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Front cover photography: Exploration of the collapse dolines, such as the one at the Small Natural Bridge in Rakov Škocjan, has enabled a deeper understanding of karst processes in recent years (photograph: Matej Lipar).
Fotografija na naslovnici: Raziskave udornice, kot je ta pri Malem Naravnem mostu v Rakovem Škocjanu, so v zadnjih letih omogočile globlje razumevanje kraških procesov (fotografija: Matej Lipar).

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MONITORING LAND-USE CHANGE USING SELECTED INDICES

Mojca Foški, Alma Zavodnik Lamovšek

ALMA ZAVODNIK LAMOVŠEK

Vineyards as the prevailing land use in the Lendavske gorice Hills.

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Monitoring land-use change using selected indices

ABSTRACT: This article presents various indices for describing the characteristics of land use and monitoring land-use change in various periods. These indices were either developed by the authors or were derived from landscape metrics. They were calculated for five selected sites of agricultural land (sites) for the time when the Franciscean Cadaster was introduced and for 2015. A comparison of the values of the indices revealed the changes in the selected sites, and the conclusions present an opinion on their suitability. It was found that the numerical values of the indices reflect visually detected changes in the graphic representation of land use, and they could therefore be introduced into the system for monitoring land-use changes.

KEY WORDS: land use, index, landscape metrics, Franciscean Cadaster, Slovenia

Spremljanje sprememb rabe zemljišč z izbranimi indeksi

POVZETEK: V prispevku predstavljamo indekse za opisovanje značilnosti rabe zemljišč in spremljanje sprememb rabe v različnih časovnih obdobjih. Indekse smo oblikovali samostojno ali jih prevzeli iz krajinske metrike. Izračunali smo jih za pet izbranih območij kmetijskih zemljišč (polja) v času nastanka franciscejskega katastra in v letu 2015. S primerjavo vrednosti indeksov smo na izbranih poljih ugotavljali spremembe, v zaključku pa podali mnenje o njihovi ustreznosti. Ugotovili smo, da številčne vrednosti indeksov odražajo spremembe, ki jih vizualno zaznavamo tudi pri grafični upodobitve rabe, zato menimo, da bi jih lahko vpeljali v sistem spremljanja sprememb rabe zemljišč.

KLJUČNE BESEDE: raba zemljišč, indeks, krajinska metrika, franciscejski kataster, Slovenija

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1 Introduction

Land use and land-use changes are a reflection of economic, political, and social conditions (Bičík, Jeleček and Štěpánek 2001; Antrop 2005). Land use is identified using various methods: fieldwork, identification based on available data, and, in recent decades, automated classification of remote sensing images (Kokalj and Oštir 2005). Determination of land-use changes requires data on land use over time. The first records on land use in Slovenia date back to the Theresian Cadaster (1774–1754), whereas the Franciscean Cadaster (established between 1818 and 1827) and the Revised Cadaster (1869) are most frequently used for studying land-use changes. They also depict land uses in a graphic section, offering better representation of their spatial distribution (Petek and Urbanc 2004). Tax assessment prompted rather detailed consideration of agricultural land use; specifically, at the plot level (Ribnikar 1982). The Franciscean Cadaster as a source for studying land-use changes has been used by Petek (2005; 2007), Kladnik and Petek (2007), Verderber (2013), Golob (2014), Harvey, Kaim and Gajda (2014), Bičík et al. (2015), Gabrovec and Kumer (2019), and many others.

The Franciscean Cadaster was also used as a source to study land-use changes in this study. Land-use changes in selected sites were checked using indices, which were developed either on our own or were derived from landscape metrics. Index development depends on the study purpose, scale of observation, size of the study area, and type of data (raster or vector). This article shows how the indicators developed are suitable for describing land-use changes, and that the numerical values obtained reflect changes detected by visually comparing mapped land uses in two time periods (at the time the Franciscean Cadaster was introduced and in 2015 using Land Use data base (Evidenca dejanske … 2015).

Landscape metrics (LSM) began to take root after 1995 for analyzing the situation and changes in the landscape and ecological spatial characteristics. This is a successful method for determining the heterogeneity of land cover (Turner et al. 2003) as well as for identifying changes. Landscape metrics indices for quantifying landscape elements and landscape compositions were developed by McGarigal and Marks (1995), McGarigal (2002) and further improved until the most recent version of the software program FRAGSTATS 4.4 (McGarigal 2015). As software, Patch Analyst (an extension to the ArcGIS software; Sushant and Yuan 2012; Rempel, Kaukinen and Carr 2012) is commonly used, whereas Polenšek and Pirnat (2018) used Graphab 1.1 for spatial analysis of forest patches.

The landscape metrics method is most commonly used in ecology, where the diversity, spatial distribution, size, and shape of patches are relevant (Alberti 2005), but other sciences also benefit from its use. Irwin and Bockstael (2007), Clark et al. (2009), Shrestha et al. (2012), and Zhang et al. (2013) used this method to study interactions between urbanization and changes in parcel shape and size. Sivrikaya et al. (2007), Pijanowski and Robinson (2011), and Shoyama and Braimoh (2011) used it to analyze land-use changes across various periods.

