

VERTICAL LANDSCAPE STRUCTURE OF THE SOUTHERN PART OF VIS ISLAND, CROATIA

dr. Sanja Lozić*, Ante Šiljeg*, M.Sc., dr. Kristina Krklec**, Silvija Šiljeg*, M.Sc.

* Department of Geography, University of Zadar, Ulica Franje Tuđmana 24i, HR-23000 Zadar, Croatia. E-mail: slozic@unizd.hr; asiljeg@unizd.hr; stoplek@unizd.hr

** Department of Soil Science, Faculty of Agriculture, University of Zagreb, Svetošimunska cesta 25, HR-10000 Zagreb, Croatia. E-mail: kkrklec@agr.hr, kristina.krklec@yahoo.com

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Abstract

The paper presents some basic features of vertical landscape structure of the southern part of Vis Island, Croatia. Its aim is the determination of geocomplex types with a certain degree of stability and resistance to external influences, and confirmation or rejection of hypothesis that with the application of appropriate methods, the spatial relation between geocomplex types as well as the identification of specific dominant/stable and vulnerable/labile geocomplex types can be precisely determined. The results should serve as the basis for estimation of current status and future trends in the development of geocomplex types as well as the environmental changes.

Key words: vertical landscape structure, geocomplex types, geocomplexes, Adriatic, Vis Island

VERTIKALNA POKRAJINSKA STRUKTURA JUŽNEGA DELA OTOKA VIS, HRVAŠKA

Izvlaček

V prispevku je predstavljena vertikalna pokrajinska struktura južnega dela otoka Vis, Hrvaška. Njegov namen je določitev tipov geokompleksov z določeno stopnjo stabilnosti in odpornosti proti zunanjim vplivom. Avtorji poskušajo potrditi ali zavrnilo hipotezo, da je možno z uporabo ustreznih metod natančneje določiti prostorske odnose med tipi geokompleksov ter poiskati specifične dominantne/stabilne tipe geokompleksov. Rezultati se lahko uporabijo za ugotavljanje obstoječega statusa in prihodnjih trendov razvoja tipov geokompleksov in okoljskih sprememb.

Ključne besede: vertikalna struktura površja, tipi geokompleksov, geokompleksi, Jadran, Vis

I. INTRODUCTION

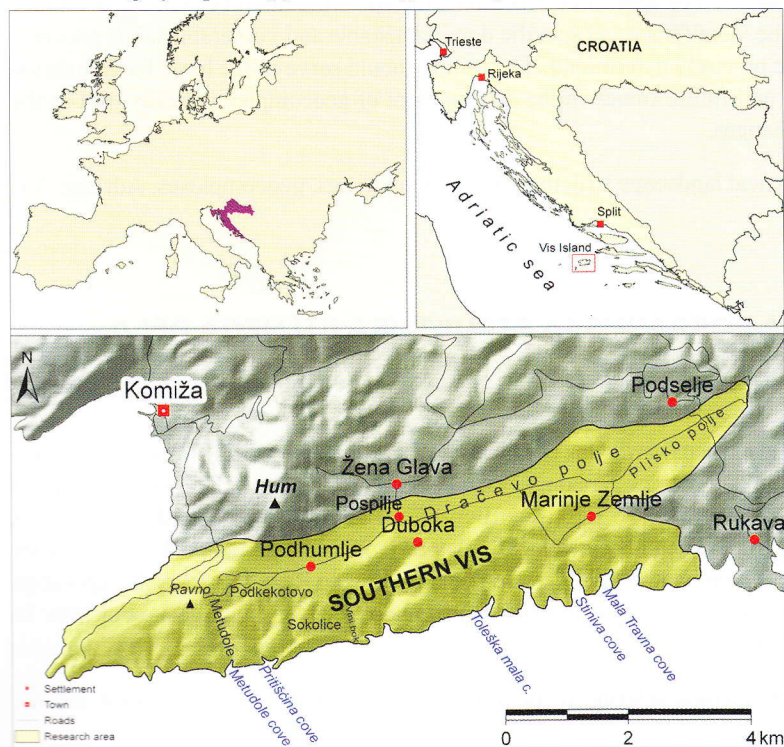
In landscape element investigations, hierarchical approaches to classification are often used (Zonneveld, 1989). By measuring and analysing, based on pre-selected criteria, it is possible to identify homogeneous landscape elements to a greater or lesser extent (depending on the scale). The criteria are represented by different quantitative or qualitative environmental variables (geological, geomorphological, climatological, pedological and vegetational features as well as the agricultural/urban/transportation features of land use and the historical-geographical characteristics of the study environment), that will correspond to the demanding geoinformatic criteria in the further analysis (Forman and Godron, 1986; Zonneveld, 1989; Culotta and Barbera, 2010).

Karst systems all over the world are extremely fragile and susceptible to all kinds of external shocks that cause irreversible changes (Ford and Williams, 2007). Considering internal abiotic and biotic differences, karst areas of the Adriatic islands present a mosaic of different landscapes, which is particularly expressed in the area of Vis Island.

Investigated area includes the southern part of Vis Island (20.86 km²) (Figure 1) and it has been selected because of its exceptional bio/geodiversity of the natural environment.

Figure 1: Geographical position of investigated area

Slika 1: Geografski položaj preučevanega območja



Studied area can be divided in two morphostructurally distinctive parts: northern part dominated by poljes, and southern part which represents limestone mountainous area without significant recent agricultural production and almost unpopulated.

During the historical development and even today, geographical isolation of Vis Island has affected its socio-economic development. Demographic aging and depopulation, especially in the 20th century (Nejašmić and Mišetić, 2006) influenced the changes in landscape of the island (intensifying the process of vegetational succession and dry stonewalls degradation).

In this research, vertical landscape structure of landscape units (geocomplex types) was analysed. Landscape types have been determined on the basis of their abiotic (lithological and geomorphological features) and biotic elements (natural and cultivated vegetation), taking in consideration the human impact during the previous time (field cultures on cultivated land and in urbanised areas).

By using GIS tools, overlapping of three parameter layers related to abiotic and biotic features (lithology, slope inclination and vegetation types), 2556 basic units (geocomplexes) have been obtained. By generalization according to the similarity principle of the component features, 132 geocomplex types have been determined (2556 individual geocomplexes classified into 132 types). These types represent generalized homogeneous spatial units which remained basis to all further analyses.

In the next stage of investigation, vertical structure features have been determined by the relation between geocomponents (lithological structure, vegetation types and slope inclination) and analysed for each geocomplex type separately.

The final goal of this research is the confirmation or rejection of the hypothesis that by the application of the above mentioned procedures, it is possible to precisely determine the spatial relations between the geocomplex types as well as the existence of specific dominant/stable and vulnerable/labile geocomplex types. The results should serve as the basis for estimation of the current status and future trends of geocomplex types development as well as environmental change in general, in positive or negative direction, which can be applied in future planning and protection of the investigated area.

2. RESEARCH METHODS

For the analysis of the vertical structure of the landscape, three parameters were used: lithology, vegetation and slope inclination. Each parameter consists of several classes (slope – 5 classes, vegetation – 10 and geology – 5), and each class consists of elements of different sizes, which are present at various locations within study area.

