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SPATIO-TEMPORAL LANDUSE/LANDCOVER (LU/LC) CHANGES OF SIGNIFICANT LANDSCAPE „BARAĆEVE ŠPILJE“

PROSTORNO VREMENSKE PROMJENE ZEMLJIŠNOG POKROVA I NAČINA KORIŠTENJA ZEMLJIŠTA ZNAČAJNOG KRAJOBRAZA „BARAĆEVE ŠPILJE“

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SAŽETAK

Promjene u načina korištenja zemljišta i zemljišnog pokrova (LU/LC) uzrokovane različitim antropogenim i prirodnim čimbenicima važan su predmet brojnih znanstvenih istraživanja. U radu je provedena analiza prostorno-vremenskih promjena LU/LC za područje Značajnog krajobraza (ZK) Baraćeve špilje u razdoblju od 1960. do 2021. godine. Primjenom zračnih snimaka i metode hibridne klasifikacije uspješno su izvedeni LU/LC modeli te analizirane prostorno-vremenske promjene. Napuštanje poljoprivrede kao osnovne djelatnosti i polagano nestajanje antropogenog utjecaja dovelo je do nestanka niskog raslinja u obliku travnjaka, livada i pašnjaka, dok su postupno počeli prevladavati grmlje i šuma. U skladu sa stupnjem zaštite istraživanog područja, razmotrene su smjernice za zaustavljanje negativnih trendova promjena LU/LC-a.

Ključne riječi: Baraćeve špilje, prostorno-vremenske promjene, model zemljišnog pokrova i načina korištenja zemljišta, simulacijski model

ABSTRACT

Changes in the land use/land cover (LU/LC) model caused by different anthropogenic and natural factors are an important object of numerous scientific research. In this paper, an analysis of the spatio-temporal changes (LUCCs) for the area of Significant landscape (SL) of the „Baraćeve špilje“ in the period from 1960 to 2021 was performed. Using aerial photographs and a hybrid classification method, LU/LC models and spatio-temporal changes (STCs) analysis were performed. The research showed that the abandonment of agriculture and the slow disappearance of anthropogenic influence led to the disappearance of low vegetation in the form of lawns, meadows and pastures, while the bushy vegetation and forest gradually prevailed. Finally, in accordance with the degree of protection of the studied area guidelines for stopping negative trends in LU/LC changes were considered.

Keywords: Barać caves, spatio-temporal changes, land use/land cover changes, simulation model

1 INTRODUCTION AND BACKGROUND

Due to the growing anthropogenic influences biodiversity and natural resources of protected areas are changing and disappearing (Jones et al., 2018). Landscapes by their very nature require a multi-resolution approach in their monitoring, modeling, and management (Šiljeg et al., 2020). The protection of landscapes is carried out by acquiring knowledge about that area, which may include the identification, and classification of the landscape elements and the assessment of the threat which endangers original or altered natural values (Zaštita prirode, 2021). Disturbance of biodiversity leads to a decline in ecosystem productivity, loss of resistance to external influences, decline in the number of living organisms, and ultimately destabilization of the food chain (Opuni-Frimpong et al., 2021). Intensive agriculture (Maracahipes-Santos et al., 2020), heavy industry (Xu et al., 2015), deforestation (Giam, 2017), invasive vegetation (Linders, et al., 2019), mass tourism (García-Ayllón, 2018) and natural disasters (Davare, 2022) have been recognized as the biggest factors of changes in different ecosystems. To counter the losses and make biodiversity "useful", there are initiatives and promotion of categorizing specific, unique areas as "protected areas". This includes legal or any other effective means of managing a defined area with the aim of long-term conservation of nature with associated ecosystem services and cultural values (Dudley, Stolton, 2008). One of the most famous and oldest (1948) international organizations working in the field of nature conservation and sustainable use of natural resources is the International Union for Conservation of Nature (IUCN). In an attempt to describe and categorize different management approaches in individual areas, the IUCN has identified seven different categories of protected areas according to specific management objectives. They go up to the strictest category Ia - strict nature reserve to - a protected area with sustainable use of natural resources (EEA, 2022). A formal declaration of a specific area as "protected" does not necessarily imply stopping negative changes in its landscape (Islam et al., 2019, Rodríguez-Rodríguez et al., 2019, Sobhani, et al. 2021). Namely, different anthropogenic factors are not the only ones changing the landscape structure. Sometimes this is the result of natural processes where nature itself affects the balance between the landscape elements, making it more difficult to preserve its "original condition". The number of research papers that analyze spatio-temporal changes (STCs) in protected and other areas in the Republic of Croatia (Marić et al., 2022, Jogun et al., 2019) and the world is constantly increasing (Rodríguez-Rodríguez et al., 2019, Twisa, Buchroithner, 2019, Schirpke et al., 2020, Bhandari et al., 2021, Sobhani et al., 2021, Yohannes et al., 2021). STC monitoring methods are becoming increasingly advanced (Morgan et al., 2020, Marić et al., 2022). Over time, the methods of analyzing STCs have evolved from the application of analog photographs to modern geospatial technologies (eng. *geospatial technology* – GST) (Zbierska, 2022). Namely, today the monitoring STCs in LU/LC models and derivation of simulation models are unthinkable without the application of one of the three main components of GST (Bhandari et al. 2021). The most used sensors in the acquisition of spatial data required for performing LU/LC models are RGB and multispectral cameras (Navulur, 2007). The use of multispectral images in the analysis of spatio-temporal changes depends on their spatial, spectral, radiometric, and temporal resolution. Namely, from the acquired multispectral images, the LU/LC models can traditionally be performed using pixel-oriented methods (supervised and unsupervised) by applying different classification algorithms (Saputra, Lee, 2019, Šiljeg et al., 2022, Marić et al., 2022, Kamaraj, Rangarajan, 2022) and today's dominant geographic object-based image analysis (GEOBIA) approach. Spatio-temporal changes (STCs) LU/LC are defined as a change in the way the land cover is used or as a change in the long-term of its biophysical characteristics in a given interval (Verma et al., 2020). The detection of STCs represents the process of recognizing the difference in the thematic meaning (attribute) of an area, object, or phenomenon by observing it in different time intervals (Singh, 1989). STC is an important process in monitoring and managing natural resources and urban development because it provides a quantitative analysis of spatial distribution and patterns of specific spatial attributes. It is necessary to consider four aspects of STCs (Macleod, Congalton, 1998):

(a) detect the changes that have occurred;
(b) determine the nature of the change;
(c) measure the area of the detected change;
(d) assess the spatial pattern of change.

Accurate and up-to-date information on spatial-temporal changes of LU/LC within the protected area is extremely important for decision-makers in resource management, spatial planning, and preservation of protected areas (Singh et al., 2015, Zbierska, 2022). Management of protected areas (PA) implies the implementation of a series of activities and measures aimed at the long-term preservation of the landscape value.

