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Izvorni znanstveni članak

Some Basic Indices of Horizontal Landscape Structure of the Southern Part of Vis Island, Croatia

Sanja LOZIĆ, Ante ŠILJEG – Zadar[1], Kristina KRKLEC – Zagreb[2], Mladen JURIŠIĆ – Osijek[3], Silvija ŠILJEG – Zadar[1]

ABSTRACT. This research is based on application of landscape metrics in GIS environment for determination of the basic features of horizontal landscape structure of the southern part of Vis island, Croatia. Landscape elements (or geocomplex types) are determined based on their abiotic (lithological and geomorphological features) and biotic elements (natural vegetation cover). Anthropogenic impact during historical-geographic development (agriculturally cultivated land and urbanized areas) are also considered. By means of GIS tools, the three layers of abiotic and biotic parameters were overlayed (lithology, slope inclinations and types of vegetation cover) and 2556 basic units (geocomplexes) were obtained. Generalization of this basic units by criterion of similarity enabled extraction of 132 types of geocomplexes. This types represent generalised homogenous spatial units which were basis for all further analyses. In the next phase, landscape metrics has been applied in order to determine basic characteristics of horizontal landscape structure: total area of each geocomplex type (including minor elements or basic geocomplexes included in each type), frequency, average areas of individual geocomplexes within types and spatial variability index. The main goals of the research are precise determination of abiotic and biotic features of landscape elements, their spatial structure and interrelationships, classification, typology and determination of existence of specific dominant/stable and vulnerable/labile geocomplex types. The results should serve as methodological framework for evaluation of the current state and future development trends of landscape elements of the researched area. They can be applied in planning and preserving landscape of the southern part of Vis island, and other areas as well.

Keywords: southern part of Vis island, horizontal landscape structure, landscape metrics, geocomplexes, geocomplex types, typology.

[1] doc. dr. sc. Sanja Lozić, Department of Geography, University of Zadar, Trg kneza Višeslava 9, HR-23000 Zadar, Croatia,
Ante Šiljeg, prof., Department of Geography, University of Zadar, Franje Tuđmana 24i, HR-23000 Zadar, Croatia,
Silvija Šiljeg, prof., Department of Geography, University of Zadar, Trg kneza Višeslava 9, HR-23000 Zadar, Croatia,

[2] Kristina Krklec, B.Sc., Faculty of Agriculture, University of Zagreb, Svetošimunska 25, HR-10000 Zagreb, Croatia,

[3] prof. dr. sc. Mladen Jurišić, Faculty of Agriculture, University J. J. Strossmayer, Kralja Petra Svačića 1d, HR-31000 Osijek, Croatia, e-mail: mladen.jurisic@pfos.hr.

1. Introduction

Karst systems are difficult to recover anywhere in the world, hence they are extremely sensible and liable to various sorts of external disruptions which cause irreversible changes (Ford and Williams 2007). Considering its abiotic and biotic versatility and complexity, as a part of the Dinaric and Mediterranean karst, the carst environment of the Adriatic islands is notedly specific (Woodward 2009).

The area analyzed in this research includes the southern part of Vis island (20.86 km^2 of area, Fig. 1.), which was chosen due to the impressive biodiversity and geodiversity of its natural environment as well as the distribution of the cultural landscape formed from the historical and geographical development of the island.

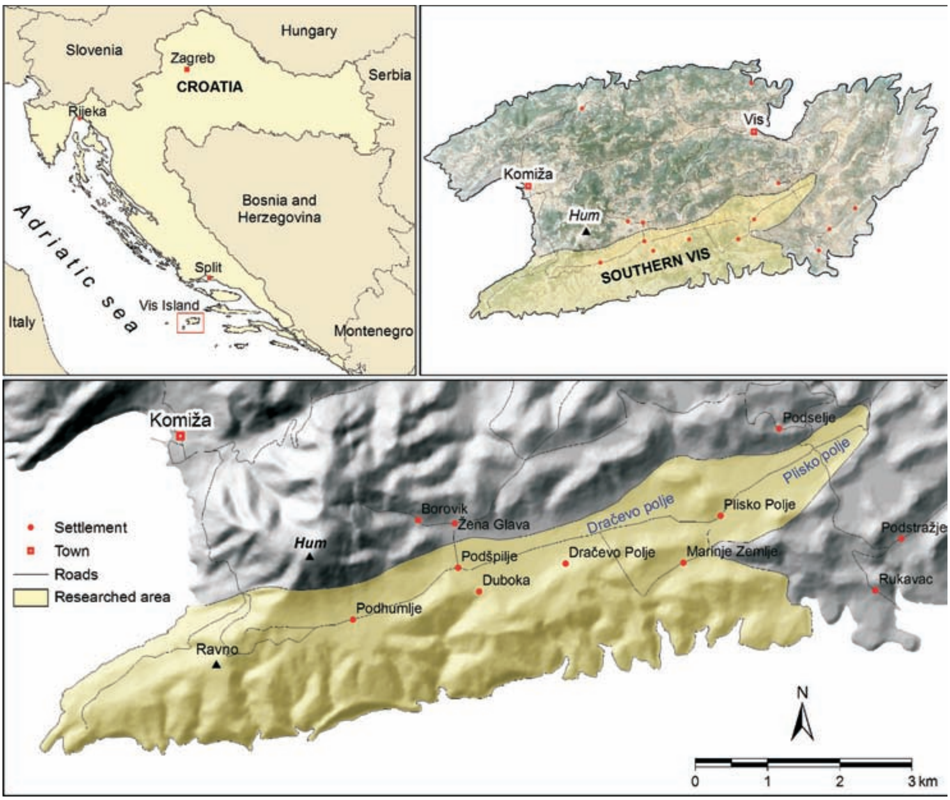

Fig. 1. *Geographical position of the researched area.*

The border of the area was determined based on its geomorphostructural qualities (dominant faults and geomorphological structures). The reasearched area could be divided into two morphostructurally and physically different parts: the north part, dominated by karst fields (which contain the agricultural production of Vis island, Croatia; Latitude: 43° 02′ 42″; Longitude: 16° 09′ 06″) and the south part, which represents a limestone landscape with numerous hills, but without any important agricultural areas and negligible level of population. The most notable element of this part of the island is the natural environment, with the exception of the various tourist objects which have been developed recently near the shore (mainly in the smaller bays). During the historical development, but also today, the socioeconomic growth of Vis island was negatively influenced by its geotraffical position. The most important consequences of such situation are the process of demographic ageing and depopulation, most notably during the 20^{th} century (Nejasmic and Misetic 2006). Those processes have also influenced the change in the natural and cultural environment of Vis island, meaning the intensification of succession of vegetation and degradation of dry stone walls.

A large number of works have been written on the topic of theoretical and practical application of quantitative methods in the landscape ecology, concepts of relation between biodiversity and geodiversity and natural and anthropogenous effects on the stability/instability of the geoecological system of the landscape, which is itself the main aim of this research. In their research, which partly deals with the various problems in karst environment of Dinarides (including the Adricatic coast and islands), Gams et al. (1993) have looked into the changes of karst landscapes which have been directly connencted to anthropogenic influences. In it, is has been stated that most of the negative anthropogenic actions have affected the natural vegetation (deforestation), soil (erosion) and water resouces, and that statement has been largely confirmed during the research on Vis island.

There is a large number of works dealing with indexes applicable in landscape ecology (Gustafson 1998; McGarigal and McComb 1999; Turner et al. 2001; Botequilha Leitao and Ahern 2002; Botequilha Leitao et al. 2006; Haines-Young and Chopping 1996; Johnson and Patil 2007), which point out the importance of high quality determination and understanding of the spatial structure of the landscape. Considering the universality of those indexes, their application is possible in the analysis of karst landscapes, aimed at more effective planning and managing. Biogeographical problems are also greatly important in landscape ecology. For example, Lavorel (1999) analyzed the ecological diversity and resilience of Mediterranean vegetation to negative external effects. The author points out a hypothesis that ecological diversity can greatly influence various aspects of the stability of an ecosystem. This hypothesis can also be applied in the case of Vis island due to its exceptional biological diversity; there have been 872 species of plants researched on the island so far (Domac 1955; Flora Croatica Database 2004). Hooper et al. (2005) explored the effects of biological diversity on the fuctions of ecosystem and point out that an important factor can be the existence of a larger number of species which affect the actual processes in a stabilizing manner (especially on the disturbance and variations of abiotic conditions). Authors also point out that there are still some ambiguities about the exact mechanisms and conditions under which the biodiversity affects characteristics of an ecosystem. The authors consider this problem worthwhile for future researches, especially the problem of the results of biotic factors on the changes in abiotic environment of karst systems of Vis island, as well as other karst environments of insular and coastal areas of Adriatic.