By the overlapping of the parameters, new synthetic elements (geocomplexes), containing common attributes of parameters, were obtained. Due to a large number of elements (2556 combinations within parameters) and in order to manipulate data easily, in new overlapped layer the following actions were done:

- connecting of elements with identical attributes (132 synthetic classes (geocomplex types) were obtained), and

- reclassification (numeric value/code was added to the attributes within overlapped layer, e.g., to the ‘Lower Cretaceous limestones/garrigue-macchia/12°–32°’ geocomplex type value/code 33 was added).

Since at the landscape level the vertical structure cannot be displayed spatially, horizontal structure (spatial distribution of geocomplex types) served as a basis for analysis. That enabled the comparison and determination of hierarchy of connectivity strength of complete landscape. Connectivity strength index was used to determine the correlation between pairs of vertical structure elements (e.g., lithology – vegetation, lithology – slope, slope – vegetation) and served as an indicator of stability/instability of the parameters relationship within geocomplexes.

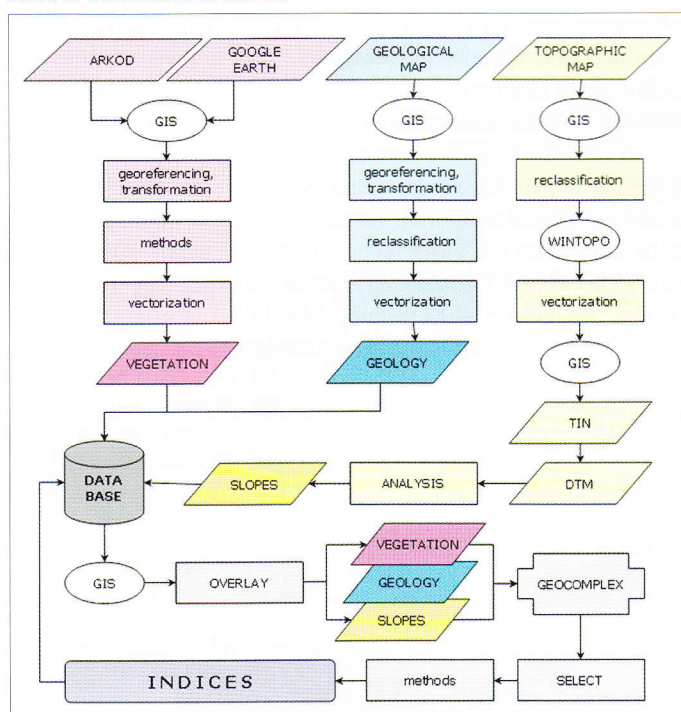
In most studies dealing with landscape, the vertical structure is ignored (and consequently, horizontal structure is preferred; Haines-Young and Chopping, 1996; Gustafson, 1998; McGarigal and McComb, 1999; Turner et al., 2001; Botequilha Leitão and Ahern, 2002; Botequilha Leitão et al., 2006; Johnson and Patil, 2007). Only few researches (Bezowska, 1986; Kurnatowska, 1998; Richling, 1992; Kozłowska et al., 2006) are dealing with this issue which is of extreme importance because it allows determination of connection between parameters in a specific location (e.g., impact of slope inclination on vegetation distribution).

Slope inclination parameter was derived from a digital elevation model (DEM), which was created using semi-automatic and manual vectorization of contour lines of topographic maps (scale 1 : 25,000). WinTopo (tool for raster vectorization; WinTopo, 2012; Taie et al., 2011; Dharmaraj, 2005) was used for vectorization and this process consisted of several steps: (1) colours sampling, (2) noise removal, (3) skeletisation – Zhang Suen algorithm was used, (4) detection of edges, (5) connection of vector lines and (6) converting contour lines to shapefile. Attribute values (altitude) were added to converted layer. To obtain continuous surface with a series of z-values, contour lines were interpolated using triangulation irregular network (TIN) method (Mitas and Mitasova, 1999; Webster and Oliver, 2001; Isenburg et al., 2006; Jordan, 2007). Vector terrain model was produced and converted to raster for easier calculation of slope, exposition and elevation. GIS software calculates the slope inclination by using 3 x 3-squares method and calculates the maximum rate of altitude change of the central cell to the neighbouring cells (Burrough and McDonnell, 1998). Spatial resolution of the raster model was determined by cartographical rule method (Hengl, 2006), and was 12.5 meters.

Vegetation was manually vectorized (based on analysis of ARKOD, 2012, orthophoto maps in scale 1 : 5,000). According to species composition, ten vegetation classes were determined. During process of vectorization special attention was paid to the topological relations between classes (in order to avoid problems when overlapping with other parameters).

Geology layer was vectorized using Basic geological map (scale 1 : 100,000; Borović et al., 1977). Analogue map was scanned, georeferenced (using projection transformation with 10 reference points), colours were reclassified and coordinates were transformed.

Figure 2: Methodological scheme
Slika 2: Metodološka shema



3. GEOLOGICAL FEATURES

Structurally, Vis Island represents an anticline. The anticline core is formed of clastic sediments with gypsum and anhydrite in association with pyroclasts, as well as spilites and the diabases of Upper Ladinian – Upper Norian age, while the limbs are formed of carbonate sediments (limestones and dolomites) of Cretaceous age (Borović et al., 1977).

According to the hydrogeological properties, Terzić (2004) distinguishes several basic groups of rocks:

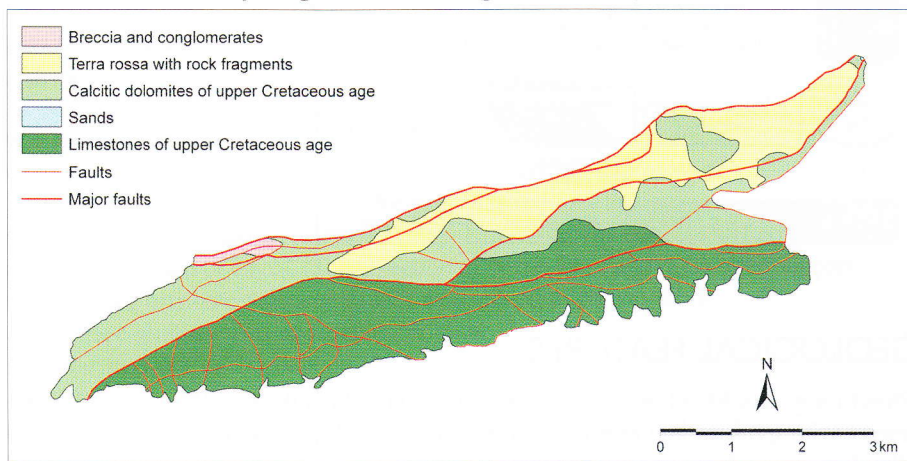
- Neocomian dolomites with low permeability and porosity covering relatively narrow zone around waterproof clastics and magmatites of Komiža Cove (the contact between these two units is tectonic) (Borović et al., 1977);
- carbonate rocks with medium permeability and cracking-dissolution porosity, calcareous dolomites, limestones of Cenomanian-Turonian age, limestones and dolomitic limestones of Berriasian age with marls and marly layers, and limestones of Aptian-Albian age which form the largest part of the area (Borović et al., 1977). They are partly karstified and porous enough to allow relatively rapid infiltration of rainwater into the ground;

- carbonate rocks of high permeability and cracking-dissolution porosity – white limestones of Senonian age, partly rudist limestones of Turonian age and karstified limestones of Cenomanian-Turonian age. Retention of the water in these fractured and karstified rocks is very limited, depending on the location;
- Quaternary rocks and sediments of alternating properties, interseed and cracking porosity – aeolian sands, terra rossa, colluvium breccias and conglomerates.