The basic observation unit in landscape metrics is a »patch« (Polenšek and Pirnat 2018; Foški 2017). For the purpose of this study, a patch is understood in the same way as it was defined by Irwin and Bockstael (2007, 20673) and Shrestha et al. (2012); namely, as a contiguous area of the same land use. This method is most commonly used with raster data, particularly when study areas are large (Wu et al. 2002). When comparing areas, one must first allow for equal quality of input data or raster-to-vector conversion under the same conditions and at the same scale (Wu et al. 2002). The use of indices at different levels and at different scales is reasonable using vector data.

McGarigal (2015) identified six groups of indices and, within each group, indices may be defined at the patch level (defined for individual patches), class level (all the patches of a given type), and landscape level (all patches in the study area), as shown in Table 1. Based on their meaning, one can distinguish between a group of indices that express land-use composition (e.g., the number of different land uses, land-use proportions, or the number of patches) and a group of indices expressing the characteristics of a spatial pattern (Ramezani et al. 2013).

At the level of the study area, land-use diversity indices are particularly interesting (Table 1, gray field), which can be divided into three groups: 1) indices of patch number and density, three indices, 2) land-use diversity indices, three indices, and 3) indices of land-use distribution in the area, three indices (McGarigal 2015, 164-171; Foški 2017). The indices can be used for monitoring land-use changes across time. Shannon's diversity index and Simpson's diversity index are most commonly used (Robič 2004; Pijanowski and Robinson

Table 1: Number of indices of landscape metrics based on McGarigal (2015) for individual characteristics at the patch, class, or landscape level (authors' own classification).

Index groups	Patch (number of indices)	Class (number of indices)	Landscape (number of indices)
Area and edges	3	7	6
Shape	5	7	7
Compactness	3	7	6
Contrast	1	3	3
Aggregation	3	16	15
Diversity	0	0	9

2011; Ramezani and Holm 2011; Comer and Greene 2015). A comparison of indices (Lo Papa, Palermo and Dazzi 2011, 340) showed that for describing land-use diversity it is enough to choose a single index, either from the second group or from the third.

For the purpose of this study we also used some landscape metrics indices; the patch richness index (PR), the number of patches (N_z), the relative land-use diversity index (RPR), and Simpson's diversity index (SIDI), as developed by McGarigal and Marks (1995) and McGarigal (2015). We developed the Use Proportion Index (IDr) and the Index of Shape and Size of Patches (IOV_z) ourselves (Foški 2017). A combination of indices was used to analyze land use in selected sites (enclosed arable land) at the time the Franciscean Cadaster was introduced and in 2015. Our thesis was that numerical values (indices) can describe the characteristics of land use in two time periods and that the changes in index values are also reflected visually; that is, on graphic representations of land use in two time cross-sections. To that end, this article graphically presents land use in two time cross-sections, whereas values and changes in indices are expressed numerically and with graphs.

2 Working method and data

The working method consists of three steps: 1) development and selection of indices, 2) calculation of indices for selected test areas in two time cross-sections, and 3) evaluation of results.

The indices were determined based on the literature and land-use characteristics in Slovenia. For this, the following data are required:

- Land-use diversity in the study area (patch richness and the number of all patches);
- Distribution of land-use proportions in the study area (the ratio between the proportions of land uses);
- Characteristics of patches (shape and size) in the study area (contiguity and the size of individual patches); and
- Relationships between all land uses.

The indices were selected and developed (Table 2) so that they are computable using vector data. The patch richness index (PR) and the number of all patches are greater than 1, and all other indices range from 0 to 1. The extension FK was added to the indices calculated from the Franciscean Cadaster data (e.g., $PR_{\_FK}$).

Five sites were selected as areas of observation: Zatolmin, Vinjole, Predoslje, Kleče and Podgora, and Pernice (Figure 1). These differ in terms of arable land division (Ilešič 1950), land-use diversity, size of contiguous areas of one land use, land-use fragmentation, and different landscape types (Perko, Hrvatin and Ciglič 2015). Vinjole (arable land division into irregular blocks) is not an independent settlement but instead a hamlet of Lucija; it was selected because of its mix of olive and grape patches, significant overgrowth, and small-size patches. In Zatolmin (arable land division into irregular blocks), fields and grassland intermix; the fields are as a rule small and inside meadows, and there is little overgrowth. In Predoslje (arable land division into furlongs) and Kleče and Podgora (arable land division into continuous strips), open fields in large patches prevail, and land-use diversity is small. Agricultural land was consolidated in Predoslje. At Pernice (arable land division into enclosures) there is a mix of various uses in large and small patches, the area is undulating, and agricultural land is surrounded by forests.