Culotta and Barbera (2010) used a multidisciplinary approach in the charting of the traditional cultural landscapes and also classify various types based on their primary abiotic natural factors (geomorphology, lithology, climate and topology). In their next phase, they classify elements of enviroment based on the combination of biotic factors and anthropogenic effects. In such approach various types of landscapes are defined as specific, recognisable and consistent combinations of numerous factors (geological features, geomorphological structures, soil, vegetation, area usage, morphology of parcels and settlements), which differ from one type of landscape to another.

Considering the integration of information from different scientific fields in the reasearch of landscape ecology a crucial step, the authors of this research have also employed a similar multidisciplinary approach in their recent researches (Lozic et al. 2009, 2010).

2. Materials and Methods

This research employs as many different scientific methods, techniques and procedures as required to achieve precise data measurements for high quality geographic analysis. Analysis of the researched area was based on the application of various GIS methods, especially the analysis of the digital relief model (Burrough 1986). Methods also include the aquisition of primary data (topographic maps of Vis island, scaled 1:25 000) as well as secondary (ARKOD, digital ortophoto of areas, geological maps etc.), field research, geographical spatial anaylsis, statistical methods and production of thematic maps).

A model of research (Fig. 2.) was established after the hypothesis and aims. The modeling process included the analysis of goals, conceptual, logical and physical model. The second step was to determine parameters which were divided into three main parameters (geology, slopes and vegetation) and two auxiliary (exposition and pedology) which had not been included in the model, but were used for interpretation.

By working out DMR, via methods integrated within the actual program, raster layers were aquired and then converted into vectors, which simplified the spatial analysis of the reasearched area. After that, various data on specific elements

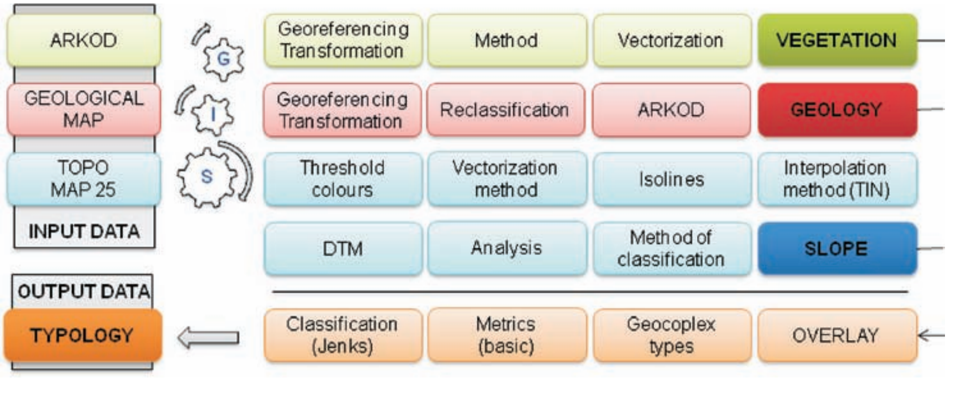

Fig. 2. *Methodological scheme.*

were inputted into atribute tables of layers. Layers containing gological information, slopes and vegetation were the basis of further analysis of landscape. Automatic overlapping of layers, their classification and arrangement allowed for the construction of simple units of landscape (types of geocomplexes), application of landscape metrics in spatial analysis of types of geocomplexes (Gustafson 1998; McGarigal and McComb 1999; Kurnatowska 1999; Turner et al. 2001; Botequilha Leitao and Ahern 2002; Botequilha Leitao et al. 2006; Haines-Young and Chopping 1996; Johnson and Patil 2007) and the classification based on "natural breaks" method (Jenks 1963, 1967). Using this classification method, one can determine natural breaks in series of data by merging classes of similar values, while minimizing square deviation of classes' arithmetic median. This is an iterative process which starts with an arbitrary gap in series of data by comparing variations within the classes, after which successive gaps are continuously compared until a minimal variance has been found.

All of the above mentioned methods have enabled a higher quality interpretation of data, typology of landscape and the formation of adequate conclusion.

3. Results

3.1. Geological Features

Vis island is a part of the "middle Dalmatian islands" tectonic unit (Borovic et al. 1977). This tectonic unit is a part of Adriatic carbonate platform which extends mainly under the Adriatic sea (Channel et al. 1979; Anderson and Jackson 1987; Battaglia et al. 2004; i Korbar 2009). Regional compression has created a tectonic frame for geomorphological processes and the development of karst terrain (Susnjar 1967; Grandic et al. 2004).

Using hydrogeological characteristics, Terzic (2004) notes several types of rocks:

(1) Neocom dolomites with low permeability and low fracture porosity. They include a relatively narrow zone surrounding watertight clastic rocks and magmatites of Komiza bay, which come into contact in a fault (Borovic et al. 1977).

(2) Carbonate rocks of medium permeability and fracture-dissolutional porostiy – calcitic dolomites, slab limestones of Cenomanian-Turonian age, limestones and dolomitic limestones of Berriasian age with marlstone and marl inlayers, and limestones of Barremian, Aptian and Albian (Borovic et al. 1977) and they compose the majority of the terrain. These rocks are partialy karstified and permeabile enough to allow a relatively fast infiltration of the precipitational water into underground.

(3) Carbonate rocks of high permeability and fracture-dissolutional porosity – white Senonian limestone, partly Turonian rudist limestone, and karstified Cenomanian-Turonian limestone (Borovic et al. 1977). Water containment in these cracked and karstified rocks is very limited and primarily depends on spatial distribution.

(4) Quaternary rocks of random characteristics, with particle and fracture porosity – eolian sand, terra rosa, and conglomerates.

Geological mapping of the researched area was carried out by Terzic (2004), and a GIS analysis was used for purposes of this research, calculating total surface of each lithological element. The area included in this research has been made up of limestone (9.51 km^2) and calcitic dolomites of late Cretaceous period (6.89 km^2), while the surface contains terra rossa with karstified elements (4.28 km^2), breccia and conglomerates (0.18 km^2) and sand (0.02 km^2) of Quaternary age (Fig. 3.). Quaternary sediments of karst fields, local depressions and fractures are the youngest layers on Vis islands. Faults on the southern part of the island (often presented as areas few meters wide) are mostly subparallel to the longer axis of the island.

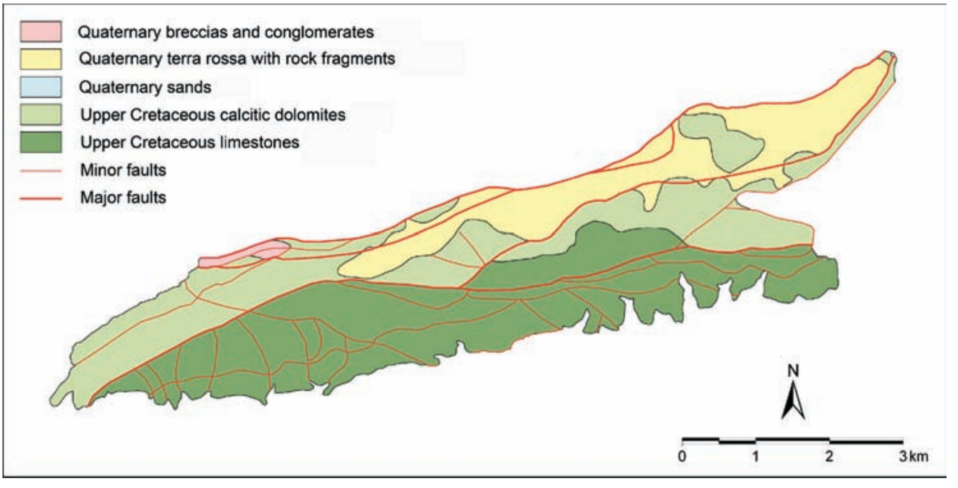

Fig. 3. *Spatial distribution of lithological units.*

The whole island has been dissected by smaller faults which often lie perpendicular to the direction of the main faults, which conditioned formation of numerous bays, karst fields, dry valleys, plateaus, slopes and ravines. Sediments have settled down in morphological depressions and hill slopes, which enabled development of vegetation and soil.