Geological mapping of the investigated area was conducted by Terzić (2004), but the authors made GIS analysis and calculated total areas (surfaces) for each lithological unit. Investigated area is formed of limestones (9.51 km², abbr. LUC) and calcitic dolomites of the Upper Cretaceous age (6.89 km², abbr. CD), while terra rossa with rock fragments (4.28 km², abbr. TRRF), breccias and conglomerates (0.18 km², abbr. BC) and sand (0.02 km², abbr. S) of the Quaternary age (Figure 3) can be found on the surface.

Figure 3: Geological map of the southern part of Vis Island (according to Terzić, 2004)

Slika 3: Geološka karta južnega dela otoka Vis (po Terzić, 2004)



4. GEOMORPHOLOGICAL FEATURES

Southern part of Vis island is dominated by altitudes up to 200 meters above sea level (Figure 4). Limestone mountain of Hum (587 m) dominates the northwestern part of the study area, while the negative relief forms (poljes) are formed on dolomites, mostly along the faults. The slope of southern coast is dissected by gullies and dry valleys.

Slope inclinations mostly reflect morphostructural relief features of the southern part of Vis Island. Five categories have been allocated. The largest part, 48.8% (10.191 km²), belongs to the category of 12 to 32 degrees, followed by inclinations of the category 5 to 12 degrees with 27.3% (5.698 km²), and inclinations of the category 2 to 5 degrees with the

representation of 13.4% (2.785 km²). Slopes with inclinations higher than 20 degrees cover 9.1% (1.9 km²) of the observed area, while the smallest part belongs to the inclinations higher than 32 degrees with 1.4% (0.286 km²). Denudational processes become very active on the slopes steeper than 12 degrees (including the activation or increase of erosional processes, attrition and mass wasting).

Denudational processes are characteristic for the slopes over 12 degrees and are more intensive on the slopes more exposed to the sunshine during the day/year (S, SE, SW

Figure 4: The hypsometric map of the study area

Slika 4: Hipsometrična karta preučevanega območja

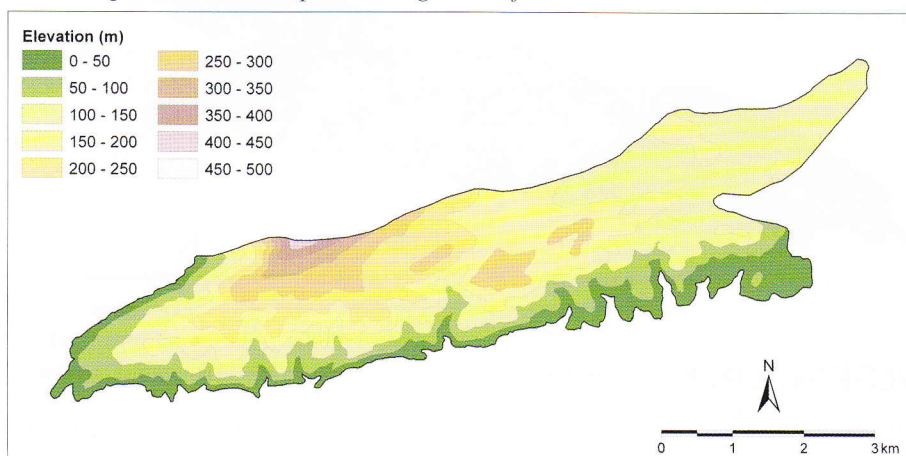
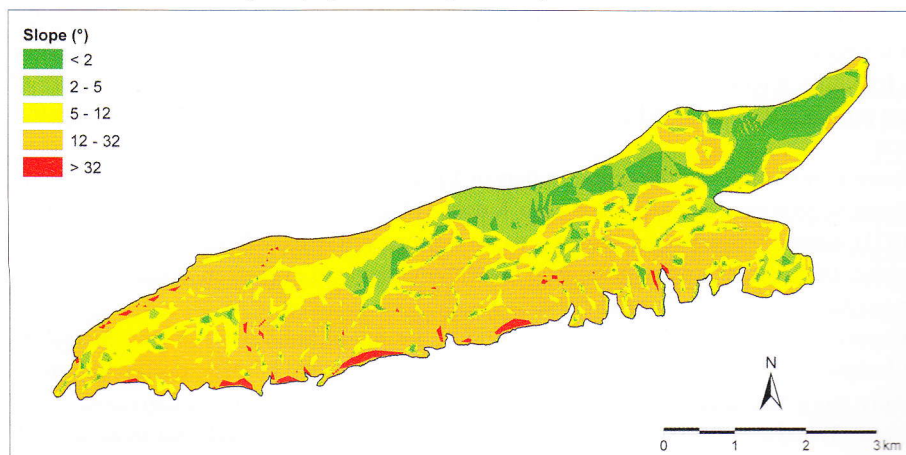


Figure 5: Slope inclination map of the study area

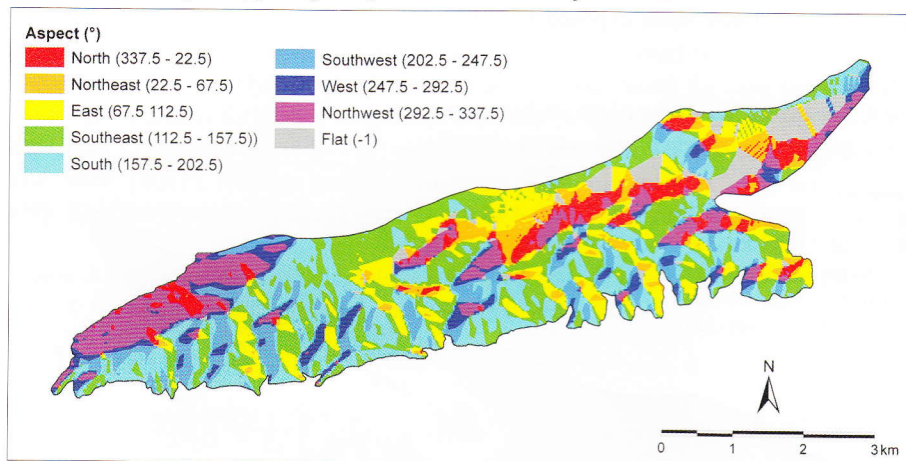
Slika 5: Karta naklonov površja preučevanega območja



expositions) because of the modification of solar radiation influences. That means increased temperature amplitudes which cause stronger mechanical weathering of the rock mass and soil drought (especially in summer) which have negative influence on vegetation cover.