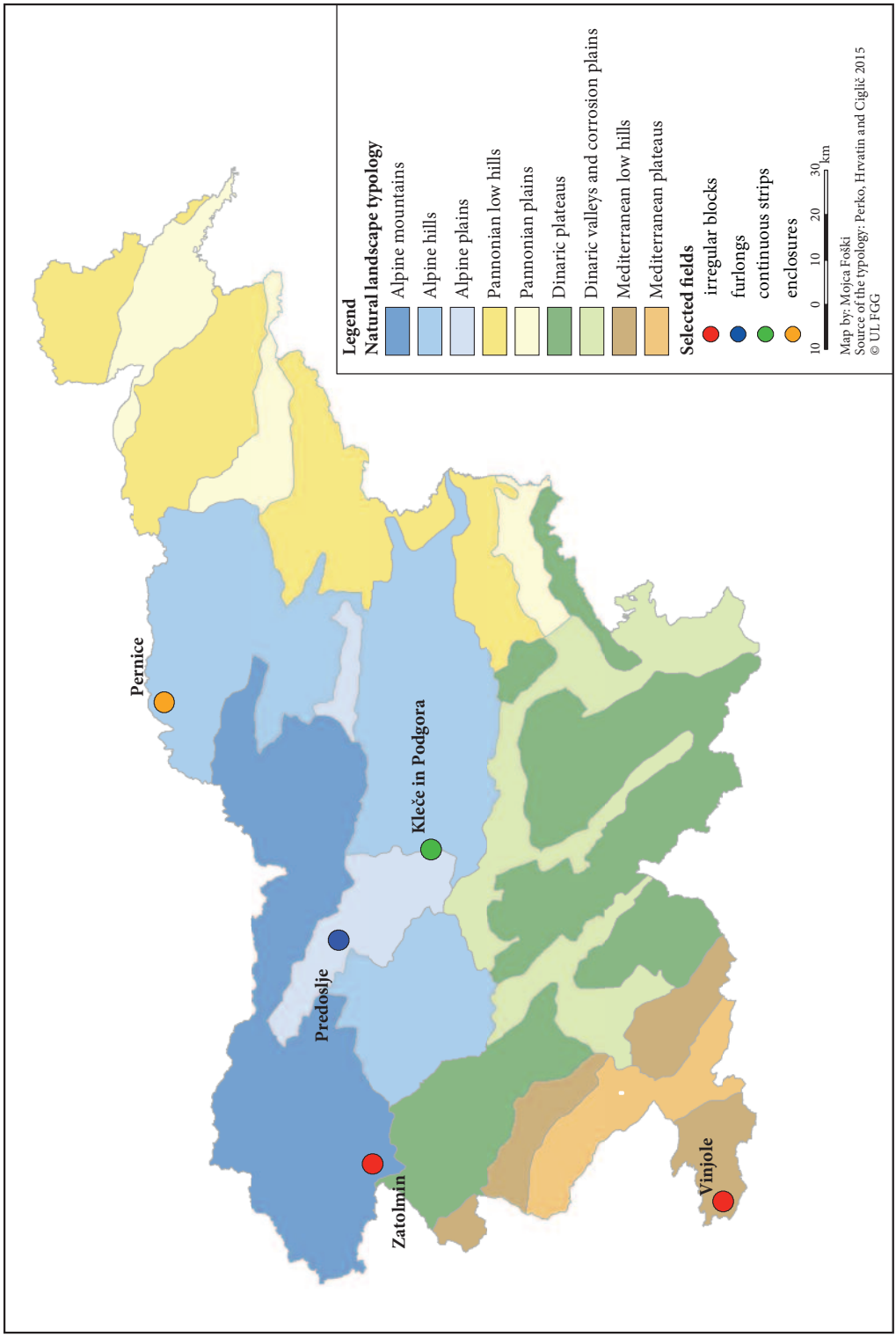
Table 2: Selected indices for land-use characteristics.

	Index type name	Equation; Range	Brief description
Diversity of land use	Patch richness index	$PR = m$ $PR \geq 1$	m = number of different land uses Nz = number of all patches.
	Number of all Patches	Nz $Nz \geq 1$	m_{max} = maximum number of possible land uses. $m_{max} = 25$
	Index of the Relative Number of Land Uses	$RPR = \frac{m}{m_{max}}$ $0 < RPR \leq 1$	$m_{max\,PR} = 25$
Land-use proportion distribution	Land-use proportion index	$IDr_i = \frac{R_i}{A_0}; R_i = \sum_{i=1}^{n} r_i$ $0 < IDr_i \leq 1$ $\sum_{i}^{m} IDr_i = 1$	R_i = area of a single land use; this is the sum of areas of all patches of land use r. A_0 = area of the site. The sum of proportions of all land uses in a site is 1. If a single land use exists, the index value is 1. The value of 0 is unattainable.
Characteristics of patches of a single land use	Index of shape and size of patches	$IOV_Z = \frac{I'_{kom} + 2 \times I'_{vel}}{3}$ $0 < IOV_Z \leq 1$	This describes the shape and size of a patch $I'_{kom} = \frac{4\pi A}{p^2}$; A = area and P = perimeter I_{vel} was obtained with linear standardization of patch areas using the following equation: $I'_{vel_i} = 0.05\ ha \rightarrow I_{vel} = 0$ $0.05\ ha < I'_{vel_i} < 4ha \rightarrow I_{vel_{ij}} = \frac{I'_{vel_{ij}}}{I'^{max}_{vel_{ij}}}$ $4\ ha \leq I'_{vel_i} \rightarrow I_{vel} = 1$
Land use ratios	Simpson's diversity index	$SIDI = 1 - \sum_{i=i}^{m} Ad_i^2$ $0 \leq SIDI \leq 1$	Ad_i = proportional part of land use in the study area, where there are m different land uses. $\sum_{1}^{m} Ad_i = 1$ $SIDI = 0$, when there is a single land use, approaching 1 by increasing the number and evenness of distribution of land-use proportions.

