shapes, composition and structure. Due to the changes, those new forms are changing the composition, structure and function of the initial landscape (e.g., when the forest area is deforested and the so-altered area is occupied by agriculture areas, transport infrastructure, and settlements; Bočić et al., 2018; Buzjak et al., 2018). According to Non-Forest Terrestrial Habitat Map of Croatia, there are 7 habitat types present in the study area. Considering the absolute number of habitat type patches, *fluviokarstic valley* subtype has the largest number of patches. The smallest number of patches has landscape subtype *karst polje*, but this number is the result of the small area of this landscape subtype, which is the result of geomorphological conditions. Total area of *karst polje* is only 1.5 km^2, while *fluviokarstic valley* total area is 76.10 km^2. All subtypes have numerous patches of grasslands habitat type (C) (Fig. 4). The smallest landscape subtypes, *karst polje* and *micro karstic plain*, have only 3–4 habitat types present. Presence of numerous grassland patches is the evidence of anthropogenic changes of natural landscape since forests are the primary ecosystem type

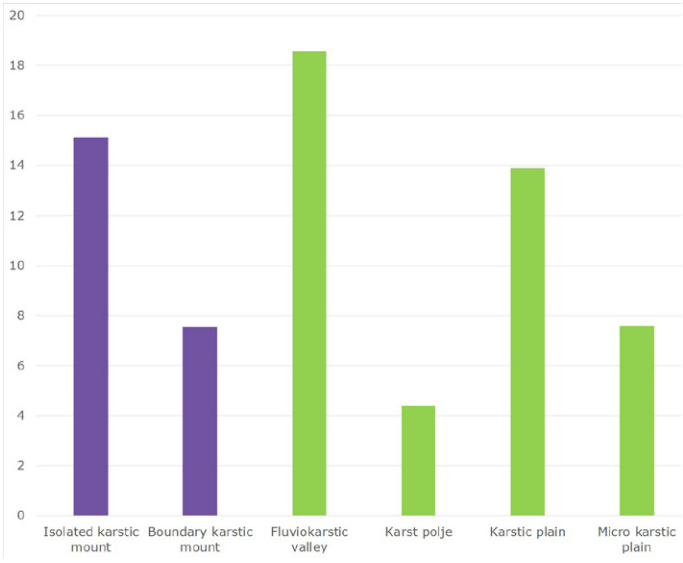


Fig. 5. Landscape Fragmentation Index (LFI).

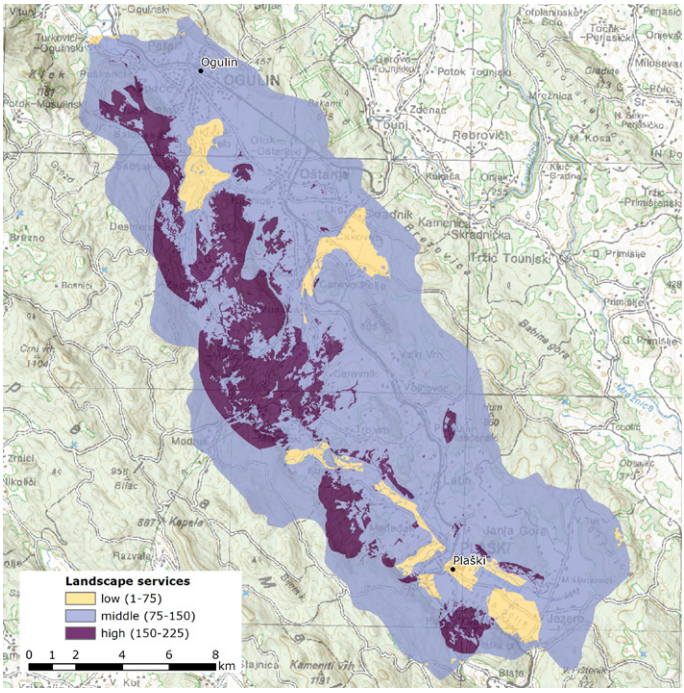


Fig. 6. Landscape services value in Ogulinsko-plašćanska Zavala.

for Croatia and this area (Trinajstić, 1998). Grasslands in Dinaric karst area relate to forest clearance for fuel and grazing (Kaligarič et al., 2006).

To examine the relation of the number of patches and area, a *Landscape Fragmentation Index* (*LFI*) was created. The LFI is expressed as the number of patches and total landscape subtype area ratio. The lowest value is recorded for *karst polje* and *boundary karstic mount* landscape subtypes, and the highest value is recorded for *fluviokarstic valley* and *isolated karstic mount* (Fig. 5). Low values of LFI are indicating low level of fragmentation, while higher values are indicating high level of fragmentation, which is connected to anthropogenic influenced landscape changes (urbanization, traffic network expansion, agriculture). As previously mentioned, such an index is a good indicator for landscape and habitat change characterized by landscape and habitat fragmentation.