In the Republic of Croatia, it is implemented within the framework of the responsibilities assigned by the Nature Protection Act (15/2018) (Marić, 2020). Therefore, most of the measures and action plans within the Management Plans of the PA are adopted on the basis of information derived from the (spatial) data available to the Institutions. At the national level, there are several categories of protection under which, according to the Nature Protection Act (NN80/2013), 408 areas are protected in nine categories: two strict reserves, eight national parks, 79 special reserves, 12 nature parks, two regional parks, 78 natural monuments, 79 significant landscapes, 27 park-forests and 120 monuments of park architecture (MINGOR, 2022). The mentioned areas make up a total of 817383.34 ha, i.e. 13.37% of the land and 1.93% of the sea surface of the Republic of Croatia (MINGOR, 2022). According to the Nature Protection Act (2005) in Article 16, a Significant landscape is defined *as a natural or cultivated area of great landscape value and biological diversity, or of cultural and historical value, or a landscape of preserved unique features characteristic of a particular area, intended for rest and recreation or especially valuable landscape*. Furthermore, it is stated *that interventions and actions that damage the elements for which he got that categorization are not allowed*. A Significant landscape is under the jurisdiction of the competent unit of regional self-government, and therefore the level of management is County or Municipal (MINGOR, 2022). According to the IUCN categorization, a significant landscape belongs to the fifth (V) category of protection called "Protected landscape/seascape", and includes those areas where there is a long-term interaction between man and nature has produced specific aesthetic, ecological, cultural, and biological values, which is why the preservation of these interactions is necessary with the aim of preserving these values (HAOP, 2021).

In this paper, the spatio-temporal changes of the LU/LC for the wider area of the Significant landscape "Baraćeve špilje" were analyzed in the period from 1960 to 2021. The paper examines the applicability of aerial photographs acquired by the State Geodetic Administration of the Republic of Croatia and provided by the managing Public institution of Significant Landscape, for the purpose of creating LU/LC models and determining changes in LU/LC and simulation modeling. The main objective is to determine the dominant spatio-temporal changes on the LU/LC models in the period from 1960. to 2021. Achieving the main objective involves going through several methodological steps and setting additional sub-goals:

• Derivation of LU/LC models for selected years within the defined period (1960 – 2021);
• Accuracy assessment of used classification algorithm (MLC[1], SVM[2], RT[3]);
• Determine the dominant spatio-temporal changes of LU/LC for the studied period (1960 - 2021).

The purpose of this paper is to help expert services and decision-makers in the management of the "Baraćeve špilje" through the analysis of the STCs of LU/LC. It will be possible to apply this research methodology to other localities where, due to the small area, it is not possible to use freely available satellite images of lower spatial resolution (eg LANDSAT, Sentinel), but there are available historical aerial photographs available.

1.1 Study Area

The study area of research includes a wider area of the Significant Landscape "Baraćeve špilje" located in the Municipality of Rakovica in the Karlovac County, 19 km south of Slunj, on the border with Bosnia and Herzegovina. The "Baraćeve špilje" was declared a permanently protected area on March 29, 2016, at the 21st session of the County Assembly of Karlovac County (Baraćeve špilje, 2022). It covers an area of 5.19 km2 and extends through three settlements: Nova Kršlja, Stara Kršlja, and Grabovac Drežnički. The official border of the "Baraćeve špilje" shown in Figure 1 was provided by the managing Public institution of the "Baraćeve špilje". STC analyses were made within a wider area, which was derived using the tool Buffer (100 m) within ArcMap.

1.1.1 Historical Overview

The first written materials related to Barać's caves date back to 1874, when I. T. Bunek mentioned them in his work Die Wassernoth im Karste (Baraćeve špilje, 2022). During the 20th century, various archaeological excavations were carried out, but the first systematic research was carried out in 2004, after the caves were arranged for the needs of tourism. The latest research was carried out in the period from June 27 to July 15, 2022, in cooperation with the Ministry of Culture, the speleological club "Ursus spelaeus" and the American universities of Wyoming and Oregon. They resulted in the discovery of a stone tool (Figure 2) whose characteristics correspond to the Pleistocene age. From the above, it can be concluded that Neanderthals lived in the area of the caves (NP Plitvička jezera, 2022).

[1] Maximum Likelihood Classification
[2] Support Vector Machine
[3] Random Tree

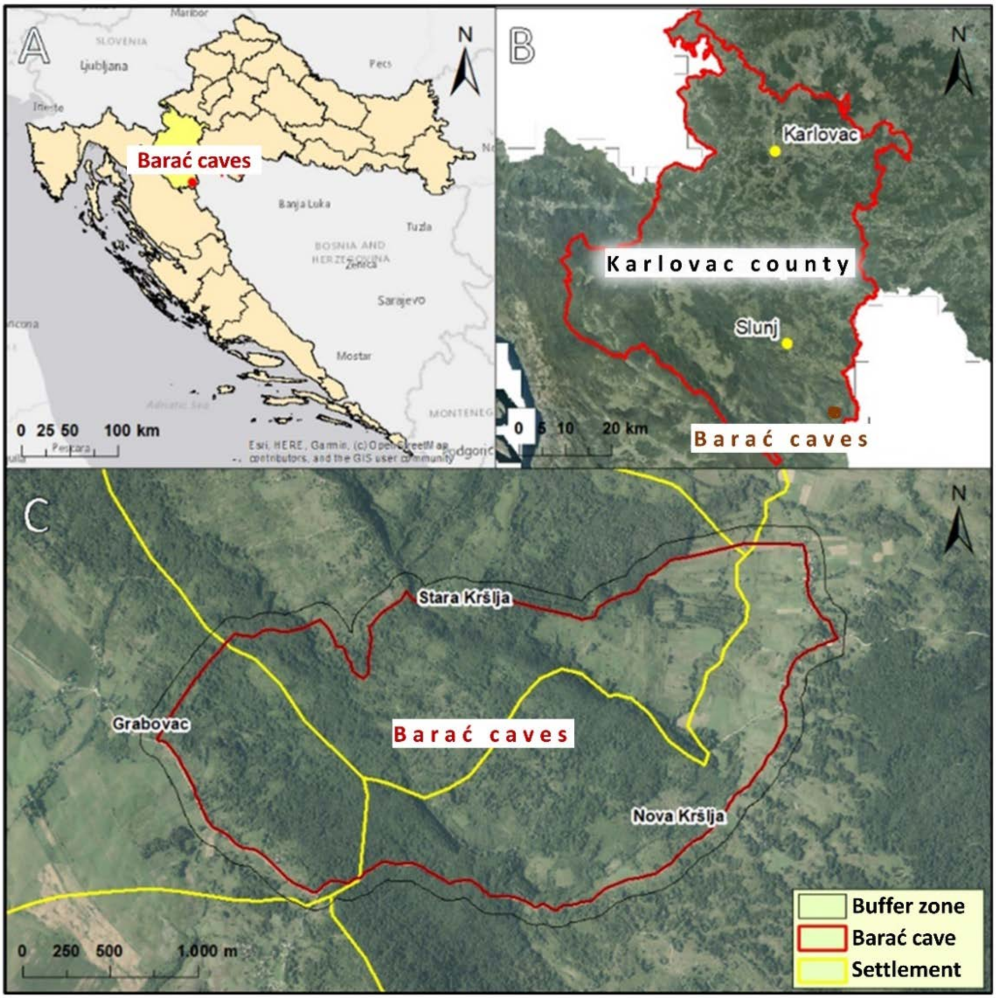

Figure 1. (A) The location of the „Baraćeve špilje“ in the Republic of Croatia; (B) location within Karlovac County; (C) settlements within „Baraćeve špilje“.

Figure 2. Tools of the Neanderthals in *Gornja Baraćeva spilja* (Upper Barać cave) (NP Plitvička jezera, 2022; Novi list, 2022).

1.1.2 Natural-Geographic Features

Within the boundaries of the protected area, the karst type of relief prevails, while the most common karst form is a sinkhole. The largest part of the surface is located in the area of the Una-Korana plateau. The landscape is located on the northwestern part of the plateau and is separated from other structural units by a reverse fault. Such a tectonic structure helped the development of complex hydrological processes that conditioned the creation of caves (Baraćeve špilje, 2022). The wider area of the „Baraćeve špilje“ has a moderately warm, humid climate with hot summers (Magaš, 2013). Rainfall is evenly distributed throughout the year, with a slightly higher amount in autumn and winter. The average annual amount of precipitation is from 1000 to 1500 mm, and the average annual temperature in this area rarely exceeds 20 ºC (Magaš, 2013).