The land divisions were based on geographical dividing lines (to a stream, road, forest, or village) or the cadastral municipality boundary. We selected a contiguous area of land showing the characteristics of arable land division (Ilešič 1950; Foški 2017). For Zatolmin and Predoslje, all of the agricultural land is considered within a cadastral municipality. For Kleče and Podgora, the agricultural land between Podgora and Kleče that is still divided into strips is considered; furthermore, nine contact enclosures within the cadastral municipality of Pernice are considered. In Vinjole we address the geographically coherent areas of a hamlet based on geographical divisions (i.e., stream, ridge, forest, or road). The sites were named after the closest settlement or hamlet. The analysis of land use in 2015 was carried out using data from the Land Use data base (Evidenca dejanske rabe … 2015). Using graphic cross-sections, the Land Use data base data were trimmed to the area of the sites. All patches smaller than 20 m², which are a consequence of the graphic cross-section of the Land Use data base with the area of a site and which are at the edges of an area, were aggregated with contiguous land use.

For all selected sites we obtained cadastral maps of the Franciscean Cadaster from the Archives of the Republic of Slovenia (Franciscejski kataster za Kranjsko 1825; 1826; Franciscejski kataster za Primorsko 1822; Franciscejski kataster za Štajersko 1825) or the State Archives in Trieste (Catasto franceschino 1818) and georeferenced them using affine transformation in ArcGIS 10.3 based on the tie points from the land

Figure 1: Distribution of test sites by various landscape types of Slovenia. ► p. 166


Legend
Natural landscape typology
Alpine mountains
Alpine hills
Alpine plains
Pannonian low hills
Pannonian plains
Dinaric plateaus
Dinaric valleys and corrosion plains
Mediterranean low hills
Mediterranean plateaus
Selected fields
irregular blocks
furlongs
continuous strips
enclosures
10 0 10 20 30 km
Map by: Mojca Foški
Source of the typology: Perko, Hrvatin and Ciglič 2015
© UL FGG
Pernice
Kleče in Podgora
Predoslje
Zatolmin
Vinjole

cadaster depiction (Zemljiški kataster 2015). Vectorization was carried out and the data were topologically sorted. Based on the records and the associated key of the Franciscean Cadaster (Franciscejski kataster za Štajersko 1823–1869; Čuček 1979; Čuček-Kumelj 1983), the land use at the time the Franciscean Cadaster was introduced was classified into twenty-five classes: field, vegetable garden, fruit garden, hop plantation, field with fruit trees, field with olive trees (olive grove), vineyard, vineyard with olive trees, dry meadow, wet meadow, meadow with scrubland, meadow with fruit trees, pasture, pasture with trees, wetland, wetland with rushes, deciduous forest, coniferous forests, mixed forest, grove, shrubs, built-up land (occupied by structures and tracks), water, quarry, clay pit or rock and other. Some categories, such as saffron, chestnut plantations, paddy fields, and so on, were not included in the total sum of land uses because we assumed that they are not found in Slovenian territory. Altogether, the Land Use data base contains twenty-five land uses (Interpretacijski ključ 6. 2. 2014).

The analysis (calculations of indices and graphic representations) was performed in ArcGIS 10.3 (Esri); Microsoft Excel 2010 and IBM SPSS 23 software were used for calculations and statistical processing.

3 Results

Figure 2 shows land uses in selected sites for 2015 and for the time when the Franciscean Cadaster was introduced. Table 3 shows the calculated values of indices (PR, Nz, RPR, IDr_{max}, SIDI) and the IDr distribution. The Use Proportion Index (IDr) is shown in the last column of Table 3 as a graph. For each land use its proportion is shown, and the graphic representation shows the relationships between land-use proportions in two time periods. For example, in Pernice there are ten different land uses identified today (PR = 10), but only two land uses stand out in terms of proportion (Table 3, the last column). There were five land uses (PR = 5) there at the time the Franciscean Cadaster was introduced, but they were more evenly distributed (Table 3, last column).

Figure 3 shows the case of Vinjole with a graphic depiction of the IOVz and IOVz_FK values, and Figure 4 shows the distribution of values IOVz and IOVz_FK in the histogram with ten equally sized classes. The same methodology was used to analyze all other selected sites; the analysis results are available in Foški (2017, 187–202).