The cumulative map shows landscape servic-

es values across study area (Fig. 6). Landscape services are classified into three categories. Low value class occupies 18.5% of the study area, middle class 77.7% and high value 16.2%. Areas with low value are distributed insular and are parts of macro-landscape type *planated relief*. The highest values are part of macro-landscape type *dissected relief*. High value of landscape services is present in landscape subtype *boundary karstic mount* with 24% of area with high landscape services value.

Considering Fig. 7, role of different landscape services in the whole landscape services value can be determined, as well as their spatial distribution. The high values coincide with the transition zones between the different landscape units. Provisioning services have the highest values in mountain units and in the transition zones from mountain to valley areas due to forests and the appearance of large karst springs. Socio-cultural services show a similar trend, with the highest values in the zones of high aesthetic and recreational value with diverse relief, karst phenomena and natural forests. For its regulating services the most interesting is the fluviokarst area, due to the drainage network, and transitional zones to karst with large caves and important biodiversity (Gottstein Matočec, 2002). This kind of information serves as a good basis for decision making in the environment impact assessment procedures or planning. From the other side, there is no solid basis to conclude that only "hotspot" areas are the ones in need of protection. For better justification and delineation of areas in high demand of protection, additional criteria should be applied, such as rareness of certain landscape service. Also, risk assessment of landscape services would serve as good additional information.

The same methodology was used to valorize landscape services and geodiversity occurrence, which enhances the possibility of comparison. Geodiversity assessment valorization criteria are listed in Table 2.

Geodiversity value is divided into 3 categories with equal intervals. The mean value of geodiversity is 43.8, which fits the class of middle geodiversity value. First class of low geodiversity value occupies only 0.26% of study area, which is why this class is barely visible in Fig. 8. Middle geodiversity value class occupies 52.1% of total area, while high geodiversity

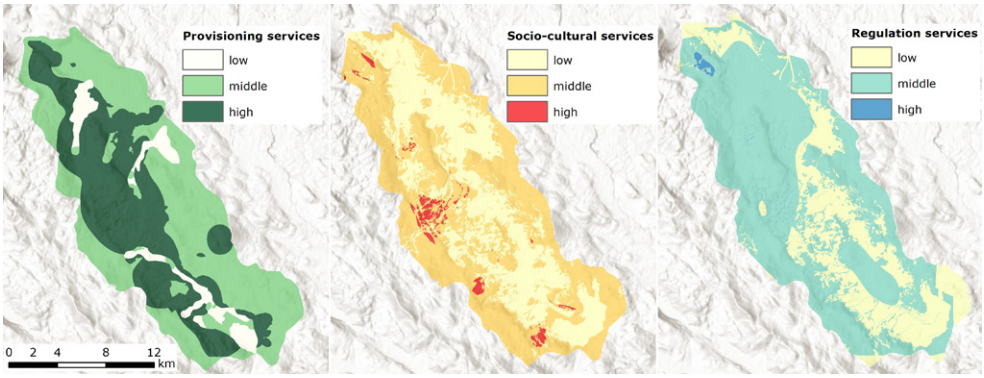


Fig. 7. Provisioning, Socio-cultural and Regulation services values in Ogulinsko-plašćanska Zavala.

T a b l e 2. Geodiversity valorization table.

Criteria	Criteria feature		Criteria feature categories	Points
Scientific value (100)	Lithology (25)	Carbonates	Presence	12.5
		Quaternary deposits	Presence	25
	Structure (25)	Fault density	0-0.3	8.3
			0.3-0.6	16.7
			0.6-1	25
	Landforms (25)	Dolines kernel density (5)	0-20	0.625
			20-40	1.25
			40-60	1.875
			60-80	2.5
			80-100	3.125
			100-120	3.75
			120-140	4.375
			140-160	5
		Spring caves (5)	Presence	5
		Caves (5)	Presence	5
		Springs Kernel density (5)	0-1	1.8
			1-2	3.4
			2-3.85	5
		Ponors (5)	Presence	5
	Morphometry (25)	Slope (8.3)	0-2	1.4
			2-5	2.78
			5-12	4.16
			12-32	5.54
			32-55	6.92
			>55	8.3
		Dissected relief (8.3)	0-5	1.66
			5-100	3.32
			100-300	4.98
			300-500	6.64
			500-800	8.3
		Hypsometry (8.3)	46-300	2.76
			300-600	5.54
			600-965	8.3

value class occupies 47.7%. As in the case of landscape services, the western mountainous part of the study area has higher geodiversity value. The highest values are recorded in the landscape subtype of *boundary karstic mount* (48% of total subtype area). The high values are also present in subtype of *fluviokarstic valley* (57% of total subtype area). Since whole study area was assessed by DEM as primary data source, landscape subtype *fluviokarstic valley* has a big percentage of high geodiversity value areas even though it is densely populated and consequently built. Spatial distribution and shape of geodiversity classes (Fig. 8)

is at the most similar to spatial distribution and shape of provisioning services classes (Fig. 7).