The most common type of habitat within the protected area is represented by forest habitats (Baraćeve špilje, 2022). Almost half of the area is covered by beech and mixed hornbeam forests. In this area, forests alternate with thickets, heaths, lawns and mosaics of cultivated areas. In the past, grasslands were used for grazing, and today, due to the cessation of anthropogenic influence, they slowly gradually develop into thickets, and then into forests. Such development is gradually changing the landscape diversity and microrelief of pasture areas.

1.1.3 Demographic Features

The area of Rakovica Municipality, like the entire Republic of Croatia, is experiencing a demographic decline and it can be regarded as demographically depressed area (Mrđen, Marić, 2018). In the period of 20 years, from the census of 2001 (2623 inhabitants) (DZS, 2001) to the new census of 2021 (2225 inhabitants) (DZS, 2021), the number of inhabitants decreased by almost 400, which is 15.17% of the total number of inhabitants. The settlements (Grabovac, Stara Kršlja and Nova Kršlja) within which the Significant landscape of „Baraćeve špilje“ is located have a total of only 384 inhabitants. According to the 2011 population census (DZS, 2011), the most represented demographic group are men aged 40 to 55.

2 MATERIALS AND METHODS

2.1 Data Acquisition

Aerial photographs of the State Geodetic Administration (DGU) for the wider area of "Baraćeva špilje" were acquired from the managing Public institution of Significant Landscape. Furthermore, the UAV photogrammetry survey was carried out with the aim of creating a reference LU/LC model for the year 2021.

2.1.1 Aerial photographs

The aerial photographs provided by the managing Public Institution of "Baraćeve špilje" represent a period from 1960 to 2018. Table 1. shows the year of acquisition, spatial resolution, and the coordinate system in which the data were located. Images are marked with three colors.

The orange color indicates the images that were not used in the research because they do not contain the study area. The yellow color indicates the images for the year 2020, but considering that there is a new digital orthophoto (DOP) for the year 2021, it was not necessary to use it. The images which were used in the analysis are marked in green. Considering the detail of the submitted images, it was decided to set the spatial resolution of DGU images to 0.5 meters. Images from 1960 to 2009 were acquired with special analog cameras and had to be digitized, while images after 2009 were acquired with digital cameras. The cameras were attached to special gyroscopically stabilized stands above the openings on the floor of the aircraft. The operation of the cameras is controlled by navigation GNSS and inertial measurement systems (IMU). The geometric accuracy of measuring cameras is extremely important, therefore regular calibration is carried out. Other secondary data were provided by the „Baraćeve špilje“ Public Institution and their permission for use was obtained.

Table 1.
Specification of acquired images from managing Public institution of „Baraćeve špilje“

Location	**Format**	**Year**	**GSD**[4]	**No. of bands**	**Geo-reference**	**Coordinate system**
Rakovica	TIFF	1960.	0.4	Grey scale	Yes	HTRS96 TM Croatia
Rakovica	TIFF	1960.	0.4	Grey scale	Yes	HTRS96 TM Croatia
Rakovica	TIFF	1960.	0.4	Grey scale	Yes	HTRS96 TM Croatia
Rakovica	TIFF	1960.	0.4	Grey scale	Yes	HTRS96 TM Croatia
Rakovica	TIFF	1962.	0.5	Grey scale	Yes	HTRS96 TM Croatia
Rakovica	TIFF	1962.	0.5	Grey scale	Yes	HTRS96 TM Croatia
Plitvička jezera	JFIF	1979.	1	3	No	Unknown
Plitvička jezera	JFIF	1979.	1	3	No	Unknown
Plitvička jezera	JFIF	1979.	1	3	No	Unknown
Slunj	JFIF	1985.	1	3	No	Unknwon
Slunj	JFIF	1985.	1	3	No	Unknwon
Slunj	JFIF	1985.	1	3	No	Unknwon
Slunj	JFIF	1985.	1	3	No	Unknwon
Slunj	JFIF	1985.	1	3	No	Unknwon
Slunj	JFIF	1985.	1	3	No	Unknwon
Slunj	JFIF	1985.	1	3	No	Unknwon
Slunj	JFIF	1985.	1	3	No	Unknwon
Slunj	JFIF	1985.	1	3	No	Unknwon
Rakovica	TIFF	1997.	0.0021	3	No	Unknown
Rakovica	TIFF	1997.	0.0021	3	No	Unknown
Rakovica	TIFF	1997.	0.0021	3	No	Unknown
Rakovica	TIFF	1997.	0.0021	3	No	Unknown
Rakovica	TIFF	1997.	0.0021	3	No	Unknown
Rakovica	TIFF	1997.	0.0021	3	No	Unknwon
Rakovica	TIFF	1997.	0.0021	3	No	Unknwon
Rakovica	TIFF	2007.	0.0021	3	No	Unknwon

[4] Ground Sampling Distance

Rakovica	TIFF	2007.	0.0021	3	No	Unknwon
Rakovica	TIFF	2007.	0.0021	3	No	Unknwon
K. Ljeskovac[5]	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2006/07.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2011.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2014.-16.	0.5	3	Yes	HTRS96 TM Croatia

[5] Kordunski Ljeskovac

K. Ljeskovac	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2018.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia
K. Ljeskovac	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia
Rakovica	TIFF	2020.	0.5	3	Yes	HTRS96 TM Croatia

2.1.2 UAV Photogrammetry Survey

The High-resolution DOP of the "Baraćeve špilje" for 2021 was created by the *Geospatial Analysis Laboratory* (GAL)[6] in cooperation with the Prehnit[7]. In total 4336 high-resolution aerial images were collected using UAV DJI Phantom 4 Pro. The UAV survey was performed using the Single Grid Mission with a front and side overlap of 80%. The missions were planned with the help of ArcMap, considering the terrain morphology, while the mission flight was done using the DJI GS Pro application. Each mission lasted on average around 20 minutes, and there were a total of 16 conducted missions. Aerial imagery was processed with *Agisoft Metashape 1.5.1.* software. Within *Agisoft*, five steps were performed with the goal of derivating DOP.

The first step in the UAV image workflow process included image quality assessment, which was performed using the *Image quality* tool. After that, the relative orientation of the aerial imagery

[6] http://gal.unizd.hr/
[7] https://prehnit.hr/hr/

was evaluated using the *Align* tool, which connects the overlapping photos using a sparse cloud or tie points. By solving the relative orientation problem, the intrinsic calibration parameters of the camera were evaluated, which were re-optimized with each deletion of the tie points using the *Gradual selection* tool. The next step involved adding orientation points (GCPs) and check points (CPs) which are used to solve the absolute orientation problem of the reconstructed sparse point cloud.

Figure 3. Acquisition of GCPs (ground control points) and CPs (check points).

The optimal placement of GCPs and CPs was determined before going out on the field, and it was conditioned by the terrain characteristics. A total of 16 orientation points were marked and collected within the study area. After adding orientation points to the reconstructed model and georeferencing the sparse cloud of points, a dense point cloud was generated. In the next step, a digital surface model (DSM) was generated with a spatial resolution of 9 cm. The final step involved creating the DOP using the *Build Orthomosaic* tool. Figure 4 shows a systematized view of all images used in the research.