3.2. Geomorphological Features

The southern part of the island prominently features heights up to 200 m. Limestone exaltation of Hum (587 m) dominates the northwestern part of the researched area, while dolomites made basis for a number of negative terrain shapes (fields), mainly near faults. Hill slope near the shore has been dissected by ravines and dry valleys.

Slope gradients mostly reflect morphostructural features of the south Vis terrain (Fig. 4.). Five categories of slopes have been isolated. Most of them, 48.8% (10.191 km^2), are categorized as 12.01–32°, followed by 5.01–12° category which makes up 27.3% (5.698 km^2) and slopes of 2–5° category, which make up 13.4%

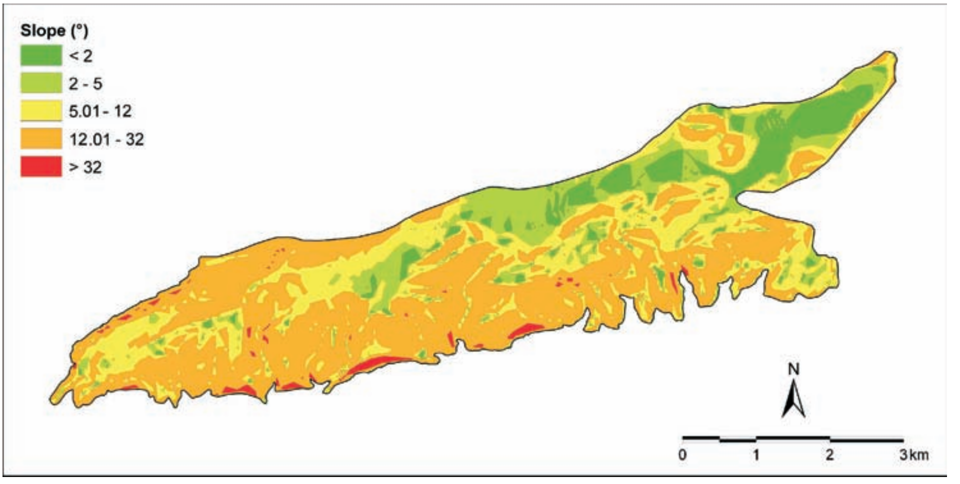

Fig. 4. *Slope gradients of the researched area.*

(2.785 km^2). Slopes in the category of <2° make up 9.1% (1.9 km^2) of the researched area, and the least represented categories are those >32° which make up 1.4% (0.286 km^2). Considering that the slopes above 12° gradient prominently feature heavy denudational processes, this also means that activation or intensification of rock creeping and collapsing.

Denudational processes characteristic to slopes greater than 12° are more intense on S, SE and SW expositions of the south part of Vis. The reason for that is a modification of Sun radiation, in terms of increasing temprerature amplitudes of air and ground, more instense mechanical degradation of rock formations, shorter vegetational periods and more direct exposition of slopes toward the rainy winds (scirocco).

Among external factors that influence the shape of the terrain the the most important are climatological and paleoclimatological factors. This mostly relates to pluvial-thermic features. For the most part, this area takes from 700 to 1000 mm of precipitation a year, but the distribution of precipitation is uneven during a year. Maximal precipitation occurs during the colder part of the year, which are usually short lasting rainfalls that affect the shape of the terrain by soil washing and forming ravines, which is especially evident on exposed and watertight parts of terrain.

Since Vis island is characterized by lack of water, or inexistence of permanent surface water streams, genesis of today's terrain structure is probably the outcome of the following palogeomorphological phases: (1) the phase of instensive karstification during the humid and warm period of late Pliocene, when the amount of precipitation was higher than potantial evaporation or transpiration, and (2) the phase of instensive fluvial-karstic shaping in Pleistocene, during increased sezonal thermic contrasts and changes in the hydrological regime (Van Straaten 1970; Weawer et al. 1998).

Fluvial-karstic processes were present in areas where karst processes dominate today, and the evidence of that is the existence of fluvial-karstic and erosional fossil structures: gullies, ravines, dry valleys, basins and fields. Breakdown of limestone and dolomite on steeper exposed slopes of concave terrain shapes, under the effect of notable thermic changes (freezing – defreezing), has resulted in shattered material, and, due to gravitational processes, significant amounts of colluvial and deluvial material have been sedimented at the bases. Amidst the climate change, i.e. the period of warmer and more humid conditions in Holocene, fluvial-karstic process was slowed down, while karstic process was intensified, the evidence of which is passivization of colluval sediments and vegetation growth on those sediments.

Slope bases, areas with lower slope gradients (bottoms of dry valleys and basins covered in slope correlatives and residium), areas mostly composed of dolomites, and areas that have preserved autochton vegetation are characterized by the existence of semicovered and covered karst. The formation of this type of karst has been greatly influenced by lower susceptibility of the base rock toward corrosion. Valleys and basins are mostly prominent in the middle of the island, where there is a significant amount of dolomite, while the coastal areas of dolomite are characterized by ravines (Fig. 7.). Coastal areas of the southern part of Vis island were shaped in late Pleistocene-Holocene sea level rise (Segota 1963).

3.3. Vegetational Features

Abiotic characteristics of its ecosystem and anthropogenic effects have presented the most significant effect on the composition and distribution of specific vegetational elements of south Vis during its history as much as today. The largest part of the researched area has been covered in homogenous or combined areals of specific climate-equivalent evergreen forests, macchia, garrigue and grass communities on rocky grounds. Once very important, the terraced agricultural areas are being overgrown with vegetation today, and, coupled with natural vegetation, they create a mosaic structure covering the majority of the researched area.

Forest communities of the southern part of Vis island can be classified as steno-Mediterranean vegetational zone of evergreen forests (Querco ilicis – Pinetum halepensis, Loisel 1971), eu-Mediterranean vegetational zone of evergreen forests (Myrto Quercetum ilicis) and hemi-Mediterranean vegetational zone of evergreen-deciduous forest (Ostryo-Quercetum ilicis, Trinajstic 1985., Raus et al. 1992).

Forests of Aleppo pine, in combination with holm oak (*Querco ilicis – Pinetum halepensis*, Loisel 1971) in areas with xerotherm climate cover, appear in more humid biotopes of microclimate. Forests and macchias of holm oak with myrtle (*Myrto – Quercetum ilicis*, Trinajstic 1985.) is the most thermophile community, developed in areas where ecological conditions are suitable for its growth, most notably the temperature changes during winter (median minimum of the coldest month being between 6 and 8°C) and adequate amount of precipitation (1000 mm a year on average, with maximum reached during the cold season of the year). Forests of holm oak and hornbeam (*Ostryo-Quercetum ilicis)* have developed in higher elevations, which also support colder and more humid conditions.

During the historical and geographical evolution, degradation of autochtonous forests was a result of pastures and excessive and irrational forest cutting, often employed on hills on which the soil and vegetation could not hold on for longer periods due to very long dry seasons and high temperatures. Another factor that should be added is the destructive outcome of wildfires, whether natural or caused by man, in order to gain new agricultural areas (Gams 1987, 1991). The exact level of degradation depended on the morphology of terrain, soil characteristics and availability. The most negatively affected areas were those located near settlements on the edges of fields, where the initial forests had almost been cut down to non-existent level. The process of forest degradation in recent history has been reduced to minimum, and a notable succession is evident in the whole area, a process similar to larger areas of Mediterranean (Debussche et al. 1996; Lavorel 1999). Macchia, the result of forest degradation, is in progression today. It has been preserved in more isolated areas, where it is also more dense and almost completely impassable. It is often interchanged with forests of holm oak, Aleppo pine and mosaicly intechanged with rocky pastures in areas which have been significantly degraded. Garrigue, being the next stage of degradation, is the result of anthropogenic effects (pastures, forest cutting) or progression from previous rocky pastures, on areas with shallow soil which are exposed to intense insolation and drought during summer. Garrigue often combines with other types of vegetation in most areas, e.g. in abandoned agricultural areas (mostly former vineyards) where it combines with further levels of degradation, mostly eu-Mediterranean and steno-Mediterranean rocky pastures. Today, large areas of garrigue are found in areas of transition into successive climate equivalents of holm oak macchia or they are being overgrown by Aleppo pine forests. Garrigue remains on the same degradational level in some areas due to unfavorable abiotic conditions of the biotope (very shallow and rocky soil, pronounced terrain dynamics).