Figure 6: Slope aspect of the study area

Slika 6: Karta ekspozicij površja na preučevanem območju



5. VEGETATION FEATURES

Abiotic features of ecosystem along with the anthropogenic influence in the past and nowadays, have influenced the composition and distribution of characteristic vegetation species and associations of the southern part of Vis Island. The largest part of the area (78.3%) is covered by homogeneous or mixed areals of associations of evergreen forests, macchia, garrigue and bare rock with sparse grass vegetation. Very significant terraced agricultural areas in the past are nowadays in different overgrowth stages, along with the natural vegetation cover and form a mosaic structure in the largest part of the investigated area. It mainly refers to *Quercus ilex* forests, which have been, due to the long history of human presence on Vis Island, significantly changed (reclamation, fires and other negative factors).

Forest communities of the southern part of Vis Island can be classified into stenomediterranean vegetational zone of evergreen forests (*Quercus ilicis-Pinetum halepensis*; Loisel, 1971), eumediterranean vegetational zone of evergreen forests (*Myrtle-Quercetum ilicis*; Trinajstić, 1985) and hemimediterranean vegetational zone of evergreen-deciduous forests (*Ostryo-Quercetum ilicis*; Trinajstić, 1985).

Aleppo pine forests with larger or smaller proportion of holm oak (*Quercus ilicis-Pinetum halepensis*; Loisel, 1971) within the area with xerothermal climate, occupy microclimatically more humid habitats. Forest and holm oak macchia with myrtle (*Myrto-Quercetum ilicis*; Trinajstić, 1985) is the most thermophilic association, developed in areas with

favourable ecological conditions, which primarily relate to the temperature range during winter (average minimum of the coldest month between 6 and 8 °C) and sufficient precipitation (average around 1000 mm per year, with a maximum in the colder part of the year). In higher areas, where the conditions are colder and more humid, forests of holm oak and hop hornbeam (*Ostrya-Quercetum ilicis*) are widespread.

During the historical-geographical development, degradation of autochthonous forests occurred because of the excessive and irrational logging and grazing, often in areas where, due to drought and temperature, significant soil retention and vegetation regrowth was not possible. Destructive fires (spontaneous or caused intentionally to obtain new areas for cultivation of crops; Gams, 1991) need to be added to above mentioned factors. The degradation degree depended on the terrain morphology, soil characteristics and accessibility. The most degraded areas were located around the settlements on the upper parts of slopes surrounding poljes, where the original forests have almost completely disappeared due to logging and overexploitation. Nowadays, forest degradation is reduced to a minimum.

Macchia formed by forest degradation remained preserved (dense and almost completely impassable) in more isolated areas, often alternating with the holm oak or Aleppo pine forests.

Garrigue (further degradation stage) was dominantly created under influence of anthropogenic impact (grazing, logging and fires) or by natural progression of the former rocky pastures, in the areas with shallow soil and exposed to strong insolation and drought in summer. On the largest part of the area, garrigue is in association with other vegetation types, e.g., on abandoned agricultural land (mostly former vineyards) and is in association with the further degradation stage, which includes eumediterranean, stenomediterranean and rocky pastures. Today, large garrigue areas are mixed with holm oak macchia, or overgrown by Aleppo pine forests. In some areas, garrigue remains in the same degradation stage due to the unfavourable abiotic habitat conditions (e.g., very shallow and stony soil).

Rocky and bare ground areas prevail on the southern coastal slopes exposed to the wind influence (sirocco). On such surfaces, scarce shrub and grass vegetation are mostly present. Shrub vegetation occurs sporadically, mainly in less exposed areas (gullies), where the small part of soil remained, so these areas occasionally look like garrigue. Rarely and individually, Aleppo pine trees or smaller groups of other tree species occur.

Still active agricultural areas are mostly in poljes and valleys near the settlements. The most extensive are in the Dračevo and Plisko polje and other smaller poljes, representing the mosaics of different crops, mostly vineyards. Abandoned agricultural lands are present almost everywhere. These areas, once under vineyards and orchards, are found mainly on terraces built on steeper slopes in whole investigated area.

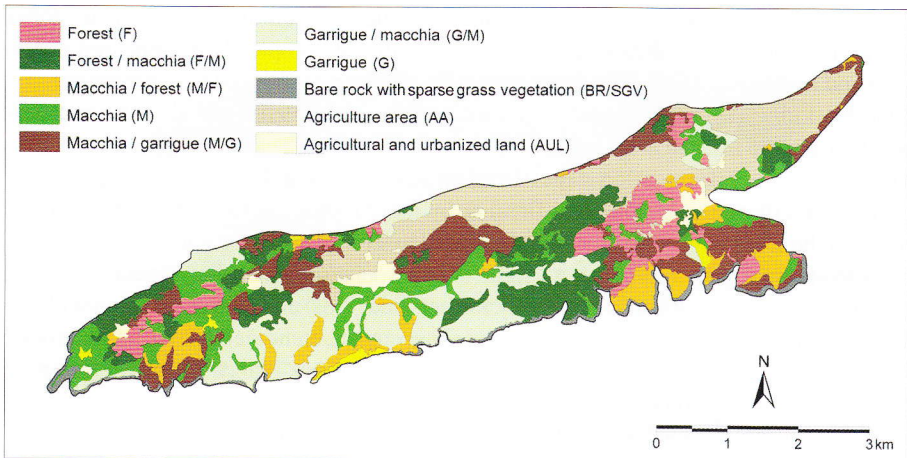
By analysing satellite images of the study area (ARKOD, 2012), different vegetation areas (natural or anthropologically modified) have been allocated. Ten types of vegetation cover have been established (including the cultivated agricultural and agricultural/urbanized land categories) which occur homogeneous or in different interrelated combinations (Figure 7):

- forest (abbr. F);
- combination of forest and macchia (as in Figure 7 and elsewhere in text higher proportion of forest, abbr. F/M);

- combination of macchia and forest (higher proportion of macchia, abbr. M/F);
- macchia (abbr. M);
- combination of macchia and garrigue (higher proportion of macchia, abbr. M/G);
- combination of garrigue and macchia (higher proportion of garrigue, abbr. G/M);
- garrigue (abbr. G);
- bare rock and sparse grass vegetation (abbr. BR/SGV);
- cultivated agricultural land in poljes (abbr. AA);
- cultivated areas on the slopes and urbanized land (abbr. AUL).

Figure 7: Vegetation map of the southern part of Vis Island

Slika 7: Vegetacijska karta južnega dela otoka Vis



6. VERTICAL LANDSCAPE STRUCTURE

Vertical landscape structure analysis represents a method by which it is possible to determine relations between geocomponents contained in each geocomplex type (Kurnatowska, 1998) and can be expressed as connectivity strength index (W). This index is based on the relation between real surfaces with specific combinations of geocomponent features and theoretical, maximum surface on which these combinations can exist. Geocomponents analysed in this research include lithological characteristics, slope inclination and vegetation characteristics.