Through this kind of geodiversity and abiotic values assessment, it is possible to detect loss of these values due to the spread of settlements and agriculture. It is also possible to detect areas in need of a protection.

The primary structure of landscape was analyzed with the comparison of two indicators (landscape services and geodiversity), so it is possible to detect a role of abiotic part of environment in the determination of landscape types and values. But besides that, naturalness of vegetation in combination with geodiversity was very useful (bio)indicator for recreational and aesthetic value of socio-cultural landscape services. It was noted that areas with higher ratio of natural vegetation are located in the areas of highly dissected relief on limestones with high dolines density. Dolines are typical and most common karst features, so easy to measure and evaluate (Pahrenik, 2012). They also indicate areas with limitations for anthropogenic activities (like agriculture), mostly interesting in forestry, especially where limestone karst with bare surface or thin soils predominate. Dolines shape, depth and slopes inclination can also represent obstacle for activities both in rural and urban areas. On the other side, combined with vegetation, they can be used as indicator for more natural areas and landscapes with high level of aesthetic and recreational values due to the preserved nature. Dolines also indicate areas of high karst porosity where pollution can be quickly transferred to aquifers. In the case of spatial planning, these terrains are not suitable for activities with high risk potential that must be introduced with special care or completely avoided (waste disposal; use, storage and traffic of chemicals; sewage management, etc.).

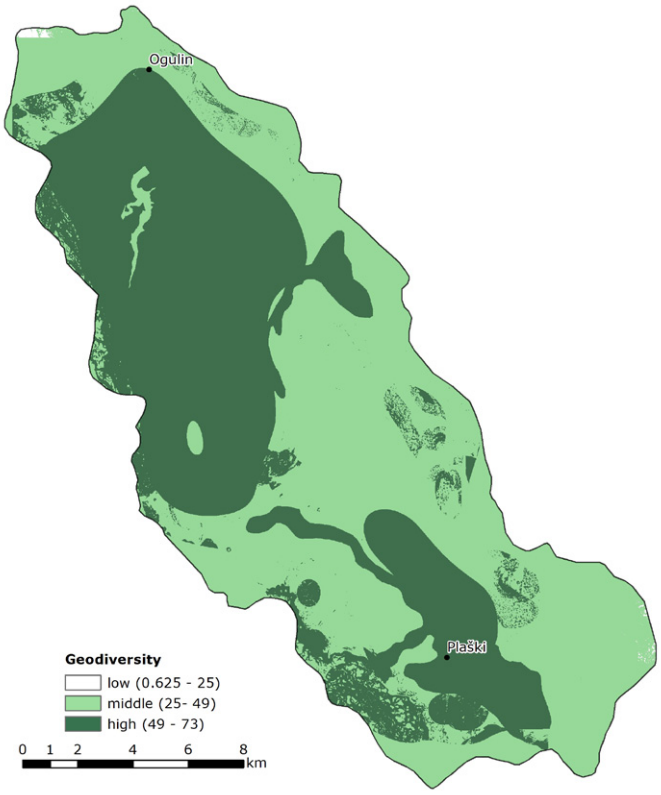


Fig. 8. Geodiversity value in Ogulinsko-plašćanska Zavala.

Conclusion

Since it is fundamental for all other landscape structures (biogene and anthropogenic), it is necessary that primary (abiotic) landscape structure analysis represents the first step in landscape typology and assessment. In this study, geodiversity and landscape services were analyzed due to its importance for primary and other landscape structures. The relative relief evaluation method was chosen for quantitative assessment of both elements. When the similar methodology is used for analysis, it makes it easier to examine how they affect one another and what kind of interdependence are they in. For this study, provisioning, sociocultural, and regulation landscape services were selected.

Delineation of landscape types based on morphogenetic relief types produced landscape units suitable for further analysis. Their present state was analyzed according to the anthropogenic impacts measured by habitat fragmentation. Low values of Landscape Fragmentation Index were recorded in areas with limited sources for human activities, especially agriculture as a traditional economy for this area. Landscape types show conformity with landscape services and geodiversity values distribution. The dissected relief units have significantly high values, while planated relief units have lower values of landscape services and geodiversity. Concerning the analyzed landscape services, the most important are provisioning services since the high value category occupies the largest area.

Because of the conformity of indicators (geodiversity and landscape), landscape types delineated based on primary landscape structure represent good spatial units for planning, environment protection and sustainable management. The primary structure can be considered as the "original structure", or the "zero state" of the landscape. It is the base for other structures (secondary and tertiary), and in some way conditions, directs, and limits them. In the process of spatial planning or environmental protection, it is efficient to use clearly defined spatial units of homogeneous features relevant to other components. Their identification requires the analysis of synergic inner (inside primary structure) and outer (with secondary or other structures) relationships of the relevant interacting landscape elements (substrate, georelief, water, soil, and potential vegetation) and their properties.

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