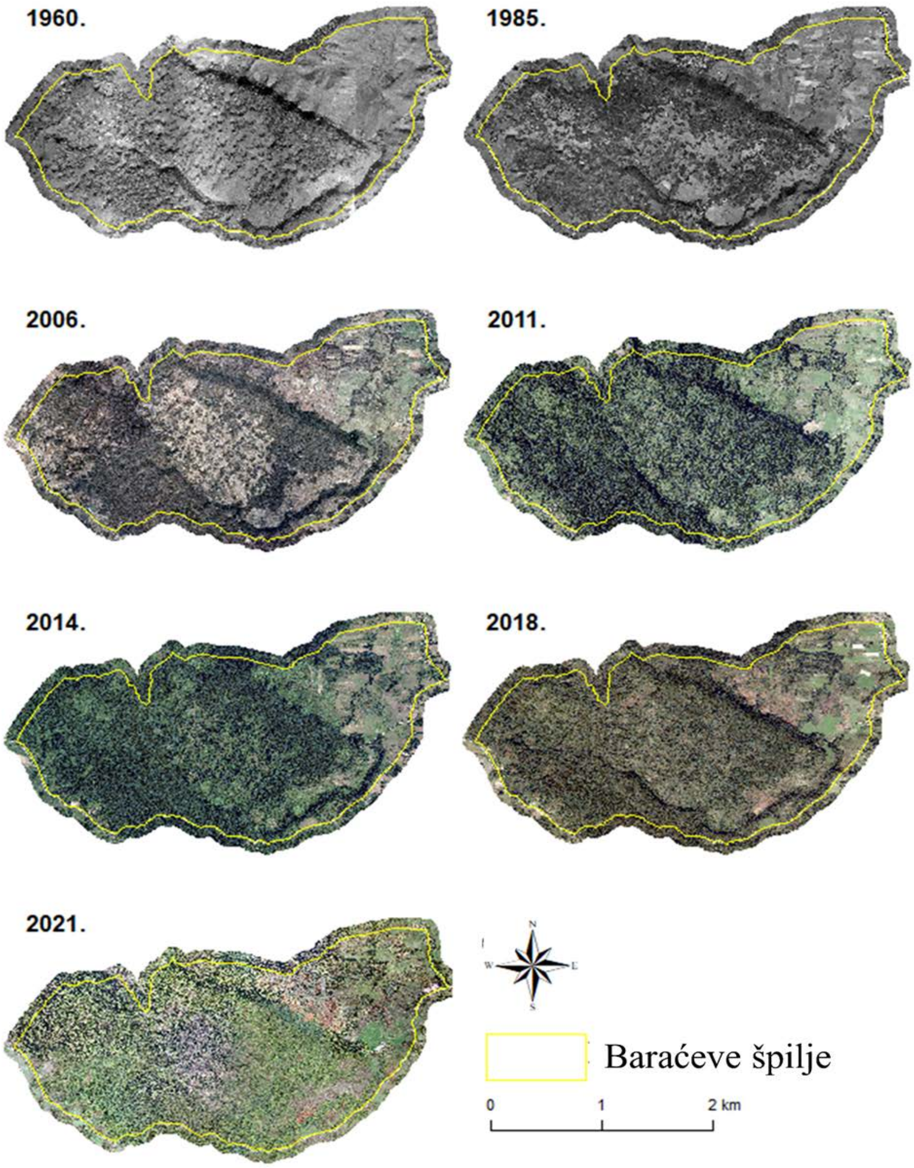

Figure 4. Acquisition of GCPs (ground control points) and CPs (check points).

2.1.3 Positional Imagery Harmonization

After data collection, it is necessary to harmonize all input data according to the reference DOP. The DOP from 2021 was chosen as the reference, and following its geometry, images that are not georeferenced were ultimately positioned and aligned in a defined coordinate system using *Georeferencing* tool. Roads that had the same shape/location in the studied period (1960 - 2021) were used as an auxiliary object for positioning. With the help of the *Swipe* tool, the positional overlap between the imagery was checked (Figure 5), which made it possible to see possible positional deviations.

Figure 5. (A) Demonstration of the georeferencing tool; (B) overlay of two imagery.

2.1.4 Harmonization of Spatial Resolution

After the positional harmonization of the data, the spatial resolution was modified on some imagery with the aim of harmonizing all input data. A spatial resolution of 0.5 meters was selected optimally. Most of the acquired imagery has this resolution. It enables a sufficiently detailed representation for the generation of LU/LC in relation to the size of the research area. Harmonization was performed using the *Resample* tool in which the *Bilinear* technique was used, which performs the spatial resolution conversion process using *bilinear interpolation* and determines a new value based on the average distance between the four closest pixels.

2.2 Iterative Imagery Segmentation

The iterative segmentation process started with the most recent year, 2021, and gradually went back towards older imagery. The problems in the segmentation process mostly related to the level of segmentation, considering that on certain imagery, due to the time of year in which the imagery was made, different classes showed a lot of similarity in spectral reflection. Likewise, the fact that the spectral resolution of the imagery does not satisfy its more detailed segmentation made the process more difficult. Namely, the older imagery has only one band, while the more recently acquired had three (RGB). Segmentation was performed by setting three user-defined parameters: (a) spectral detail; (b) spatial detail; (c) minimum segment size. After three iterative combinations of segmentation parameters, it was determined that the 20-10-10 combination will be used for the year 2021. The same process, with different output values, was conducted for each image (Figure 6).

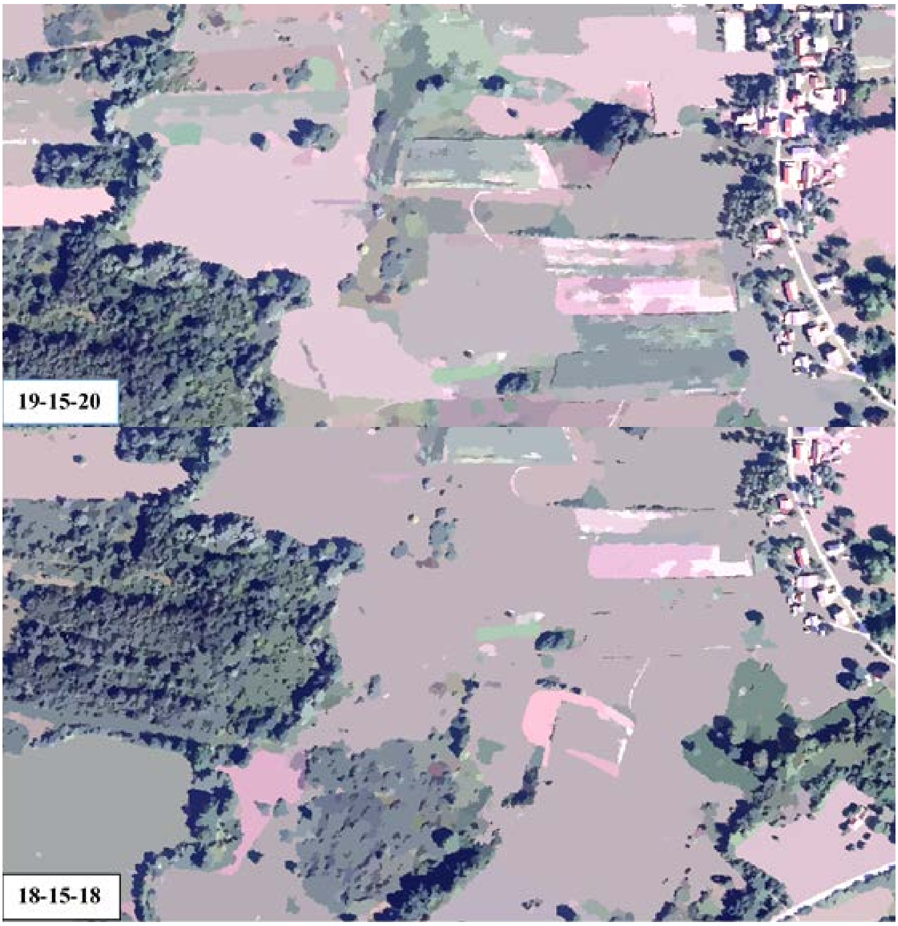

Figure 6. Comparative view of the final segmentation parameters (19-15-20) and one of the tested ones (18-15-18).