Determination of interaction features between geocomponents within each geocomplex type (vertical structure) is essential for understanding of dominance and stability within geoecosystem. Some combinations of geocomponents appear more frequently and cover larger areas (indicating a greater stability and resistance of geoecosystem to external influences), while some appear rarely or not appear at all (low stability degree and high sensitivity; Richling, 1992; Kurnatowska, 1998). Apart from frequencies, there are some other factors that can be used as indicators of stability/instability. These factors are mostly of

There is no relationship between the following geocomponent pairs: F (forest)-S (Quaternary sands), FM (forest and macchia)-S, MF (macchia and forest)-S, M (macchia)-S, GM (garrigue and macchia)-S, G (garrigue)-S, BR/SGV (bare rock and sparse rock vegetation)-S, AA (agricultural areas in poljes)-S, G-TRRF (terra rossa with rock fragments), BR/SGV-TRRF, MF-BC (breccias and conglomerates), G-BC, BR/SGV-BC, AA-BC, AUL (cultivated areas on slopes and urbanized land)-BC and M/BC. Very low relationship ($W = 0.001-0.2$) characterises following geocomponent pairs: FM-TRRF, AA-LUC, MF-TRRF, F-TRRF, F-BC, GM-TRRF, M-TRRF, MG-TRRF, AA-CD, GM-CD, MF-CD and AUL-TRRF (Figure 8). As we mentioned above, some combinations of geocomponents appear rarely or not appear at all, indicating basic inadequacy between certain kinds of vegetation cover and lithology, and thus, low stability degree and high sensitivity.

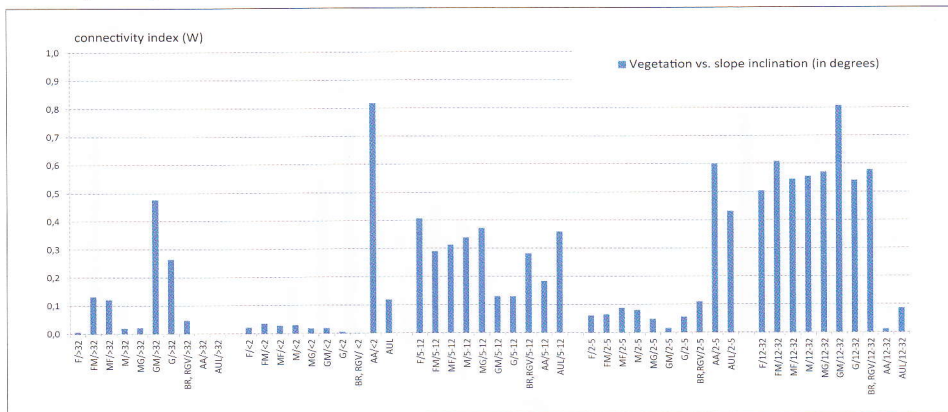
6.2. The relationship between vegetation cover and slope inclination

Some studies (e.g., Kurnatowska, 1998; Kozłowska et al., 2006) have shown clear links between vegetation cover and the type of morphodynamic surface (expressed through variations in the geomorphology of slopes). The majority of plant communities occur on a certain relief type and provide the natural boundaries for vegetation landscape units. Also, the different types of morphodynamic units are characterized by particular types of vegetation (Kozłowska et al., 2006).

High and very high relationship (W) is determined for following geocomponents pairs: AA (agricultural areas in poljes)/ $<2^\circ$, GM (garrigue and macchia)/ $12-32^\circ$, FM (forest and macchia)/ $12-32^\circ$ and AA/ $2-5^\circ$ (Figure 9). Pair AA/ $<2^\circ$ includes geocomplex type No. 64; pair GM/ $12-32^\circ$ types No. 33, 78 and 127; pair FM/ $12-32^\circ$ types No. 1, 51 and 99; and pair AA/ $2-5^\circ$ types No. 16, 62 and 112 (Figure 9).

Figure 9: The strength of relationship (based on connectivity index) between vegetation cover and slope inclination

Slika 9: Stopnja povezanosti (na osnovi indeksa povezanosti) med rastlinskim pokrovom in naklonom pobočij



There is no relationship between following geocomponent pairs: AA/>32° and AUL/>32°. Very low connection ($W=0.001-0.2$) is determined between following geocomponent pairs: BR-SGV (bare rock and sparse grass vegetation)/<2°, G (garrigue)/<2°, F (forest)/>32°, AA /12–32°, MG (macchia and garrigue)/<2°, GM/2–5°, M (macchia)/>32°, MG/>32°, F/<2°, GM/<2°, M/<2°, MF (macchia and forest)/<2°, FM /<2°, MG/2–5°, BR-SGV/>32°, G/2–5°, F/2–5°, FM/2–5°, M/2–5°, AUL/12–32°, MF/2–5°, BR-SGV/2–5°, AUL/<2°, MF/>32°, G/5–12°, GM/5–12°, FM/>32° and AA/5–12° (Figure 9).

Based on above mentioned facts, we can conclude that certain types of vegetation cover appear more frequently on slopes of certain inclination. Example are crops that always occur on slopes with inclinations <2° or 2–5°. This is logical, because due to denudation processes, thicker soil layers could only be developed on slopes with low inclination. On steeper slopes (12–32°), due to more pronounced denudation processes, soil layer is thinner and consequently, only combinations of macchia and garrigue or forest and macchia appear.

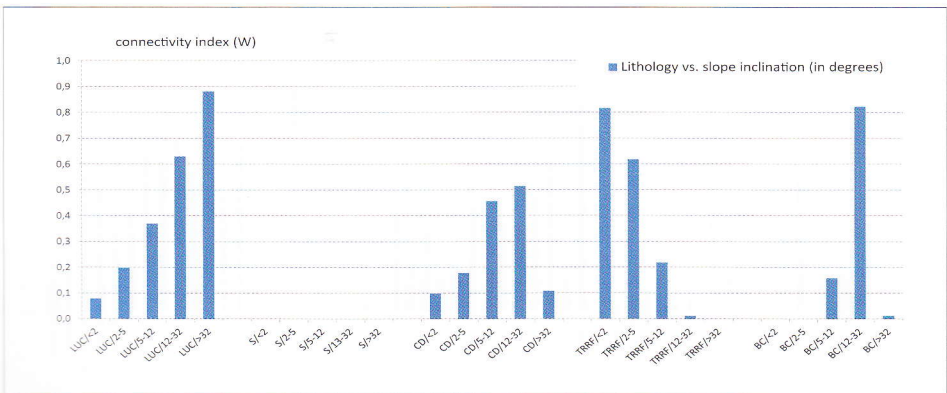
6.3. The relationship between lithology and slope inclination

The nature and structural characteristics of the bedrock determine the hillslope morphology (Carson and Kirkby, 1972; Young, 1971; Parsons, 1988; Khanchoul and Altschul, 2008) and, consequently, characteristics of vegetation cover.

High and very high relationship (W) is determined for following geocomponent pairs (Figure 10): LUC (Upper Cretaceous limestones)/>32°, BC (breccias and conglomerates)/12–32°, TRRF (terra rossa with rock fragments)/<2°, LUC/12–32° and TRRF/2–5° (Figure 10). Pair LUC/>32° includes geocomplex types No. 4, 10, 22, 27, 32, 37, 42 and 47; pair BC/12–32° includes types No. 92, 93, 96 and 97; and pair TRRF/<2° includes types No. 102, 106, 107, 110, 114, 118, 122 and 126 (Figure 10).