Rocky and barren terrain dominate mostly on the southern coastal slopes which have been exposed to wind (scirocco). In such areas, sparse shrub and grass are present. Shrub-like vegetation appears sporadically, mostly in sheltered areas (ravines), where some of the soil managed to stay present, so those areas occasionaly look like garrigue. Forests of aleppo pine or smaller groups of other trees are present rarely and on individual scale.

Agricultural areas that are still in function are found mostly on fields and basins near settlements. They are most present at Dracevo, Plisko and other smaller fields and represent mosaics of various agricultural elements, most notably permanent vineyards. Abandoned agricultural areas are present almost everywhere. Those areas, which used to be vineyards and orchards, are found mostly on terraces created on the slopes of higher grade (Gams 1987, 1991; Gams et al. 1993; Sauro 1987).

Using the analysis by orthophotography of the researched area (ARKOD 2012) different vegetational areas have been isolated (natural, anthropogenic or combination of both). Ten different types of vegetational cover have been identified (including the category of cultivated agricultural and urbanized land), which appear homogenous or combined in various degrees (Fig. 5.): forest, forest-macchia combination (with higher degree of forest), forest-macchia combination (with higher degree of macchia), macchia, macchia-garrigue combination (higher degree of macchia), macchia-garrigue combination (higher degree of garrigue), garrigue,

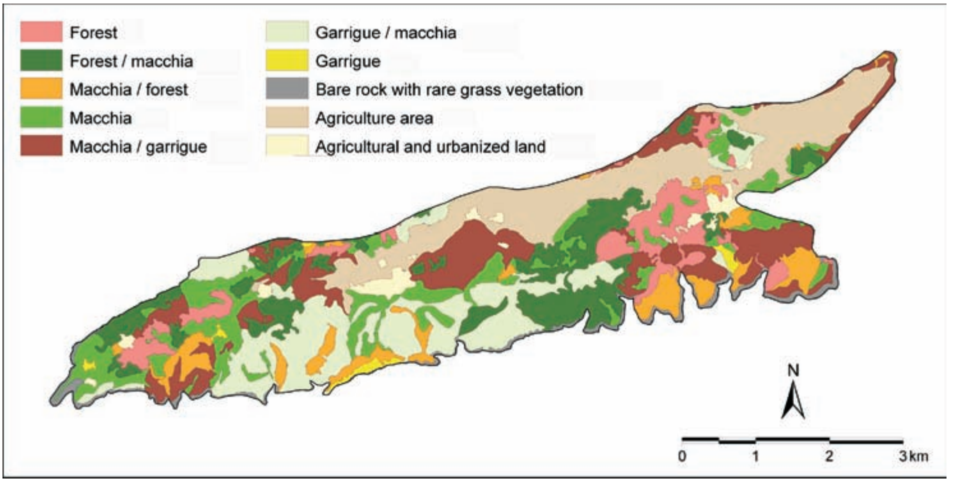

Fig. 5. *Vegetational map of southern Vis.*

rocky ground and grass vegetation, cultivated agricultural land on karst fields, cultivated land on slopes and urbanized land.

3.4. Basic Indicators of the Horizontal Structure of Landscape

Parameters of size and frequency of the appearance represent some of the basic indicators by which it is possible to define the internal structure of landscape and the relation between some smaller internal elements that make up a landscape (Turner 1989; Kurnatowska 1999; McGarigal and McComb 1999; Turner et al. 2001; Botequilha Leitao 2006). The researched area was analyzed based on four indicators of landscape metrics: 1. total area of geocomplex types, 2. frequency of geocomplex types, 3. average area of individual complexes within those types, and 4. index of spatial variabilty.

Results of the analysis are directly dependant on the scale of research, since the scale determines whether there will be less or more details concerning the typology of geocomplexes (Turner et al. 1993, 2001). This research aims to be as precise as it can be when determining input and output data, considering the size and geographical features of the researched area (of which a more detailed description is given in the “Methodology” section). By applying GIS method there were initially 2556 isolated individual geocomplex types, which were then generalized and, based on the criteria of similarity, brought down to 132 types (which are numerated and described in detail in the atribute table, although it is not presented in this paper due to its large size).

3.5. Total Area of Geocomplex Types

High total values of areas of geocomplex types indicate stability and domination of geoecosystem of a specific land. They also indicate a degree of resilience of geoecosystem towards changes brought about by negative external effects (whether natural or anthropogenic). Some studies have shown that the stability of geoecosystem increases with its size (Kurnatowska 1999; Armsworth and Roughgarden 2003). On the other hand, some authors indicate that the large area presents higher exposition of its population to changing natural and anthropogenic conditions, which results in changes in the geoecosystem as well. This causes changes in the size and features of populations, but also increases their vulnerability (Armsworth and Roughgarden 2003). Some authors indicate that it would be preferable if geoecosystem areas were large enough, because it increases the complexity of mosaic of communities in various phases of natural development. Because of that, natural processes happen in a diffusal manner (such as perturbation and recovery) and do not represent a large effect on the ecosystem as a whole (Turner et al. 1993). Considering the importance of these questions, one of the aims of this research was to determine what effects does the size of geocomplex types have on the determination of stability (domination)/instability (vulnerability) of types of geocomplexes and their comparison. The total area of all geocomplexes within the researched land is 20.8 km^2. Considering the large amount of numeric data, 132 types of geocomplexes were generalized on the basis of "natural breaks" method (Jenks 1963, 1967) in five different categories of various total areas (category 1 = the smallest total area; category 5 = the largest total area; Fig. 6.). The largest total area is present in geocomplexes numbered 33, 112 and 110 (category 5). Somewhat smaller, but still significant in size, are geocomplexes No. 1, 69, 73, 23, 18, 51 and 28 (category 4; Fig. 6.).

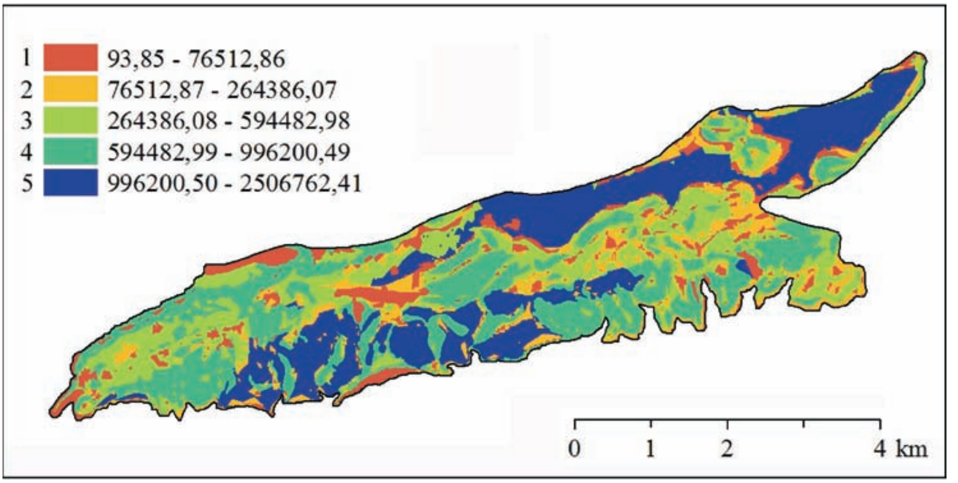

Fig. 6. *Spatial distribution of total area of geocomplex types (expressed in m^2).*

The smallest total area characterizes 94 types of geocomplexes (category 1, Fig. 6.). Although they make up for 71.2% of total number of geocomplex types, they amount to only 9.99% of total area of south Vis because of their small size. These types of geocomplexes cover smaller areas (93,85 – 76512,86 m^2), mostly the northern, middle and northeastern part of the researched land. They are often located near roads, settlements, edges of forests or southern slopes of hills, exposed to effects of abrasion and wind.