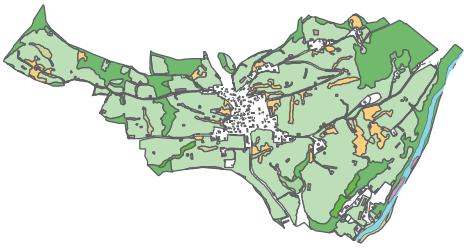
The number of various land uses (i.e., richness; Table 3, column 1) increased in all sites, the most at Vinjole (i.e., from three during the establishment of the Franciscean Cadaster to twelve land uses in the Land Use data base). In Vinjole, the number of patches (Nz) increased significantly as well, from eighteen to 464. The number of patches remained almost the same in Predoslje, whereas the prevailing land-use proportion changed (IDr_{max}). Interestingly, during the establishment of the Franciscean Cadaster, fields prevailed ($IDr_{max\_FK} = 0.93$) with much larger areas than those today ($IDr_{max} = 0.49$), even though agricultural land consolidation was undertaken in the area. A similar trend of a decreasing proportion of arable land is observed in Kleče and Podgora ($IDr_{max\_FK} = 0.93$; $IDr_{max} = 0.62$). In Zatolmin, meadows with trees prevailed at the time the Franciscean Cadaster was introduced, whereas today meadows prevail (land-use code 1300 from the Land Use data base). In Vinjole, olive groves still prevail, but their proportion decreased substantially ($IDr_{max\_FK} = 0.97$, $IDr_{max} = 0.26$); at present, olive groves are identified only when they are the prevailing land use in an area larger than 500 m² (Interpretacijski ključ 6.2 2014). Forest land prevails in Pernice, whereas pastures with trees prevailed when the Franciscean Cadaster was introduced.

Land-use changes can be identified using Simpson's Diversity Index. At Vinjole, Simpson's diversity index changed from 0.07 during the introduction of the Franciscean Cadaster to 0.99 in 2015. An index close to 0 suggests the prevalence of a single land use, as is evident in Figure 2 (Vinjole in 1818), whereas an index value close to 1 suggests an equal distribution of a larger number of land uses, as is evident in Figure 2 (Vinjole in 2015). Importantly, when the Franciscean Cadaster was established, the land use »vineyard with olive trees« was registered for almost all of Vinjole, whereas today mixed uses are no longer in place and the land uses »vineyard« or »olive grove« are registered separately if they cover an area greater than 500 m² (Interpretacijski ključ 6.2 2014). Land-use diversity inside individual parcels during the establishment of the Franciscean Cadaster was greater, whereas today land-use diversity in the entire study area of Vinjole is greater (PR = 12). The same values of SIDI and SIDI_FK for Predoslje and for Kleče and Podgora

Figure 2: Land use in 2015 and at the time the Franciscean Cadaster was introduced. ► p. 168–169

Zatolmin

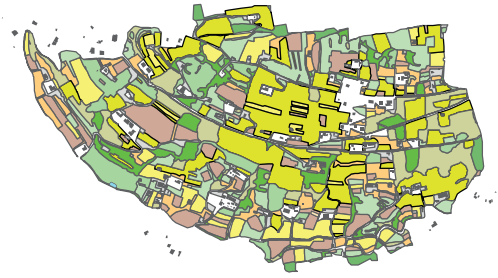
2015



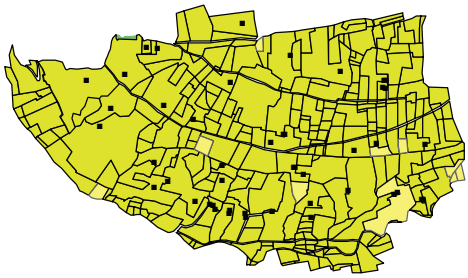
1822

Vinjole

2015



1818



Predoslje

2015

1826

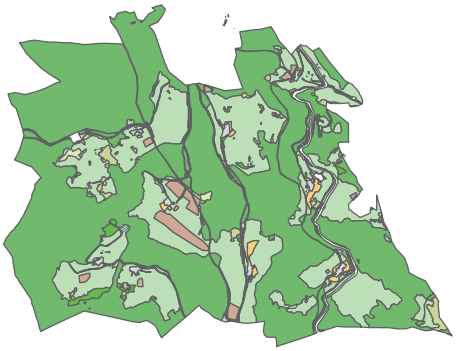
Kleče and Podgora

2015

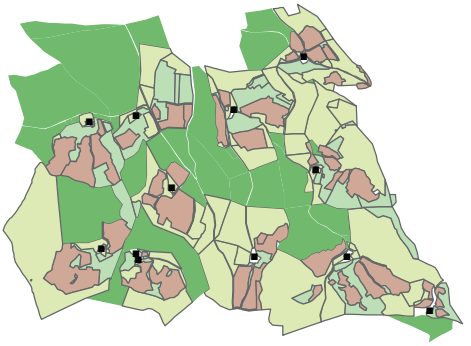
1825

Pernice

2015



1825



Legend land use 2015

- Objects
- Arable land
- Vineyards
- Extensive orchards
- Meadows and pastures
- Olive groves
- Overgrown areas
- Forest trees on agricultural land
- Riparian overgrowth and forest hedges
- Forest
- Built–up areas and related surfaces
- Waters

Legend land use 1818–1826

- Objects
- Arable land
- Vegetable garden
- Vineyards
- Vineyard with olive groves
- Dry meadows
- Meadows with orchards
- Pasture/Pasture with trees
- Coniferous forest
- Deciduous forest

0 0.25 0.5 0.75 1 km

Content and map by: Mojca Foški
Source: Catasto franceschino 1818; Franciscejski kataster 1822–1826; Evidenca ... 2015

show a similar trend of changes. A similar value of SIDI (close to 0.55) is found in Zatolmin, Predoslje, Kleče and Podgora, and Pernice; two land uses prevail, as illustrated in the graphs (Table 3, last column). The proportion of prevailing land use (IDr_{max}) at the time the Franciscean Cadaster was established and that of today suggests that prevailing land use has changed.