Figure 10: The strength of relationship (based on connectivity index) between lithology and slope inclination

Slika 10: Stopnja povezanosti (na osnovi indeksa povezanosti) med kamninsko zgradbo in naklonom pobočij



Minimal connection (0.0001–0.0003) is determined for following geocomponent pairs: S (Quaternary sands)/ $<2^\circ$, S/2– 5° and S/5– 12° ; very low (0.01–0.2) for geocomponent pairs TRRF/12– 32° , BC/ $>32^\circ$, LUC/ $<2^\circ$, CD/ $<2^\circ$, CD/ $>32^\circ$, BC/5– 12° and CD/5– 12° . There is no connection between pairs S/12– 32° , S/ $>32^\circ$, TRRF/ $>32^\circ$, BC/ $<2^\circ$ and BC/2– 5° (Figure 10).

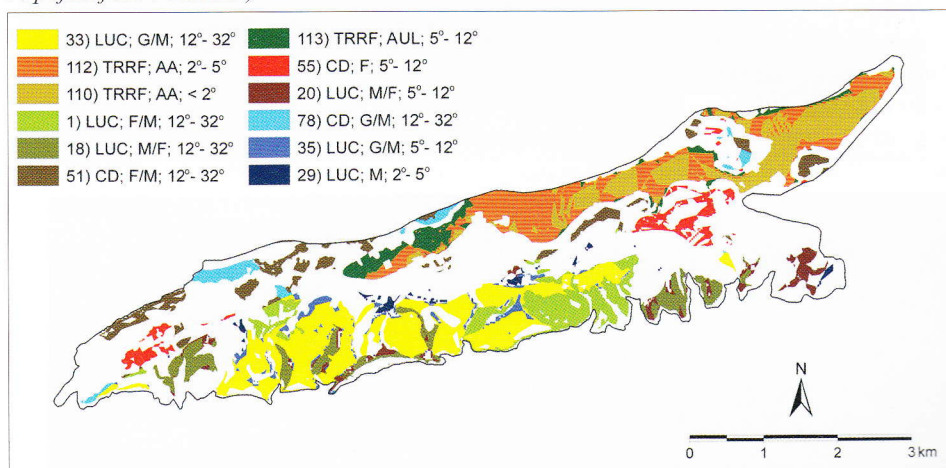
7. CONCLUSION

A detailed insight into the interrelation between the vertical landscape structure and the vertical connection of geocomponents of geocomplex types was provided by the comparative analysis and synthesis of vertical landscape structure parameters of the southern part of Vis Island. This approach allowed determination of the stability degree of each geocomplex type and the determination of the most stable and most dominant types, as well as the most unstable and the most sensitive ones.

Based on the strength of vertical connection of geocomponents, gained from connectivity index, twelve most stable and most dominant types (Figure 11) from all of 132 geocomplex types have been allocated.

Figure 11: Most stable and dominant geocomplex types in the investigated area (abbreviations are explained in text)

Slika 11: Najstabilniji in dominantni tipi geokompleksov na preučevanem območju (okrajšave so pojasnjene v besedilu)



Some examples that have been further analysed during field investigations are shown here: geocomplex types No. 33 (Figures 11, 12), 112 (Figures 11, 12) and 110 (Figure 11).

The largest, most stable and most dominant geocomplex type (No. 33) prevails on large areas of the southern coastal slope. Considering the environmental factors, thin layer of soil has been developed in these areas. Elevation range is relatively large, ranging from 0 to 250 m, mostly on convex slope parts oriented towards south and southeast and, therefore,

occasionally under significant wind (sirocco) and sea influence. There is a prevalence of garrigue association well adapted to habitat conditions, while macchia is present sporadically, in the microclimatically protected places, with a slightly thicker soil layer (e.g., gully bottoms).

Due to the relatively unfavourable physical-geographical conditions, these areas are uninhabited and human impact on the landscape is minimal. Expressed adaptive abilities (morpho-anatomic, subcell and physiological-biochemical adaptations to external conditions) of the existing vegetation and the absence of negative anthropogenic impact are the main reasons for preserving landscape balance. Because of the physical-geographical conditions, changes in ecosystems in terms of progressive succession of garrigue to macchia could not be expected to a significant extent.

The second geocomplex type according to the size (No. 112) includes higher parts of Dračevo and Plisko polje, which have mainly anthropogenic soils with vineyards. There has been a long-term human impact on the natural landscape transformation, which partly reflects today's landscape appearance as well. Agriculture (especially viticulture) prevails and due to intensive agricultural use in the past these areas have not been urbanized. Based on the vertical structure indicators, as well as field researches, it can be concluded that there is a balance between geocomponents and anthropogenic impact. This means that the land use in the past respected the natural conditions, while nowadays large parts of the area are abandoned in terms of agricultural usage. It is left to natural process of renewal and succes-

Figure 12: Example of the part of the largest and dominant geocomplex type No. 33 (Sokolica–Vini bok–Duboka, south of Podhumlje) characterised by high connection between geocomponents (ARKOD, 2012)

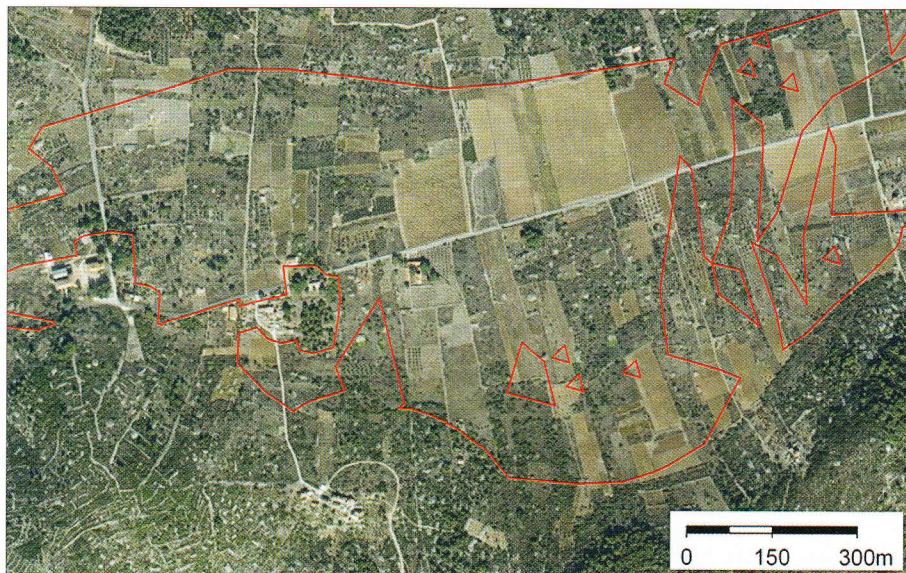
Slika 12: Del največjega in dominantnega tipa geokompleksa št. 33 (Sokolica–Vini bok–Duboka; južno od Podhumlja) z značilno visoko stopnjo povezanosti med geokomponentami (ARKOD, 2012)



sion, which can further increase the stability of this geocomplex type. However, sometimes, it is not absolutely clear that the abandonment of agriculture increases the stability of system because natural factors (especially soil type) have a significant role in this process. This can be seen in areas where intensive soil erosion is present (e.g., soil erosion in flysch of Istria is still very strong after many decades; Zorn and Petan, 2008).