3.6. Frequency of Geocomplex Types

Frequencies of geocomplex types indicate the portion of a specific geocomplex type within the total researched land area and, together with total area, they represent an additional indicator of distribution, domination and stability. They are expressed as:

$$FTG = TG_1/A,\ TG_2/A,\ TG_3/A \ldots\ TG_{132}/A,$$

where:

$TG_{1,2,3 \cdots 132}$ = area of specific geocomplex types

A = total area of all geocomplexes in the researched land.

High values of frequencies, as well as total areas, are characteristics of large and dominant types of geocomplexes. Within the researched land, out of 132 geocomplex types, three of them have the highest values (category 5; numbers 33, 112, 110), while seven of them have somewhat lower values, but still make up a significant share of total area (category 4; 1, 69, 73, 23, 51, 28 i 71; Fig. 12). These ten types of complexes amount to 53.57% of the total land.

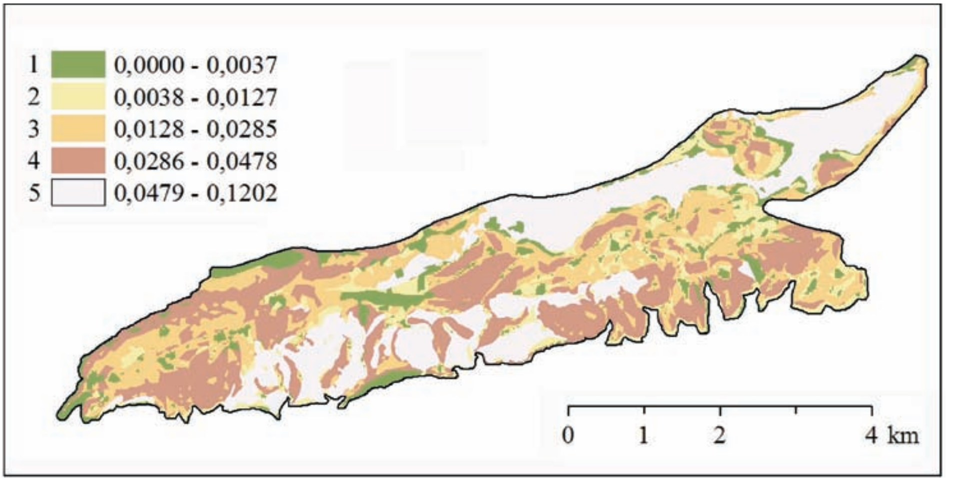

Fig. 7. *Spatial distribution of frequency categories of geocomplex types (expressed in %).*

Contrary, the lowest frequencies, valued closed to 0 (category 1, Fig. 7), were assigned to 92 geocomplex types, which indicates a very large number of spatially dispersed, unstable and delicate types of small areals (they make up only 9.24% of the researched land), threatened by natural or anthropogenic effects.

3.7. Average Areas of Individual Geocomplexes Within Their Types

Average size of a geocomplex was measured by summing up the areas of all individual geocomplexes of a specific type, after which the claculated value was divided by number of geocomplexes, according to this formula:

$$\overline{A}G = (AG_1 + AG_2 + AG_3 \ldots AG_n)/G_n \,,$$

where:

$\overline{A}G$ = average area of a geocomplex within its type

AG = area of an individual geocomplex

G_n = total number of geocomplexes within a specific type.

Higher values of average area of individual geocomplexes should be an additional indicator of stability of a certain type of geocomplex. The average size, calulated for all individual geocomplexes of the researched lad (n=2556), summs up to 8481,1 m^2, although there are considerable variations between different types of geocomplexes. Just like the parameters of total area, using "natural breaks" method, 132 types of geocomplexes were assigned in five different categories (1 = the lowest average value of geocomplex; 5 = the highest average value of geocomplex; Fig. 8.). Those types of geocomplexes that contain individual units of largest areas are numbered 33 (category 5) and 112 (category 4). As much as 93 types of geocomplexes contain the smallest elements (category 1). Considering that there are significant differences between the number and size of individual geocomplexes within those 132 types, an analysis of correlation between parameters of total and average (median) size was made, in order to find out how much the size of an individual complex relates to the total size of geocomplex types.

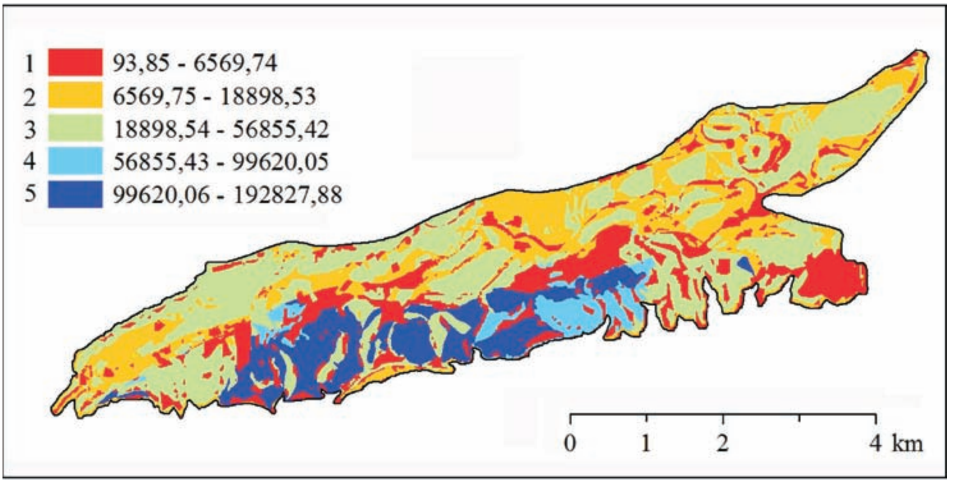

Fig. 8. *Spatial distribution of categories of average areas of individual geocomplexes within their types (expressed in m^2).*

The reasearch showed that the correlation is 0.52% (with 95% certainty, Fig. 9.), which means that in more than half of the cases certain types of large geocomplexes are comprised of large individual units (geocomplexes).

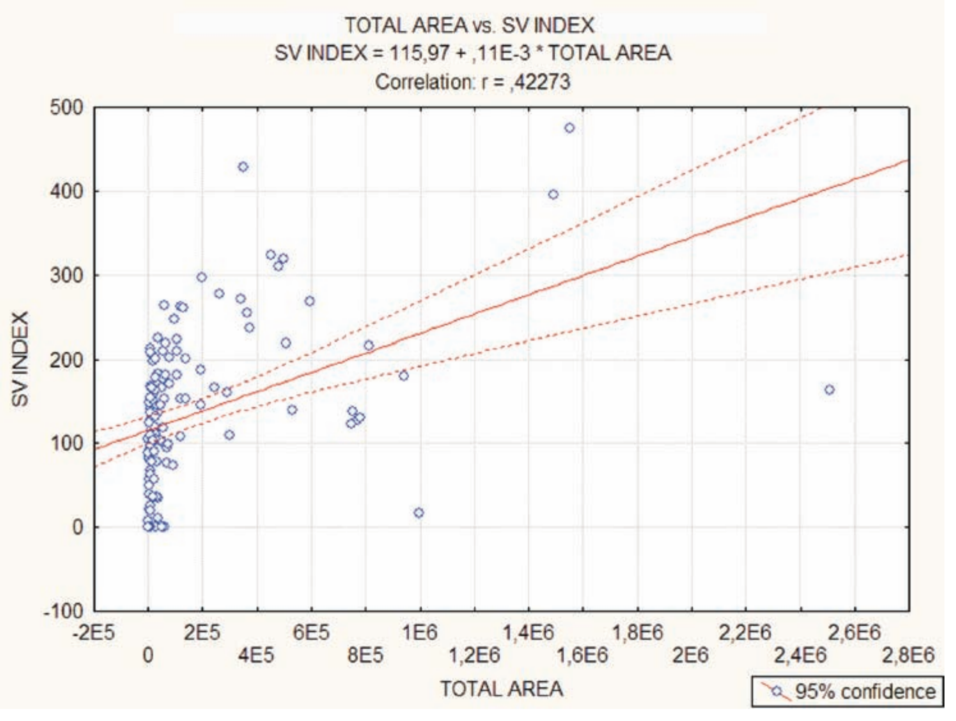

Fig. 9. *Relation of total area of geocomplexes and average area of individual geocomplexes within their types.*

In other cases, individual geocomplexes within their types show a significant heterogeny considering their size. It can be concluded that the present state of stability and trends of developments of geoecosystems within geocomplex types cannot be determined with a satisfactory level of precision at this stage, so further analyses of more precise indicators are required.