2.3 Automatic Image Classification (SVM, RT, MLC)

After the segmentation, it was necessary to classify all the specified segmented images using the three defined classification algorithms (SVM, MLC and RT). The first step was to determine the number of classes and define it thematic meaning. Considering the heterogeneity of the study area, the spectral and spatial detail of the available images, it was determined that the LU/LC model contains seven classes:

• Forest
• Low vegetation
• Bushy vegetation
• Cultivated areas
• Agricultural roads
• Urban facilities
• Roads

The first step in automatic classification involved assigning test samples. Initially, it was decided to automatically extract the four classes including low vegetation, forests, bushy vegetation and cultivated areas. However, when performing the test classification, it was noticed that the class of cultivated areas was incorrectly classified as low vegetation due to spectral similarity, smaller area of elements in the research area, and poor spectral and radiometric resolution of the image. Furthermore, other areas in the image that do not belong to the cultivated area class were classified in that class, for example the road class. After this, cultivated areas were extracted by manual vectorization after performing automatic classification.

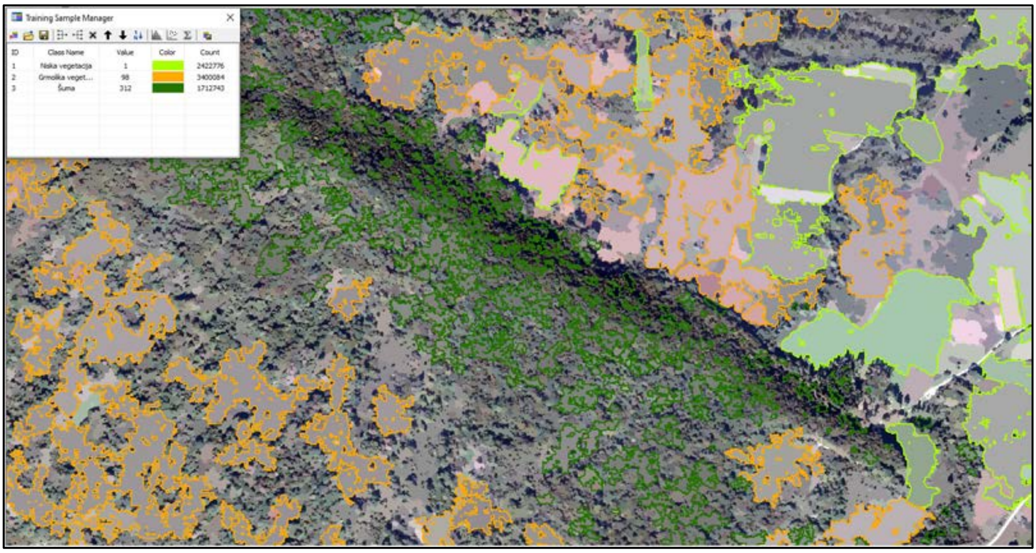

Figure 6. An example of marked training samples on a segmented image.

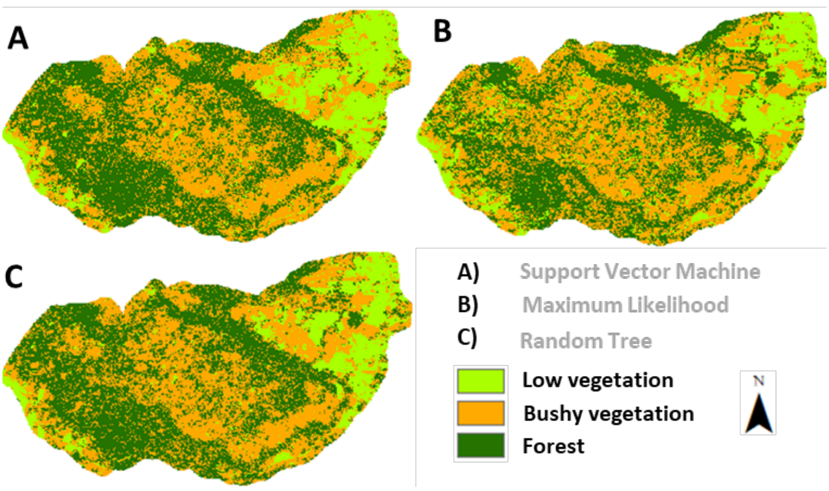

Figure 7. Automatically derived LU/LC (2018) models for tested classification algorithms.

Due to the poor spectral resolution of the imagery in all three tested classification algorithms, noises of less represented classes were observed in some areas, which is why the *Boundary tool* was used. After the noises were corrected, the next step was to assess the accuracy of the tested classification algorithms. Figure 7 shows the automatically derived LU/LC (2018) models for the three tested classification algorithms.

2.3.1 Accuracy Assessment of Derived LU/LC

It is important to emphasize that accuracy assessment was done for unmodified, automaticaly derived LU/LC models on which manually vectorized classes (Urban facilities, agricultural roads and cultivated areas) was not added. Namely, addition of those classes would artificially increase the accuracy of the derived models. The stratified random sampling method was chosen which randomly distribute samples in each class, and each class has a number of points proportional to its relative area. For the LU/LC model (2018) confusion matrices were created based on 500 samples. Two attributes are added to each point, class from LU/LC (classified) and actual (ground truth) value which was added manually according to the original RGB imagery. After creating the first point layer for the *Support Vector Machine*, the attribute *Classified* was modified for the other two classification algorithms (ML and RT). Namely, the initial point layer was created as a new layer and was modified using the *Update Accuracy Assessment Points* tool. Based on these two parameters, *overall accuracy* and the *Kappa coefficient*, which indicates the final accuracy of the model, are created in the confusion matrix. According to the *overall accuracy* parameter and the *Kappa coefficient*, *Support Vector Machine* proved to be the most accurate, for which the *Kappa coefficient* was around 0.68 (Table 2), and the overall accuracy percentage was 79%.

Table 2.
Accuracy assessment of classification algorithms for LU/LC (2018)

		SVM				
Class	Low vegetation	Bushy vegetation	Forest	Total	User's accuracy	Kappa
Low vegetation	71	12	8	91	0.78	0
Bushy vegetation	12	137	57	206	0.67	0
Forest	2	10	191	203	0.94	0
Total	85	159	256	500	0	0
P_Accuracy	0.84	0.86	0.75	0	**0.79**	0
Kappa						**0.68**
		MLC				
Class	Low vegetation	Bushy vegetation	Forest	Total	User's accuracy	Kappa
Low vegetation	62	15	7	84	0.74	0
Bushy vegetation	17	127	86	230	0.55	0
Forest	6	17	163	186	0.88	0
Total	85	159	256	500	0	0
P_Accuracy	0.73	0.80	0.64	0	**0.70**	0
Kappa						**0.53**
		RT				
Class	Low vegetation	Bushy vegetation	Forest	Total	User's accuracy	Kappa
Low vegetation	57	9	3	69	0.83	0
Bushy vegetation	21	131	63	215	0.61	0
Forest	7	19	190	216	0.88	0
Total	85	159	256	500	0	0
P_Accuracy	0.67	0.82	0.74	0	**0.76**	0
Kappa						**0.61**

2.3.2 Manual Modification of Automatically Derived LU/LCs

After the accuracy assesment process the manual modification of all LU/LCs generated by the SVM algorithm was performed. This involved updating the vectorized classes of *agricultural roads*, *urban facilities*, and *cultivated areas* on the automatically derived LU/LCs models. Namely, due to the specificity of the spectral and radiometric resolution of the acquired imagery, which is not detailed enough to distinguish all LU/LC classes, it was decided to conduct a hybrid classification approach in which the automaticaly derived LU/LC models were updated with mentioned classes that were manualy vectorized. This type of classification (Marić et al., 2022), is sometimes called "mixture" approach (Alshari, Gawali, 2021) refers to the manual vectorization of those classes that do not occupy a large area in the studied area, and due to their shape, size and complex spectral features are difficult to accurately extract using automatic classification process.