Figure 13: Dominant geocomplex type No. 112 located in western part of Dračevo polje (ARKOD, 2012)

Slika 13: Dominantni tip geokompleksa št. 12 v zahodnem delu Dračevskega polja (ARKOD, 2012)



Geocomplex type No. 110 is present in the lowest parts of Dračevo and Plisko polje. Height differences are small and the entire area is located at around 100 m above sea level. Anthropogenic soils prevail and because of the intensive agricultural use in the past and recent reduction of anthropogenic pressure, the area of this type is very similar to the type 112 by its characteristics.

For the most stable geocomplex types, a strong connection between vertical geocomponents (lithology, vegetation and slope inclination) is characteristic while indicating a high degree of internal cohesion (Kurnatowska, 1998; Kozłowska et al., 2006). This is of great importance because the internal cohesion directly affects the ecosystem resistance to negative external influences.

The allocation of geocomplex types with low stability and high sensitivity degree is very important, because it enables more efficient current and future protection of their geoecosystems. When the changes occur within these geocomplex types (due to the negative impact of natural and anthropogenic environmental factors), they are often irreversible and, if it comes to regeneration, a long period of recurrence time (in most cases, the system cannot

return to previous state) is usually required. The reasons to that are mostly significant losses of pedological and/or vegetation cover.

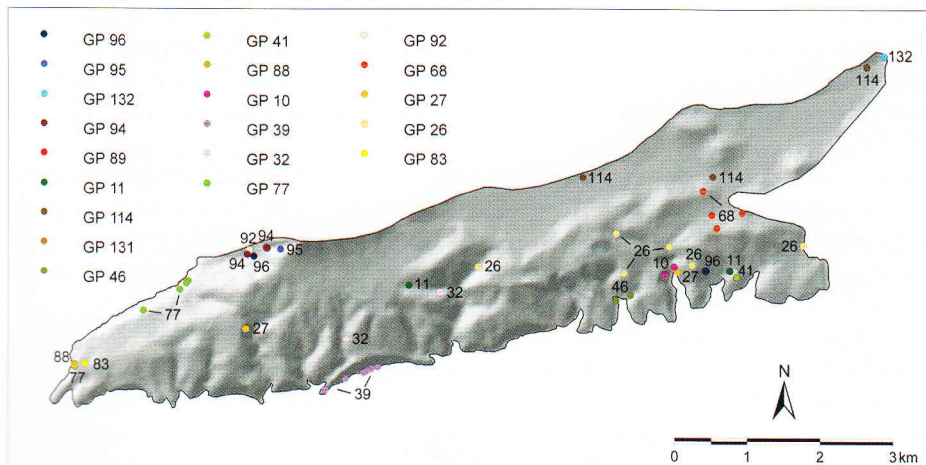
By application of the comparative analysis and synthesis parameters of the vertical landscape structure (very weak vertical correlation of one or more geocomponent pairs), twenty most unstable and most endangered geocomplex types (Figure 14) have been determined. Several examples analysed in detail during the field research are shown in figures 15 and 16.

Parts of the geocomplex types No. 96, 11 and 41 (shown in Figure 15) are situated near Mala Travna cove on the south coast. The bedrock is Upper Cretaceous limestone, covered with a thin layer of terra rossa or lithosols. All three areas are located on the slopes of a gully which leads to cove, with a low altitude (50 m) and a large range of slope inclination (5–32°). They are exposed to the south, southwest and southeast, and therefore exposed to a strong negative sea and wind (sirocco) influence. Related to this, in these areas, continuous sediment erosion and denudation processes are present, along with the strong anthropogenic influence expressed through apartment building construction and infrastructure (roads).

Nowadays, maintenance of terraces has been abandoned, resulting in intensification of the mentioned geomorphological processes which strongly restrict natural succession of vegetation. All this enhances a continuous destabilization and increased vulnerability of this geocomplex types.

Figure 14: The most sensitive and endangered geocomplex types (GP 96 = MG – BC – 12–32°; GP 95 = MG – BK – >32°; GP 132 = MG – S – 2–5°; GP 94 = MG – BC – 12–32°; GP 89 = FM – BC – 5–12°; GP 11 = AUL – LUC – 12–32°; GP 114 = MF – TRRF – <2°; GP 131 = MG – S – <2°; GP 46 = BR/RGV – BC – <2°; GP 41 = BR/RGV – LUC – <2°; GP 88 = BR/RGV – CD – >32°; GP 10 = F – LUC – >32°; GP 39 = G – LUC – 2–5°; GP 32 = M – LUC – >32°; GP 77 = M – CD – >32°; GP 92 = F – BC – 5–12°; GP 68 = MF – CD – <2°; GP 27 = MG – LUC – >32°; GP 26 = MG – LUC – <2°; GP 83 = G – CD – 2–5°)

Slika 14: Najobčutljiviji in najbolj ogroženi tipi geokompleksov



Geocomplex type No. 27 (Figure 16) is located on the coastal part of Stiniva cove. It has been formed in Upper Cretaceous limestones covered with a thin layer of terra rossa and lithosols. Considering high inclination ($12\text{--}32^\circ$) and the constant sea and wind influence, the existing soil layer is exposed to continuous denudation which does not allow the development of more dense vegetation cover.

These examples show that the main factors of influence on these geocomplex types were negative anthropogenic impacts (deforestation, construction, excessive agricultural use, etc.) and abiotic habitat conditions (expressed mainly through erosion and denudation processes). If taking in consideration, along with the mentioned impacts, their spatial dispersion and the pressure of the neighbouring, more stable and more dominant geocomplex types, we can expect that over time the existing vegetation will change and adjust to environmental conditions. As a result of these processes, it could come to the transformation of these geocomplex types into more stable ones, or, in the worst scenario, to a complete disappearance of vegetation cover and strong activation of erosion and denudation processes. According to some authors (Reice, 1994; Marston, 2010), consequences of these processes are not necessarily negative. Namely, the active erosion and denudation processes on the slopes in certain circumstances, could create positive conditions for recolonisation of species and increase landscape heterogeneity.