3.8. Spatial Variability Index

A more precise indicator of the internal horizontal structure of geocomplex types, their stability and domination is the spatial variability index. It represents a standard deviation as a portion of average value of the size of geomplex types, which eliminates the effect of median values on the standard deviation. This, in turn, allows the comparison of variability of different types of geocomplexes. In other words, comparing the stadard deviation of every geocomplex with the average values of geocomplexes within a specific type gives a specific numeric value which allows a more precise comparison of variability features of different geocomplex types. Similar to the average area indicator, this indicator includes all members of a geocmplex type. Spatial variability index is calculated by this formula:

$$V = (\sigma/\overline{A}G_{1,\ 2,\ 3 \cdots n}) \times 100\%,$$

where:

σ = standard deviation of all geocomplexes within a specific type

$\overline{A}G_{1,\ 2,\ 3 \cdots n}$ = average area of all geocomplexes within a specific type.

High values of spatial variability index indicate a wide range of sizes (areas) of geocomplexes within a specific type. They mostly show up in more dominant and/or flexible types of geocomplexes, which also feature a high degree of adaptation of various species to their environment (high ecological valency). The highest spatial variability indexes characterize geocomplex types No. 110, 30, 112, 18, 53, 75 i 78 (category 5, Fig. 10.), some of which are large areas (112, 110), but the rest contain variable sizes. A similar case is with geocomplex types with the lowest values. Those are 22 geocomplex types which are often, although not necessarily, the smallest in size. Correlation coefficient is 0,42 (Fig. 11.), which means that the size of geocomplex types is directly related to their variability (i.e. a wide range of individual geocomplex sizes) in 42.3% of cases. It should be noted that the largest types of geocomplexes show the most significant variability (types No. 110, 112, under category 5, and type No. 33, under category 3). These three types of geocomplexes amount to 26.6% of total land area, which makes their effect on the whole landscape quite significant.

Generally, low variability is an indicator of imbalance within the biotic or abiotic part of the ecosystem and is often characteristic of smaller, scarcer and unstable types of geocomplexes. Some authors point out low values of correlation coeffi-

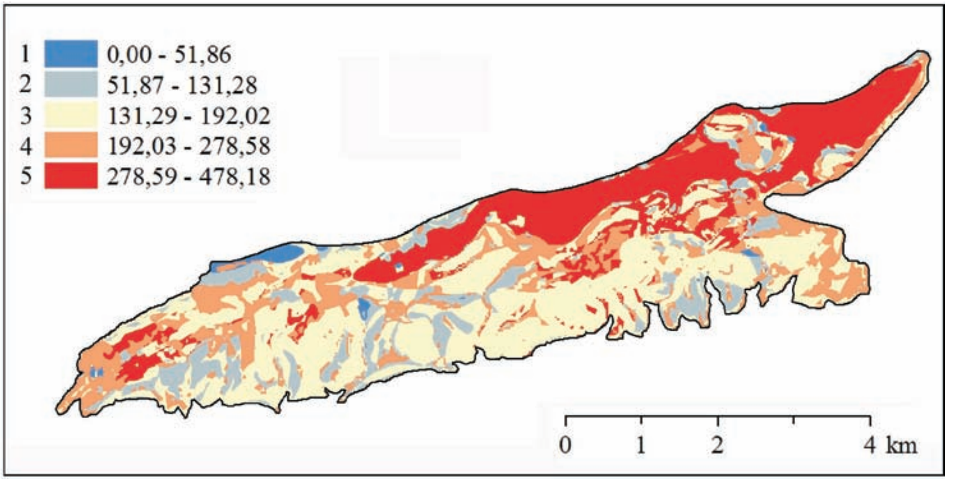

Fig. 10. *Spatial distribution of various categories of spatial variability index.*

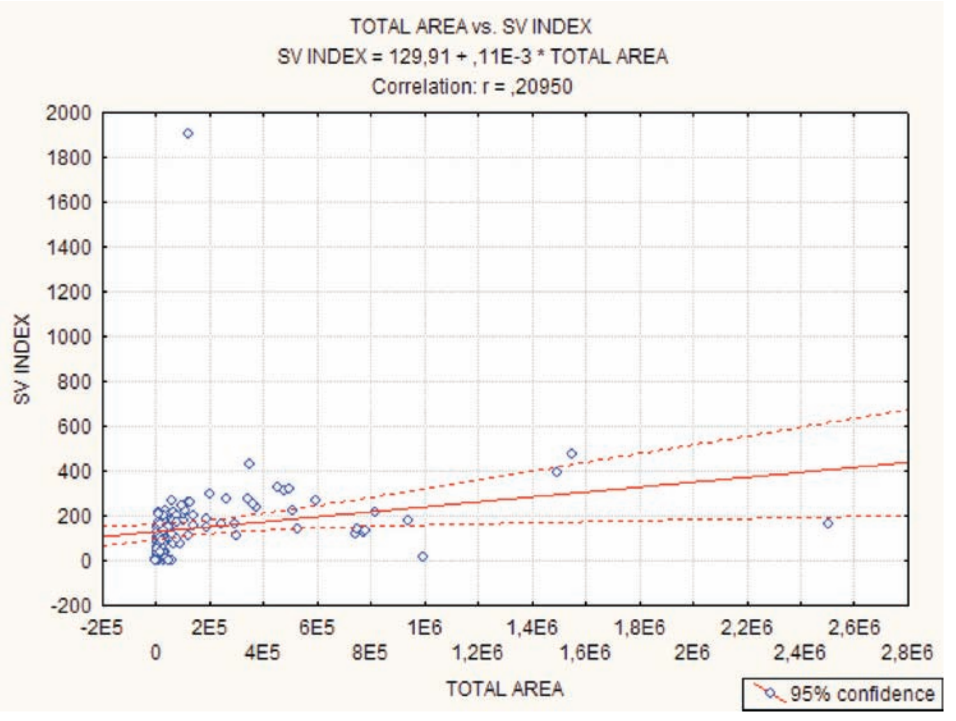

Fig. 11. *Relation between total area and spatial variability index.*

cient between indicators of the total area and those of spatial variability index (Kurnatowska 1999). In the case of southern Vis, this coefficient is considerably lower, due to the high level of anthropogenization of the landscape as a whole, specifically of some large and dominant geocomplex types (112 and 110). In cases of large and spacious geocomplex types, higer variability may be a result of an increased number of present species, more diverse abiotic conditions and anthropogenic effects. In the case of geocomplex types No. 110 and 112 high values of indexes (category 5) were most notably affected by anthropogenization of the landscape since they include karst fields with parcels of various cultures.

In the case of type No. 33 there is a completely different situation. Since it is situated on the southern coastal slope of high vertical relief dissection and inclination, combined with the absence of anthropogenic effect, variability of elements of the landscape is somewhat lower, i.e. this type shows higher internal homogeny of individual geocomplexes.

In the researched land area, geocomplex types with low variability are mostly located in the northwestern part or isolated in other parts (Fig. 10.). It can be assumed that there will be an increase in their isolation level and decrease in their size in near future, under the pressure of the nearby dominant and stable geocomplex types. This could lead to regression or even disappearance of certain species that have not succesfully adapted to their environment.

Because biomes that require specific conditions for development and growth and/or show exposition to intesive negative natural or anthropogenic effects are often present within geocomplex types with low variablity index values, it is of great importance to be aware of their spatial distribution while planning the development and protection of the environment.