Manual vectorization of the three above-mentioned classes was performed was first done for the year 2021. Then created layers were modified for the other imagery. The most demanding for vectorization was class of agricultural roads, which had to be re-vectorized for all imagery from the begining because they changed direction depending on the position of the cultivated areas.

2.3 Analysis of Spatio-Temporal Changes (STCs)

First, descriptive statistics were calculated for each derived LU/LC model, which was then presented in pie charts. From this analysis, it is possible to recognize changes that happened between certain periods and to calculate the change in percentage from the initial year to the last. After performing basic statistics, the change in the number of urban objects in the studied period was analyzed. The changes are calculated and visualized for the period from 1960 to 2021 by means of the semi-automatic classification plugin tool available for QGIS (Congedo, 2016) and the Land cover change tool that allows the comparison of two LU/LCs with the aim of assessing changes. The result is a raster of LU/LC changes, where each pixel represents a category of comparison (i.e. a combination of changes) between the two classifications, while a text file containing the statistics of land cover change (i.e. a tab-separated .csv file, with the same code we define for tif file).

3 RESULTS

3.1 Derived LU/LC Models

Figure 8 shows the derived LU/LC models using a hybrid (automatic + manual) for the wider area of the „Baraćeve Špilje“ in the period from 1960 to 2021. Table 4 shows the descriptive statistics of the LU/LC models performed after hybrid classification for all imagery.

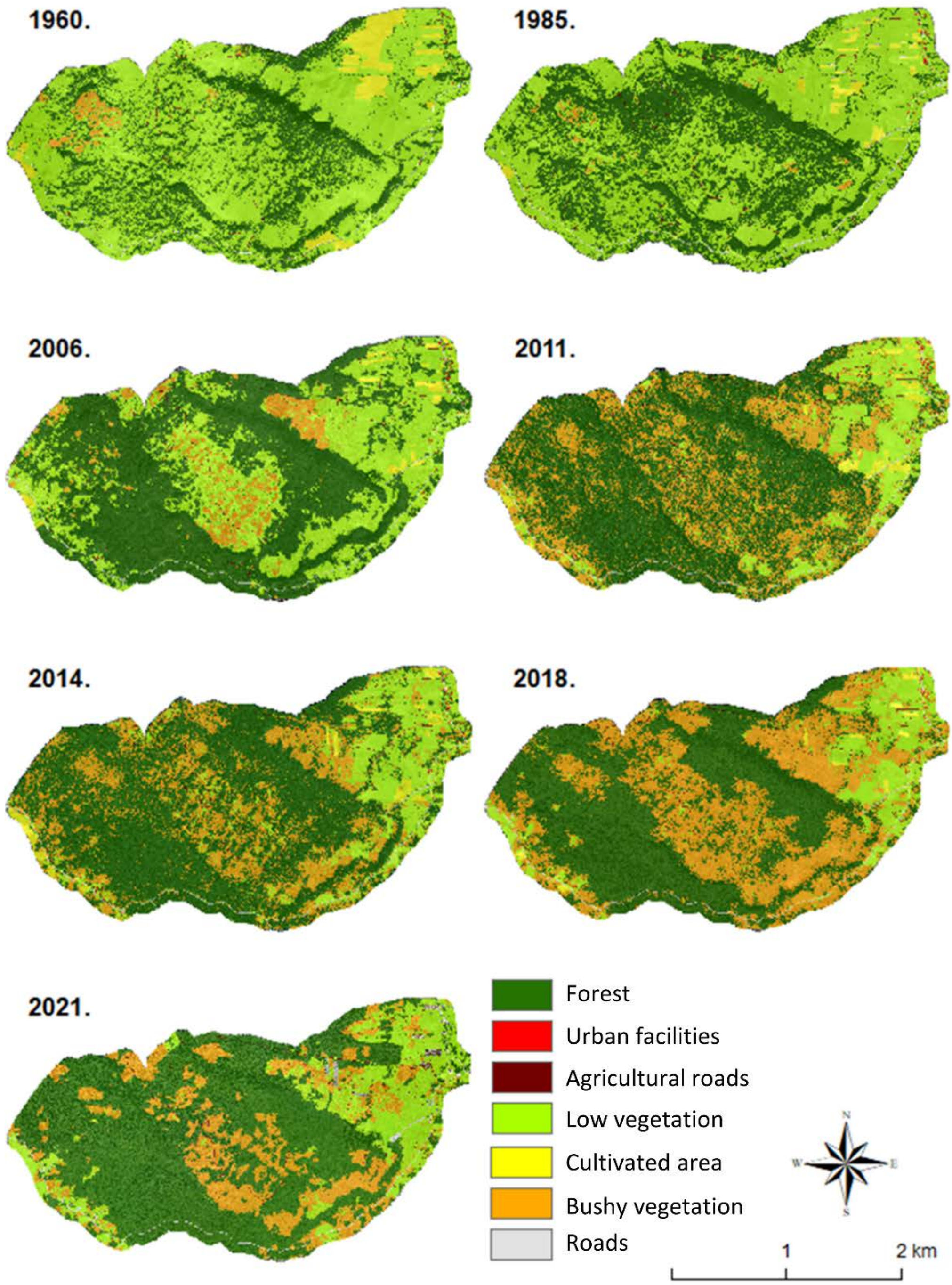

Figure 8. Derived LU/LC models within the period 1960. - 2021.

Table 3.
Class area for derived LU/LC models within the observed period

Year	Area (in km^2)						
	Low veg.	Forest	Bushy veg.	Agricultural roads	Roads	Urban facilities	Cultivated areas
2021.	1.084	3.801	1.240	0.041	0.044	0.011	0.040
2018.	0.819	3.046	2.289	0.026	0.036	0.008	0.044
2014.	1.059	3.527	1.491	0.036	0.036	0.008	0.936
2011.	0.937	3.447	1.703	0.037	0.036	0.008	0.100
2006.	2.340	3.401	0.373	0.034	0.036	0.008	0.076
1985.	3.656	2.403	0.051	0.033	0.036	0.008	0.119
1960.	3.985	1.822	0.100	0.222	0.031	0.002	0.304

The basic changes in LU/LC models that can be observed through descriptive statistics for the observed period are:

• reduction of the Low vegetation class area (more than three times)
• reduction in the area of the class Cultivated areas (more than seven times)
• increase of the Forest class area (more than twice)
• increase of the Bushy vegetation class area (more than 12 times)
• increase of the Urban facilities class area (exactly 55 times)

In the total area of LU/LC of "Baraćeve špilje" the area of Low vegetation in 2021 occupied 46.26% less area than in 1960, hen in the total area of ZK Baraćeve šilje it occupied (397.54 ha) or 63.55% total area (Table 4). This represents the class that experienced the biggest change in the studied period. The reasons for these changes can be natural and anthropogenic. From the derived model of changes (Figure 9) that the succession of vegetation was the main reason for the reduction of the *Low vegetation* class area. This results from the fact that the bushy vegetation class, along with the forest class, experienced the greatest relative and absolute increase. Namely, in the total area of LU/LC "Baraćeve špilje", the area of bushy vegetation in 2021 occupied 18.21% more area than in 1960 when it occupied (10.04 ha) or 1.61% of the total area. Furthermore, the *Forest class* in 2021 occupied 31.61% more area than in 1960, when it occupied (181.99 ha) or 29.1% of the total area. As expected, classes of *Road* and *Urban facilities* recorded a slight increase in the total area. On the contrary, the class of the *Cultivated area* recorded a decrease of 4.2% and significantly changed the location within the studied area (Figure 9). The class of *Agricultural road* also experiences a slight increase, primarily due to the relocation of the *Cultivated areas*.