Landscape structure is exposed to continuous change due to various activities related to spatial planning and management. The landscape represents an interface between natural and social processes in the environment, while planning and decision-making related

Figure 15: Examples of the smallest and most sensitive geocomplex types (No. 96, 11 and 41) near Mala Travna cove (ARKOD, 2012)

Slika 15: Primer najmanjših in najobčutljivejših tipov geokompleksov (št. 96, 11 in 41) blizu zaliva Mala Travna (ARKOD, 2012)

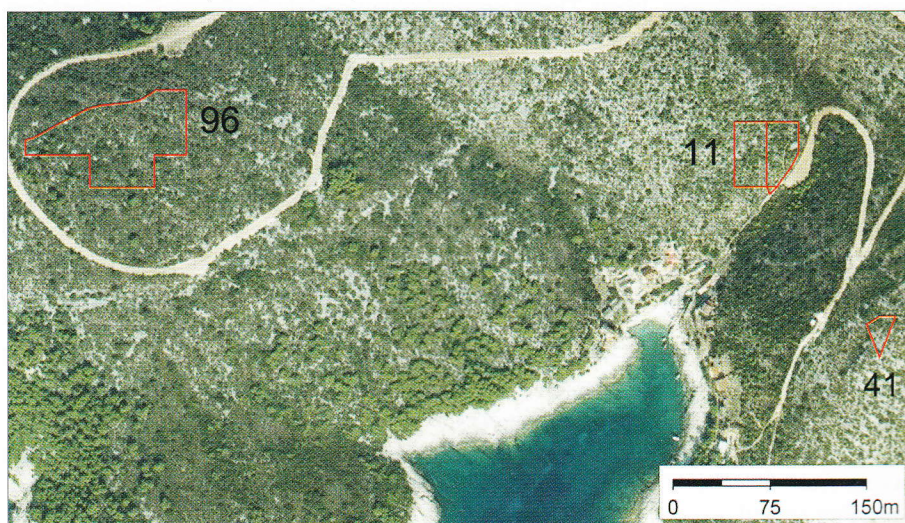
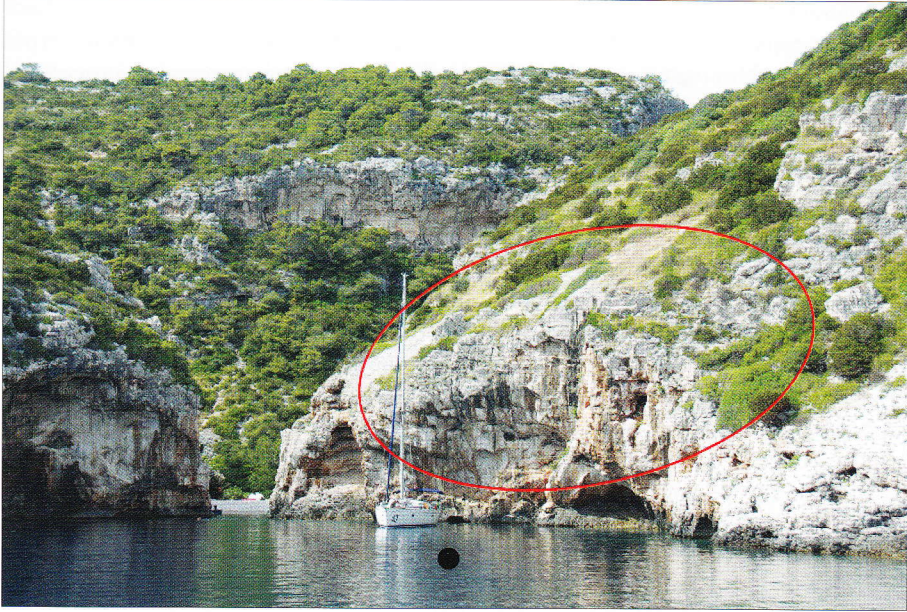


Figure 16: Part of geocomplex type No. 27 (Upper Cretaceous limestones – macchia/garrigue – $>32^\circ$), Stiniva cove

Slika 16: Del tipa geokompleksa št. 27 (zgornjekredni apnenec – makija/gariga – $>32^\circ$) v zalivu Stiniva



to sustainable development should certainly take in consideration the spatial relations of landscape elements (Turner, 1989). This is particularly important for karst areas, which are very sensitive to external influences due to their specific abiotic and biotic characteristics. Estimation of the negative anthropogenic impact on these areas is a difficult task. For that reason, there is a need for development of multidisciplinary methods and techniques, by which the changes in the environment of karst areas could be more efficiently determined (De Waele, 2009).

Natural balance disturbances have strong impact on geoecosystems and landscape as a whole; therefore many ecological processes depend on the current dynamics of abiotic and biotic elements, considering the anthropogenic influence as well. The nature of these relations is essential and often the result of periodic or episodic changes of landscape features, that consequently affects bio/geodiversity. Environmental management strategies should take into account these changes in the dynamics of landscape elements.

In the study area, a better understanding of characteristics of vertical landscape structure should allow more efficient detection of changes related to the natural landscape dynamic and anthropogenically caused disturbances, which can lead to transition of geocomplex types from the natural balance state to an imbalance state and to the increase of their vulnerability as well.

The primary task of this research was the establishment of appropriate methodology with an objective of exact analysis and synthesis of vertical landscape structure, which should improve the understanding of geoecological context of the current landscape state as well as the predictions of future development trends. Determination of the dominant, stable and resistant geocomplex types, and moreover the unstable, sensitive and non-resistant ones, could be a useful reference during the planning process and decision-making related to planning purposes and sustainable land-use in the southern part of Vis Island. This primarily refers to the preventing of excessive exploitation of natural resources (vegetation cover devastation, quarrying and mining activity), inappropriate planning in urbanized zones, industrial and transport infrastructure, inadequate agricultural use and environmental pollution.

(Translated by Mijo Župić)

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limestones), GM-LUC (garrigue and macchia/Upper Cretaceous limestones), BR/SGV-LUC (bare rock and sparse grass vegetation/Upper Cretaceous limestones), G-LUC (garrigue/Upper Cretaceous limestones), F-CD (forest/Upper Cretaceous calcitic dolomites) and AUL-CD (cultivated areas on the slopes and urbanized land/Upper Cretaceous calcitic dolomites; Table 1; Figure 8). Due to the fact that combinations of these geocomponents appear frequently and cover larger areas, we can assume that they indicate a greater stability and resistance of geocosystem to external influences. This fact has been confirmed by some other investigations on other locations in Europe (Kurnatowska, 1998; Kozłowska et al., 2006).

Table 1: High and very high relationship of geocomponent pairs and associated geocomplex types (detailed explanation of geocomponent types numbers is in chapter 2)

Preglednica 1: Visoka in zelo visoka povezanost parov geokomponent in pripadajočih tipov geokompleksov (podrobnejša razlaga številčk tipov geokomponent je v poglavju 2)

Pairs of geocomponents (vegetation cover/lithology)	Number of geocomplex types
MG-S (macchia and garrigue/Quaternary sands)	130, 131, 132
AA-TRRF (agricultural areas in poljes/terra rossa with rock fragments)	110, 111, 112, 113
MF-LUC (macchia and forest/Upper Cretaceous limestones)	18, 19, 20, 21, 22
GM-LUC (garrigue and macchia/Upper Cretaceous limestones)	33, 34, 35, 36, 37
BR/SGV-LUC (bare rock and sparse grass vegetation/Upper Cretaceous limestones)	43, 44, 45, 46, 47
G-LUC (garrigue/Upper Cretaceous limestones)	38, 39, 40, 41, 42
F-CD (forest/Upper Cretaceous calcitic dolomites)	53, 54, 55, 56
AUL-CD (cultivated areas on slopes and urbanized land/Upper Cretaceous calcitic dolomites)	57, 58, 59, 60

Figure 8: The strength of relationship (based on connectivity index) between vegetation cover and lithology

Slika 8: Stopnja povezanosti (na osnovi indeksa povezanosti) med rastlinskim pokrovom in kamninsko zgradbo