Table 3: Land-use fragmentation for selected sites in 2015 and at the time the Franciscean Cadaster was introduced.

Field	PR	Nz	RPR	IDr_{max}	LAND USE (IDr_{max})	SIDI	distribution chart IDr
Zatolmin	11	190	0.44	0.65	meadows	0.53	
Zatolmin FK	4	128	0.16	0.51	pasture	0.62	
Vinjole	12	464	0.48	0.26	olive groves	0.99	
Vinjole FK	3	18	0.12	0.97	vineyard with olive groves	0.07	
Predoslje	8	113	0.32	0.49	arable land	0.54	
Predoslje FK	4	106	0.16	0.93	arable land	0.13	
Kleče and Podgora	9	137	0.36	0.62	meadows	0.54	
Kleče and Podgora FK	4	49	0.16	0.93	arable land	0.13	
Pernice	10	271	0.4	0.63	forest	0.51	
Pernice FK	5	124	0.2	0.36	pasture with trees	0.71	

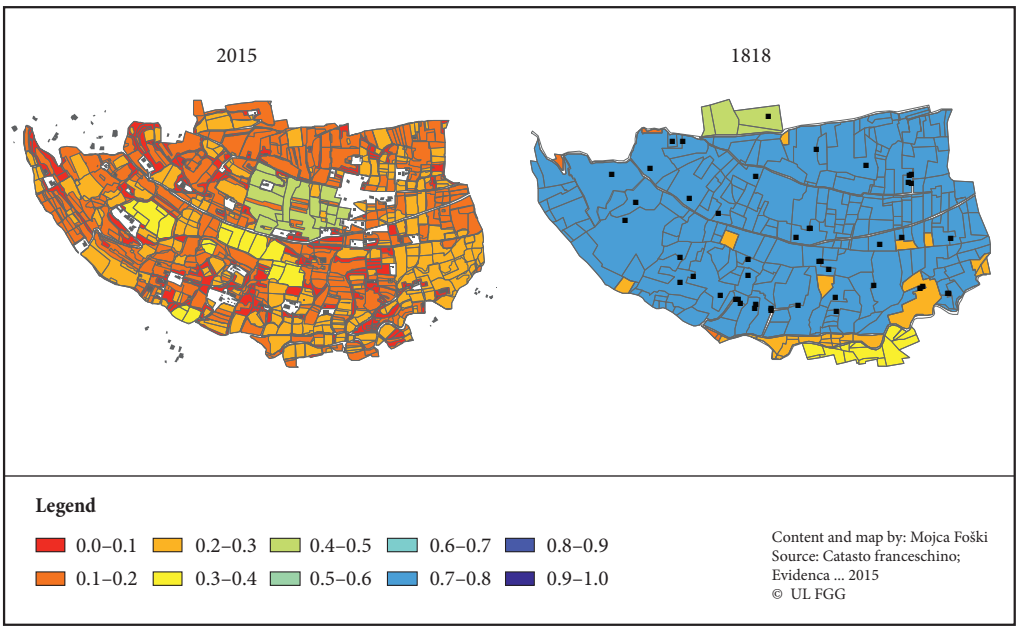
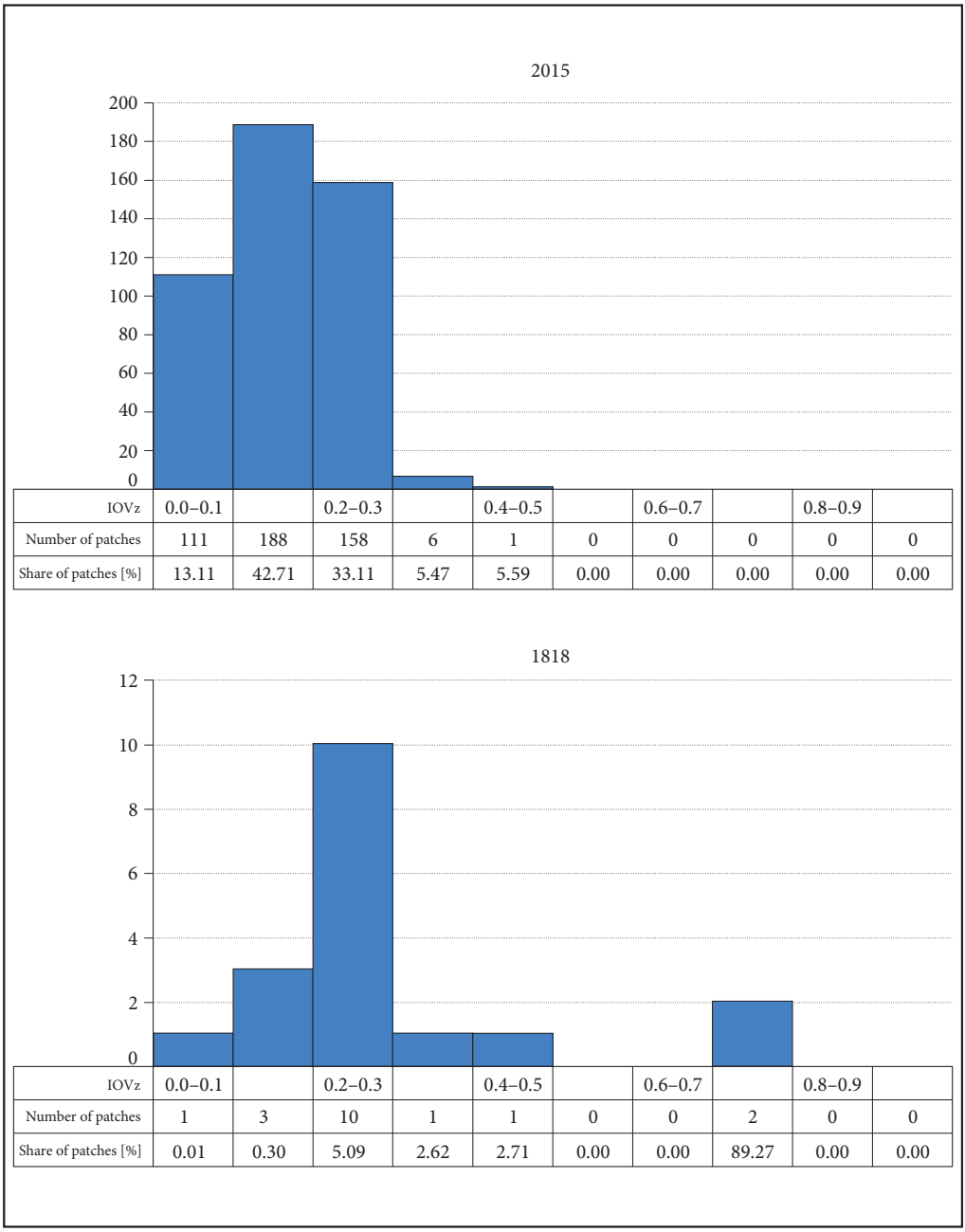