3.9. Synthesis and Typology of the Landscape

A typology of elements of the landscape of southern Vis is possible via synthesis of various indicators, as well as insight into general features of its structure and the distribution of elements within its entirety. This process offers guidelines for choosing an area of interest for sustainable management and protection of the environment to potential users. A more precise analysis can then be employed at the level of specific indicators, determination of the level of stability of each geocomplex type, determination of the most stable and most dominant types, as well as those that are the most unstable and sensitive. Based on indicators of total area, frequency, average area and spatial variability index, 132 geocomplex types were classified into five groups (types) of different level of stability and dominance (Fig. 12.; 1 = the lowest level of stability; 5 = the highest level of stability and dominance), according to the following formula:

$$(UP + FTG + SVG + IPV)/4.$$

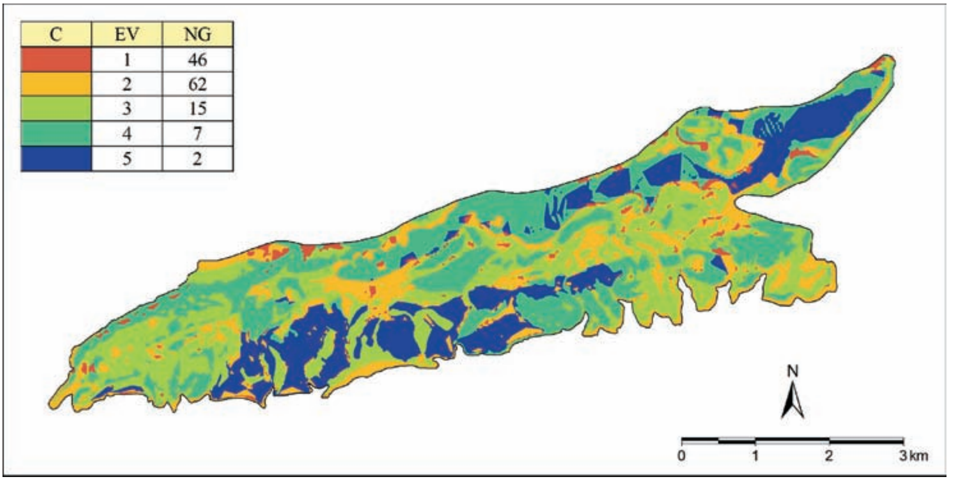

Fig. 12. *Typological map of indicators of horizontal structure.*

4. Discussion

Through several examples of geocomplex types, this paper has showed a method for determining elements of landscape and features of their structure on a general level. Types of geocomplexes have been shown that were additionally analyzed during field research: the most dominant and stable types of geocomplexes No. 33 (Fig. 13.), 112 and 110 (Fig. 14.), and the most unstable and delicate types (No. 11, 32, 39, 94, 95 i 96; Fig. 15, 16 i 17).

At the highest level of generalization, three types are the most dominant and stable: types No. 33 and 112 (category 5) and 110 (category 4; Fig. 12.).

A more detailed analysis of type No. 33 (Fig. 13.) at the level of each individual indicator shows that this type belongs to the highest category of all indicators (category 5) except those of spatial variability (category 3). This means that, apart from large size as a whole, its basic elements (geocomplexes) have large areas as well; domination is present at global and local level. Another factor that points out to this conclusion is its spatial variability index, which shows that there is no notable difference between the smallest and the largest elements within the type. In this type, vegetational communities of garrigue and barren land are dominant, a community well adapted to present conditions, while macchia occurs only sporadically, at places that are sheltered by their microclimate and relatively thicker layer of soil (e.g. bottoms of ravines). Due to relatively unfavorable physical and geographical conditions these areas are uninhabited, which in turn means that the anthropogenic effect was very low in its past or completely absent. Considerable adaptational abilites of the existing vegetation and the absence of negative anthropogenic effect are the main reasons for this landscape's preservation and balance. Changes within the ecosystem in the sense of progressive succession from barren land into garrigue, and from garrigue into macchia cannot be expected in any considerable measure due to its physical and geographical limitations.

Geocomplex type No. 33 (Fig. 13.) is mostly present on large land areas of southern slope of the island Vis, on which a relatively thin layer of soil developed due to limiting factors of its landscape (lithosol and occasionally terra rossa). Vertical dissection is relatively high, between 0 and 250 m. There are mostly convex types of slopes exposed to south and southeast, which emphasizes the effects of wind

Fig. 13. *Geocomplex type No. 33.*

(scirocco) and sea. Anthropogenic effects in the past, as well as today, have not been significant. Geocomplex types No. 110 and 112 feature a completely different physionomy and historical and geographical development from previous types, but also feature a high level of stability and domination (Fig. 14.). Type 112 encompasses higher parts of Dračevo and Plisko fields which include large anthropogenic soils with vineyards. A long-term anthropogenic effect can also be noticed in the natural landscape, partially reflecting in today's visual.

Agricultural elements dominate here (especially vineyards) and, due to intesive agricultural usage in the past, these areas have not been urbanized. Based on indicators of horizontal structure, as well as field research, a possible conclusion is that there is a blance between geocomponents and anthropogenic effects, which means that the land usage in the past had respected the natural environment. Of great importance is also the fact that there is a recent trend of abandoning the management of a significant portion of land, which have been left to natural processes of renewal and succession and that, in turn, additionally enhances the stability of this geocomplex.

Geocomplex type No. 110, which also features high values in all the individual indexes (category 4), is most prominent in lowest parts of Dracevo and Plisko fields. Vertial dissection is rather low in all of their parts, and the whole land area is located within 100 m above sea level. Anthropogenic soils are dominant here and, due to intensive usage of agricultural land in the past and regression of anthropogenic soils in recent times, this type of landscape resembles type 112. Anthropogenic effects are also reflected in the indicator of average size of geocomplex within their types. Namely, due to parcelation and size degradation, the

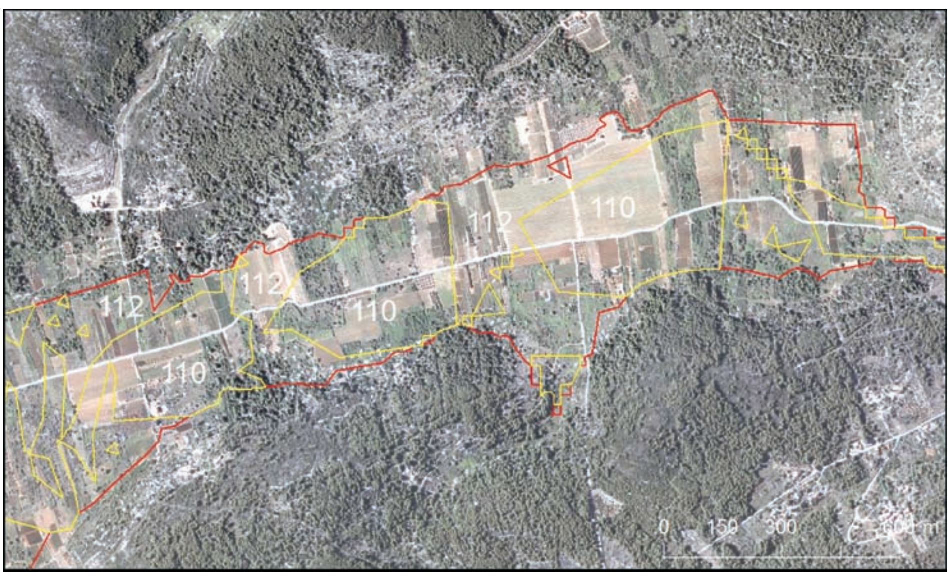

Fig. 14. *Geocomplex types No. 112 and 110 in the western part of Dračevo field. Type 112 is located on the higher peripheral parts of the field, and type No. 110 is located on lower parts near the bottom of the field. Anthropogenic soils with vineyards and other cultures dominate within both types.*

median value of these elements corresponds to categories 2 (type 110, exceptional size degradation and parcelation, Fig. 12. and 14.) and 3 (type 112, a lesser degree of size degradation and parcelation relative to type 110).