Table 4.
Spatio-temporal changes (STC) of LU/LC classes from 1960 to 2021.

ID	Class	1960 (ha)	2021 (ha)	Δ (ha)	Δ %
1	Low vegetation	397.54	108.2	-289.34	-46.257
2	Bushy vegetation	10.04	123.94	113.9	18.210
3	Forest	181.99	379.72	197.73	31.610
4	Agricultural roads	2.21	4.08	1.87	0.299
5	Road	3.17	4.39	1.22	0.196
6	Urban facilities	0.21	1.14	0.93	0.148
7	Agricultural areas	30.35	4.04	-26.31	-4.206

In a small percentage, there was the expansion of *Agricultural roads*, and *Urban facilities*, which may be a consequence of the revitalization of this area, which began in the early 2000s, when the Rakovica Municipal Council passed the *Decision on the formation of the Committee for the Revitalization of Barać caves* and assumed the role of the bearer of the revitalization program, while the first activities include landscaping, sources and the organization of various workshops. The revitalization of the area, the declaration of the "Baraćeve špilje" as a Significant Landscape, and the intensification of tourist activities resulted in a slight increase in the area of classes of *Urban facilities, Roads,* and *Agricultural roads*. The area of the *Road* class has increased following the construction of urban buildings in the northeast part of the protected area and, more recently, the heritage center - Speleon. Given that Table 4 shows a slight increase in the percentage of the area of the class of the *Urban facilities*, it was necessary to determine the count of the urban objects in the observed period (Table 5).

Table 5.
Number of urban objects in the „Baraćeve špilje“ (1960 - 2021)

Year	Number of urban objects	Growth
2021.	125	+12
2018.	113	+2
2014.	111	+1
2011.	110	+3
2006.	107	0
1985.	107	+72
1960.	35	/

As expected, in 1960 there were the fewest detected objects, while in 2021 there were the most. However, it should be noted that the number of objects has changed very little since 1985. The largest increase in the number of objects was recorded in the twenty-five-year period (1985 - 1960) and amounted to 72 objects. From 1985 to 2018, the increase in the number of objects was insignificant, a total of 6 new buildings were built. It should be noted that in the meantime, certain objects have been destroyed and overgrown with vegetation, making their detection difficult.

3.2 Typologies of LU/LC Changes (1960 – 2021)

The MOLUSCE extension creates a model of LU/LC changes depending on the identification number. It indicates from which source class to which destination class the change occurred. For example, the change from class 1 to class 2 is performed as "1→2". The identification numbers of the LU/LC classes are *low vegetation* (1), *bushy vegetation* (2), *forest* (3), *agricultural roads* (4), *roads* (5), *urban facilities* (6), and *cultivated areas* (7). Focusing on possible spatio-temporal changes in LU/LC, seven classes of changes or developmental types of classes were derived following the relevant literature (Jogun et al., 2019, Ma et al., 2018, Jovanić et al., 2017). Namely, given that the tool within QGIS does not have the possibility of deriving the thematic meaning of the observed changes (e.g. urbanization, secondary succession, etc.), it was added subsequently, considering the limitations of the input data used for classification and the knowledge of the nature of the processes taking place in the studied area. Guided by the determined classification, the derived model of changes was reclassified according to Table 6.

Table 6.
Reclassification of LU/LC class changes (1960 - 2021) according to the defined typology

Possible changes in LU/LC classes					
A	**B**	**C**	**D**	**E**	**F**
No change	**Succession of the vegetation**	**Degradation of vegetation**	**Urbanization**	**Agrarization**	**Secondary succession**
1→1	1→2	3→1	1→5;6	1→7	4→1;2;3
2→2	1→3	3→2	2→5;6	2→7	5→1;2;3
3→3	2→3	2→1	3→5;6	3→7	6→1;2;3
4→4			4→5;6	4→7	7→1;2;3
5→5			7→5;6	5→7	
6→6				6→7	
7→7				1;2;3;5;6;7 → 4	

The first group of changes is classified under the name (A) *Stagnation*, and includes seven possible combinations. It refers to areas where no change occurred, that is, to those areas where the same class type was recorded in the 1960s and 2021. In Figure 9, the specified areas are shown in gray. The main type of change hypothesized to be dominant in this area is (F) *Secondary succession*, which is defined as the change of LU/LC by the combined action of external and natural influence. Secondary succession implies the process of "natural renewal" of an area that was interrupted or slowed down by a certain event (forest fire, agriculture, urbanization), which leads to the revitalization of the area after the experienced disturbance. In this case, the secondary succession is found in areas where there is a disappearance, i.e. a change of surfaces that were under a certain anthropogenic influence (abandonment of cultivated areas, overgrowth of field roads, fouling of urban buildings) and after that, there is a restoration of the original vegetation of that area (e.g. forest, bushy vegetation, low vegetation). The next class of changes is grouped under the heading (D) *Urbanization*. This type of change involves the transformation of the natural classes within the LU/LC into the class of Roads or Urban Facilites. (E) *Agrarization* implies the transformation of all classes of LU/LC into cultivated area. Along with the mentioned change, changes of all LU/LC classes to the Agricultural roads class were added to this group. Namely, cultivated areas and the creation of Agricultural roads are interconnected processes in the context of the transformation of LU/LC. Agricultural roads are created with the aim of getting around and reaching cultivated areas faster. Thus, with agrarization comes the creation of new agricultural roads. The following two groups of changes can be considered as naturally caused changes, and include changes (B) *Vegetation succession* and (C) *Vegetation degradation* following the approach of Jovanić (2017) and Ma et al., (2018). In this case, natural changes include changes that occurred under exclusively visible natural influence, i.e. without clearly human influence. Change (B) includes a change from a lower vegetation order (low and bushy vegetation) to a higher vegetation order (shrubby vegetation and forest), while change (C) refers to a change from a higher vegetation order to a lower vegetation order. Change (B) in this case includes a change from a lower vegetation order (low and bushy vegetation) to a higher vegetation order (shrubby vegetation and forest), while change (C) refers to a change from a higher vegetation order to a lower vegetation order.

Table 7 shows the results of the surface typology of LU/LC changes for the period from 1960 to 2021. The largest area was recorded for the change of vegetation succession (313.24 ha), which includes the transformation of the lower order of vegetation into the higher order of vegetation, which is naturally conditioned. The second largest area is the class of stagnation, i.e. the absence of change (247.27 ha), which extends through the entire studied area (Figure 9). As expected, the smallest area was recorded for changes in urbanization and agraritization.