Figure 3: Index of Shape and Size of Patches (IOVz) for Vinjole.

The changes in indices are also evident in visual depictions of land use in two time cross-sections (Figure 2). As a rule, the graphic representation fails to show the entire extent of land-use diversity because the proportions of land uses are rather small. The changes in prevailing land uses (Table 3, IDr_{max}, graph) and the distribution of land uses in a site are clearly evident (Table 3, SIDI, graph).



IOVz	0.0–0.1		0.2–0.3		0.4–0.5		0.6–0.7		0.8–0.9	
Number of patches	111	188	158	6	1	0	0	0	0	0
Share of patches [%]	13.11	42.71	33.11	5.47	5.59	0.00	0.00	0.00	0.00	0.00

IOVz	0.0–0.1		0.2–0.3		0.4–0.5		0.6–0.7		0.8–0.9	
Number of patches	1	3	10	1	1	0	0	2	0	0
Share of patches [%]	0.01	0.30	5.09	2.62	2.71	0.00	0.00	89.27	0.00	0.00

Figure 4: Distribution of values IOVz for Vinjole.

The Index of Shape and Size of Patches (IOVz) shows the relationship between small and large patches. The index is calculated for each patch separately, whereas the situation for the area of a site (all patches) is best illustrated using a histogram in ten equal classes (Figure 4, the case of Vinjole). The large number of patches in lower classes (0.0–0.1; 0.1–0.2; 0.2–0.3) suggests large land-use fragmentation, particularly if the proportion of the land use in question in the site is large. The histogram for the case of Vinjole (Figure 4) shows that many patches are in the first three classes, which together make up 88.93% of the study area, whereas a detailed land-use structure is also visible in Figure 2 (the case of Vinjole). The large number of patches in higher classes (0.7–0.8; 0.8–0.9; 0.9–1.0) suggests large contiguous areas of land use, particularly when the proportion of these land uses is large. The two patches in the 0.7–0.8 class shown on the histogram (Figure 4) correspond to a full 89.27% of the area, and land-use contiguity is also evident in Figure 2 (the case of Vinjole). Because of mixed land use at the time the Franciscean Cadaster was introduced, in the area there was an even mix of vineyards and olive trees, whereas today the large number of patches in the area (Nz = 464) and their land-use diversity suggest a much higher landscape diversity of the area. The working methodology for capturing land use in the Land Use data base should be emphasized, where the number of polygons increases with each new revision of data, despite the fact that the spatial situation has not changed (Foški 2018).