Fig. 15. *Geocomplex type No. 39, located near the shore of Stiniva bay. It was formed on limestone basis from late Cretacious period, covered in a thin layer of lithosol. Considering a high slope inclination (12–32°) and constant effects of wind and sea, the existing layer of soil is constantly exposed to denudation, which inhibits the development of any sort of denser vegetational cover.*

The majority of the most stable types of geocomplexes feature strong vertical relation between geocomponents, which indicates a high level of internal cohesion that significantly affects the resilience of an ecosystem towards negative external effects. Determining geocomplex types with low level of stability and high level of sensibility is of special importance, because, in doing so, a more effective way of protection of current and future geoecosystems is provided. When those geocomplexes go through an internal change (due to negative natural or anthropogenic effects in the environment), those processes are often irreversible, and even if regeneration occurs, it usually takes a long period of restoration to the current state. The reason for that is usually a significant loss of pedological and/or vegetational cover. In the researched land area there were 46 types indentified as the most unstable and endangered geocomplexes (category 1, Fig. 12.) which amunt to 246 910 m^2 or 1.18%. With the addition of 62 types of geocomplexes in category 2, the total land area amounts to 3 920 874,34 m^2 or 18.8%, which is a significant area. Some of the examples which were analyzed in more detail are shown on Fig. 15, 16 and 17.

Fig. 16. *Geocomplex types No. 11 and 32 (source: ARKOD 2012), in the areas where anthropogenic impact is pronounced.*

From the examples above it can be concluded that the main factors that influence the endangered types of geocomplexes are negative abiotic conditions in the biome (geomorphological and pedological as well as microclimate which affect denudation), or anthropogenic effects (forest cutting, instensive dry wall construction during the historical and geographical development, road construction, excessive agricultural usage etc.).

Fig. 17. *Geocomplex types No. 94, 95 and 96 (source: ARKOD 2012), in the areas where anthropogenic impact is pronounced, in combination with limitative influence of geomorphological features.*

Considering the aforementioned effects combined with the spatial dispersion and pressure from their neighboring, more stable and dominant types, it could be expected that these types of geocomplexes will undergo a change in their current vegetational communities. That is to say, the current species will be repressed by others, more adaptable to their environment. As a result, these gecomplex types could transform into more stable types, or, in worst case scenario, they could completely lose their vegetational cover and undergo a sped up process of denudation. Some authors (Reice 1994; Marston 2010) say that results of the aforementioned processes do not need to be strictly negative in some areas. Namely, active processes of erosion and denudation on the slopes, in some scenarios, can create positive conditions for the recolonization of species and increase in landscape's heterogeny. In the case of the researched land area, this type of scenario could be possible within geocomplexes located in the lower peripheral parts and the bottoms of ravines and derasional valleys, where a decrease in slope inclination and an increase in thickness of the soil layer has occured due to long-term accumulation. Another important factor is the temporal exposition of the landscape towards external effects and/or stability/instability of the geoecosystem. When the period of exposition towards negative effects is shorter than the period needed to regenerate, a geoecosystem can become unstable and susceptible to changes. If there is a balance between the period of exposition to negative effects and the period of regeneration, geoecosystem remains stable. Where the period of exposition towards negative effects is similiar to the period needed to regenerate, and when it affects a relatively large land area, a system can remain stable, but undergoes an increase in variablity (Hooper et al. 2005). All of these three scenarios are present in the environment of southern Vis island.

5. Conclusions

Structure of a landscape is exposed to continuous change, and interactions between various elements of landscape often end up ignored during the spatial planning and managing. A landscape represents an interaction between social and natural processes in an environment, so the planning and decision making in the context of sustainable development should consider such spatial relations of its elements (Turner 1989).

Disturbances in the natural balance have a strong effect on geoecosystems and landscape as a whole, which makes a significant number of ecological processes dependant on the actual dynamic of abiotic and biotic elements, including anthropogenic effect. The nature of such relations is of prime importance, and is often a result of periodical and episodical changes in landscape's features, which consequently affects biogeodiversity. Strategies of sustainable development of environment should take these changes of landscape elements dynamics into consideration (Sprugel 1991.; Turner et al. 1993).

This is especially important for karst environments, which are significantly more vulnerable to external effects because of their specific abiotic and biotic features. Evaluation of negative anthropogenic effects in such environments is a difficult task, which calls for development of multidisciplinary methods and techniques for a more efficient determination of changes in the environment (De Waele 2009).

A better understanding of features and relations of elements of horizontal structures of a landscape in the researched land area should allow a more efficient recognition of changes connected with landscape dynamic, natural or anthropogenic, which may cause geocomplex types to change from natural balance to imbalance, resulting in their endangerment. The primary task of this research is to set a certain methodology, aimed at the exact analysis of the horizontal structure of landscape and typology at a general level, which should improve the understanding of the current stage of landscape as well as allow us to predict future trends of development. Meanwhile, it is of great importance that the methodological approach proves flexible, i.e. adaptable to various levels of complexity of needs when used in practice. Knowing about dominant, stable and resilient types of geocomplexes and, even more so, knowing about those unstable, delicate and unresilient can be of great importance for the process of planning and forming decisions about sustainable management and development of the environment of southern Vis. This especially applies to the prevention of excessive usage of natural resources (devastation of vegetational cover, mines, etc.), inadequate planning of urbanized zones, industrial or transport infrastructure, inadeqaute agricultural usage and environmental pollution. In further reasearch, for the purpose of even more precise determination of geoecological features and conditions, it would be possible to broaden the methodological scheme by additional indicators (indexes) of horizontal but also vertical structure of landscape. Also, it would be useful to focus on the biogeographical aspect, i.e. to include the problem of internal functioning of the biotic elements of the ecosystem in future reasearch. The existence of a larger number of various species that react to disturbances in the environment in different manners can be a stabilizing factor in an ecosystem (Hooper et al. 2005), which makes the knowledge of vegetational and animal species and their relation towards abiotic and anthropogenic effects of great importance. By accepting the mentioned knowledge and methods, a process of planning could be significantly focused on the preservation of stability of larger and dominant types of geocomplexes within the landscape, and, even more importantly, towards enhancing the stability of smaller, scarser and more vulnerable types. One of the important factors in this process is the preservation and enhancement of biodiversity, i.e. a wide range of species of various functional features and reactions towards environmental changes, which would, together with knowledge of landscape structure, offer greater possiblities of keeping a balanced environment in the process of sustainable management.

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Neki osnovni pokazatelji horizontalnih struktura krajobraza južnog dijela otoka Visa, Hrvatska

SAŽETAK. Ovo istraživanje se temelji na primjeni krajobrazne metrike u GIS okruženju za određivanje osnovnih obilježja horizontalnih krajobraznih struktura južnog dijela otoka Visa, u Hrvatskoj. Pejzažni elementi (ili vrste geokompleksa) određene su na temelju njihovih abiotičkih (litološka i geomorfološka obilježja) i biotičkih elemenata (prirodni biljni pokrov). U obzir je uzet i antropogeni utjecaj tijekom povijesno-geografskog razvoja (poljoprivredna zemljišta i građevinska područja). Pomoću GIS alata, preklopljena su tri sloja abiotičkih i biotičkih parametara (litologija, nagibi padina i vrste biljnog pokrova) i dobiveno je 2556 osnovnih jedinica (geokompleksi). Generalizacijom ovih osnovnih jedinica po kriteriju sličnosti omogućeno je izdvajanje 132 vrsta geokompleksa. Ove vrste predstavljaju uopćene homogene prostorne jedinice koje su bile temelj za sve daljnje analize. U narednoj fazi, metrika je krajolika primijenjena kako bi se utvrdile osnovne karakteristike horizontalne strukture krajolika: ukupna površina svake vrste geokompleksa (uključujući i manje elemenate ili osnovne geokomplekse uključene u svaku vrstu), učestalost, prosječne površine pojedinih geokompleksa unutar vrste i indeks prostorne varijabilnosti. Glavni ciljevi istraživanja su precizno određivanje abiotičkih i biotičkih obilježja elemenata krajolika, njihova prostorna struktura i međusobni odnosi, klasifikacija, tipologija i utvrđivanje postojanja specifičnih dominantnih i nedominatnih vrsta geokompleksa. Rezultati bi trebali poslužiti kao metodološki okvir za procjenu trenutnog stanja i budućih razvojnih trendova krajobraznih elemenata istraživanog područja. Oni se mogu primijeniti u planiranju i očuvanju krajolika kako južnog dijela otoka Visa, tako i drugih područja također.

Ključne riječi: *južni dio otoka Visa, horizontalne strukture krajolika, metrika pejzaža, geokompleksi, vrste geokompleksa, tipologija.*

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