Table 7.
Reclassification of LU/LC class changes (1960 - 2021) according to the defined typology

Typology of change	Area of change (ha)
(A) Stagnation	247.27
(B) Vegetation succession	313.24
(E) Agrarization	8.01
(D) Urbanization	3.03
(C) Vegetation degradation	21.69
(F) Secondary succession	32.27

Secondary succession prevailed in the northeastern (NE) part of "Baraćeve špilje". Namely, that area was occupied by predominantly cultivated areas in 1960 and was abandoned, and in these locations today the dominant classes are shrubs and low vegetation. The mentioned locations are mostly further away from the main road and buildings, while the process of agrarization was recorded for individual plots created next to newly built objects along the road. It is important to highlight the area that has not experienced changes (*stagnation*) in the LU/LC typology which occupies 247.27 ha, that is, about 40% of the area of the entire studied area. The dominant type of LU/LC change is *vegetation succession*, the area of which is 313.24 ha.

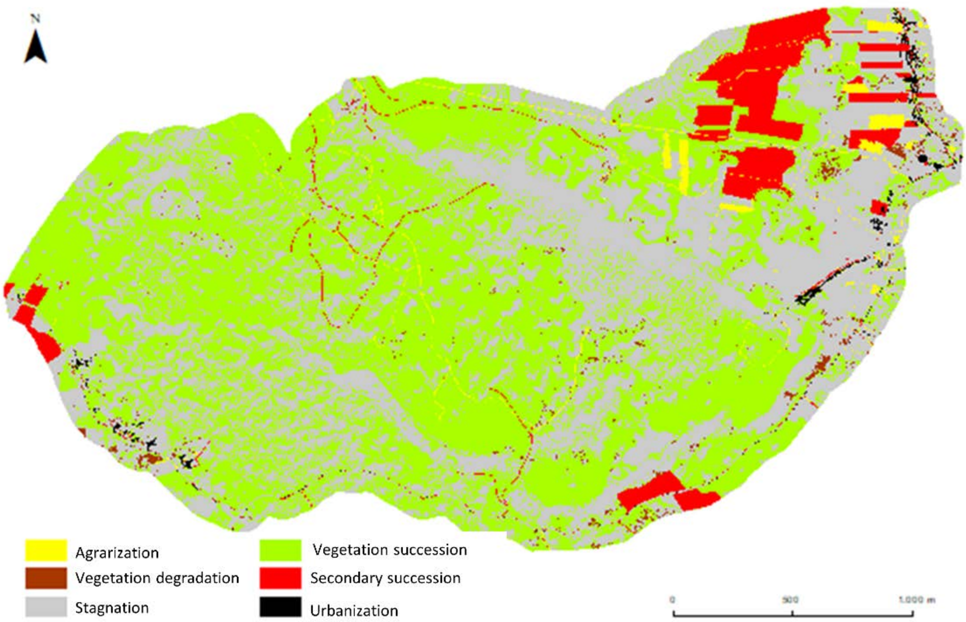

Figure 9. Spatio-temporal changes of classes in the period from 1960 to 2021.

4 DISCUSSION

The main reasons for the increase in bushy vegetation and forest class can be found in the deagrarianization, i.e. deruralization of that area and the natural process of succession of vegetation. According to Corine Land Cover data for 2018, 17% of the area of "Baraćeva šuma is currently under forest succession. According to Corine Land Cover data for 2018, 17% of the area of "Baraćeve špilje" is currently under forest succession. The area of Rakovica has recorded a continuous decline in the number of inhabitants since the Census of 1931 (Management Plan of Baraćeve špilje, 2022). Namely, the economic area of Rakovica, within which the Barac Caves are located, belongs to the hilly agricultural area of the Republic of Croatia (Magaš, 2013). Mixed production of grains, fruit, industrial plants, etc. prevails in this area, but cultivation takes place on predominantly fragmented and small properties, which does not allow the local population to be more productive. Considering the growing popularity of Plitvice Lakes, residents of this area are gradually abandoning the primary sector of activity and moving to nearby larger settlements (mainly) Slunj and opting for another type of activity, i.e. tourism (NP Plitvičja jezera). Due to these decisions of the local population, neglected areas of low vegetation gradually become overgrown and, over the years, experience a transformation from low to bushy vegetation and finally forest. The aforementioned is recognized in the official Management Plan of "Baraćeve špilje", where it is stated that the consequence of the depopulation of the wider area is the reduction of livestock, and thus of grassland areas. Due to the reduction of agricultural activities, the vegetation succession is expressed, which endangers the biodiversity and cultural landscape of the area (Management Plan of Baraćeve špilje, 2022, 44). Namely, according to the statements of the inhabitants of the Nova Kršlja settlement, in the last eight years (since 2014) the number of active population engaged in agriculture has been halved (Management Plan Baraćeve špilje, 2022, 44). Nevertheless, the category of protection Significant Landscape allows and encourages the local population to continue with the traditional type of agriculture. The original areas that were covered with grasslands and pastures unfavorable for cultivation gradually began to grow into thickets and forests due to the cessation of anthropogenic influence. It primarily refers to the cessation of meadow mowing and the cessation of grazing. Nevertheless, the anthropogenic influence did not destroy the natural diversity, and therefore today the areas of lawns and pastures have the characteristics of semi-natural habitats. The aforementioned changes are already noticeable in the period from 1960 to 1985, when agriculture made up a large part of the economy. Today, when tertiary and quaternary economic activities dominate, much more care will be needed in order to maintain the authenticity of these areas. In this context, the anthropogenic impact is seen as part of the cultural landscape that testifies to the presence of man in space and is the result of man's alteration of the natural basis. Therefore, the absence of anthropogenic impact on the landscape is not necessarily seen as a positive and desirable thing. This is recognized in the official document Management Plan for the Significant Landscape of Baraćeve špilje and associated areas of the ecological network (PU 8004) 2023-2032, where it is stated that the Institution will strive to revitalize livestock breeding and other traditional activities that are not directly related to tourism. This is an attempt to restore the traditional rural cultural landscape. The increase in the surface area of the Urban facilities is the result of the construction of supporting infrastructure, which includes a souvenir shop, landscaped paths, a bridge, a playground, fields, etc. Furthermore, the construction of a large project related to the Speleon visitor center is underway which will enable various recreational and educational activities to be held.

5 RESULTS

In the context of landscape analysis, GSTs are applied in deriving LU/LC models of spatio-temporal analysis. These models can serve as a basis for adequate decisions in the management of protected areas. As one of the younger protected areas on the territory of the Republic of Croatia, Baraćeve špilje has undergone habitat changes which to a lesser extent began to lose the originality of the landscape. Using aerial photographs and a hybrid classification method, LU/LC models and statistics of spatio-temporal changes for the period 1960. to 2021 were successfully performed. After creating the initial classifications for 2018, and applying the classification algorithm of SVM, MLC, and RT, an accuracy assessment was carried out on 500 samples. It was found that the SVM classification algorithm in the object-oriented approach has the highest overall accuracy. The Kappa coefficient was 0.68, and the overall accuracy was 79%. Regarding the type of STCs, it was established that the most dominant change in the studied period was the natural change in vegetation succession on 313.54 ha. However, after this type of LU/LC change, if the area in which the change did not occur (stagnation) is excluded, the next type of change is secondary succession.

The research showed that the abandonment of agriculture and the slow disappearance of anthropogenic influence led to the disappearance of low vegetation in the form of lawns, meadows and pastures, while the bushes and forest gradually prevailed. By encouraging the "traditional" form of anthropogenic influence allowed at this level of protection, the originality of the natural and cultural landscape can be preserved. These procedures will enable the preservation of biodiversity and maintain the conditions of original cultural landscape. The obtained data can help decision-makers in making specific action plans with the aim of maintaining or restoring the originality of the natural and cultural landscape.

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