4 Discussion

Generally, a single index can describe one land-use characteristic; the illustration of various land-use characteristics requires a larger set of indices, for which it is important that they be independent and that their number not be too large. The selection of indices for describing land use in a site was recognized as being sufficient. Because there were a maximum of twenty-five land uses both during the introduction of the Franciscean Cadaster as well as in 2015, the index of the relative number of land uses was found to be less useful. Nevertheless, this correspondence in the number of various land uses is purely accidental. The number of land uses in the Franciscean Cadaster is, in fact, larger, but we only took into account the land uses found in Slovenian territory. Its applicability would increase if the number of land uses in two time cross-sections varied. In any case, the number of different land uses in two time periods does not say anything about the comparability of individual categories. We are also unable to precisely determine the relationship between the individual categories in the past and today due to the various criteria and the purpose of determining land uses. At the time the Franciscean Cadaster was established, a distinction was made between a meadow with scrubland, a meadow with fruit trees, a pasture, and a pasture with trees. Today, on the basis of Interpretation Key (Interpretacijski ključ 6.2 2014), we register extensive orchards, permanent meadows, and marshy meadows. Pastures with trees prevailed in Pernice at the time the Franciscean Cadaster was introduced, whereas today this category is often divided into permanent grassland and overgrown areas. Even at the level of a meadow one cannot equate the land use at the time the Franciscean Cadaster was introduced with the categories used today. Today the land use in Vinjole (mixed land use at the time the Franciscean Cadaster was introduced) is classified into vineyards and olive groves separately.

Some authors (Petek 2005; Verderber 2013; Gabrovec and Kumer 2019) made a comparative table of land uses at the time the Franciscean Cadaster was introduced and in the Land Use data base, respectively, but they combined some of the categories (e.g. field, meadow, forest, and vineyard), which was suitable for the purpose of their work, whereas the information on land-use diversity in various time periods was lost. Due to the incomparability of the categories, the information on land-use richness can be somewhat misleading. This can be avoided if one is familiar with all the characteristics of identifying land use across different time periods.

A comparison of data from two time periods is possible if the data used are of equal quality (Wu et al. 2002) – which, however, cannot be said for the data on land use at the time the Franciscean Cadaster was introduced and the Land Use data base in 2015. The minimum mapping unit, working methodology, precision and accuracy of data, and data maintenance vary. We believe that such differences in data fail to impact the key findings and the checking of indices' usefulness, and that the data from the Franciscean Cadaster, particularly with vectorization in place, are highly useful for identifying land-use changes, which is in agreement with the findings by Petek and Urbanc (2005), Harvey, Kaim, and Gajda (2014), Bičík et al.

(2015), and Gabrovec and Kumer (2019). The time interval (approximately 180 years) is large enough to make the changes obvious so that they are reflected in the indices.

The number of land-use types present, or patch richness (PR), increased in all sites compared to the time when the Franciscean Cadaster was introduced. The increased number of patches, the decreased number of large enclosed patches (IOVz), and the decreased prevailing land-use proportion (IDr_{max}) suggest land-use fragmentation and larger diversity of vegetation cover. This finding contradicts some studies, which suggest a decrease in land-use diversity and particularly an increase in contiguous areas of a single land use, usually forests (Munroe, Croissant and York 2008; Hansen and Adhikari 2018). Such findings are often the result of analyses of raster data (pixel size) and in large territorial areas (data generalization; Wu et al. 2002). By studying land use in small spatial units, using vector data, one can see the changes that can be lost because of the type of data and the scale (Wu 2004). The cases of studying characteristics of land use at the micro level are essential for understanding landscape ecology (Fischer, Hanspach and Hartel 2011) and can contribute to the understanding of global problems. Some authors (Plieninger et al. 2016) also emphasize that researchers all too frequently focus on studying land-use changes rather than land-use stability. In fact, in 30.1% of the EU-27 member states' area there is no indication of an increase in fragmentation (Meiner and Pedroli 2017).

The large number of land uses is often visually not detected, particularly if the study area is not large or when the land-use structure is very fine. This is why using indices is more appropriate than visual comparisons of land-use maps. The index can be calculated for the data in various time cross-sections, and the interpretation of the values in a time series allows continuous monitoring of the land-use situation and its changes. Therefore indices could be introduced into systematic land-use monitoring in all spatial units.

The SIDI index is easy to calculate, and its value is a good indication of land-use distribution and fragmentation. It depends on the prevailing land-use proportion (IDr_{max}) and the patch richness (PR). Values up to 0.5 show low fragmentation (the case of Predoslje, and Kleče and Podgora at the time the Franciscean Cadaster was established), whereas above 0.7 the land use is fragmented (e.g., Vinjole) because the share of prevailing land use is below 40%. This index is the basic indicator of land-use fragmentation. Based on the available, regularly updated vector land-use data (the Land Use data base), we see great applicability of the SIDI index in systematic monitoring of the situation and land-use changes.

5 Conclusions

Land-use changes are among the indicators of social processes, and knowledge of these changes is crucial for many fields of research. This article proposed a method for analyzing and monitoring land-use changes using indices. Using the indices, we pointed out changes that are overlooked at smaller scales and we drew attention to land-use fragmentation and the increasing number of patches. The indices increase the objectivity of research work and facilitate systematic monitoring of the land-use situation. Indices have commonly been used for identifying land-use characteristics abroad, and we recommend their use in Slovenia as well.

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