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Vanishing landscape of the "classic" Karst: changed landscape identity and projections for the future

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HIGHLIGHTS

- Changed landscape identity of the classic Karst was perceived in the last 250 years.
- Grasslands declined for 3.5× from 1763/1787 to 2012.
- The MLP model output validation revealed 89% similarity.
- Predictions indicate the speed of grassland overgrowing of 2.2 km^2/year.
- Maintenance of grassland remnants should be incorporated in landscape planning.

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ABSTRACT

Continuous change over an area of 238 km^2 of the "classic" Karst in Slovenia, previously severely deforested, has resulted in a change of the landscape identity in last 250 years (from 1763/1787 to 2012): grasslands declined from 82 to 20% and forests progressed from 17 to 73%. The Multi-Layer Perceptron model was validated before making predictions for further landscape change using the Markov chain method: a predicted map for 2009 was produced and compared with an actual one. Image similarity statistics indicate 89% similarity and the spatial distribution of predicted grasslands agrees in 98% of locations. The prediction estimates that grasslands will cover 18 km^2 less in 2025 than today and will then shrink to just 6 km^2 (3%) in 2100. The speed of grassland overgrowing was calculated on 2.2 km^2/year. Forest area will expand by 18 km^2 until 2025, compared to 2012. In 2075, forest will cover 88% of the whole study area, and will reach 90% in 2100, achieving then an almost steady-state situation. Calculation of the spatial change trend for grasslands enabled us also to determine where in space the overgrowing process will occur during each of the predicted periods. Congruent aspects of changed landscape identity (e.g. landscape beauty, diversity, and wilderness) are discussed, but according to legal obligations regarding the conservation of Natura 2000 grassland habitats, the management with grassland remnants (5% of grasslands was already lost after the Slovenian accession to EU in 2004) are suggested to be incorporated in landscape planning.

1. Introduction

Kras, karst, carso, causse ... these are all names describing the same phenomenon in different languages, but with a single origin. The name "kras"—karst derives from the pre-Indo-European stem "ka(r)a" meaning "stone" (Kranjc, 1997). The word is still alive in Irish Gaelic (carraig = rock) and in various forms in the Iranian and Albanian languages. The French town of Carcassonne means "on the rock" (Kranjc, 1997).

The Karst (Kras, Carso) is part of a limestone karst plateau, lying above the bay of Trieste in the northernmost part of the Adriatic Sea, and is known for its geological, geomorphological, and speleological phenomena. The toponym "Kras" or "Karst", a basionym for the name "karst" or the Italian "carso", was introduced as the professional term for any karst area in the world: the term "karst" became a synonym and later a technical term for a landscape formed from the dissolution of soluble bedrock (limestone or dolomite), which

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is characterized by distinct topography with sinkholes, caves, and underground drainage systems. Consequently, the toponym Karst, which gave its name to the technical term karst, became known in the literature as "classic Karst".

The "Classic" Karst area is traditionally known as a bare, non-forested stony grassland area. This landscape identity was formed over the past two millenniums, when the area suffered severe deforestation, erosion, and almost desertification. The peak of deforestation is thought to have been in the seventeenth to nineteenth centuries (Kaligarič, Culiberg, & Kramberger, 2006). Valvasor's (1689) description is illustrative: "The earth is very stony . . . in some places one may see for miles, but everything is grey, nothing is green, everything is covered by rocks . . . The people are lacking water, yes; they are completely without it . . . Sometimes they do not have any wood and very small fields" (after Kranjc, 1997). Edward Brown, a member of the Royal Society of London, travelled to the Karst in 1669 and in 1685 published his *A Brief Account of Some Travels*, which was the first English source for international readership about the "classic" Karst area and its phenomena.

The landscape is well documented both in old pictures and in verbal descriptions. The Mercator map published in Amsterdam in 1642 (after Kranjc, 1997) shows the "Karstia" region as completely treeless. In lithographs by Valvasor (1689), the landscape is open, stony grassland with solitary trees, even in places that are now densely forested. One hundred years later, Gruber (1781) described his journey from Postojna to the Adriatic Sea: "High calcareous mountains are predominant treeless . . . stony bare landscape is more extensive, closer to the sea." Another hundred years later, Czörnig (1891) observed from the train between Ljubljana and Trieste, crossing the "classic" Karst region: "in such a civilized Europe, so hopeless an image of a bare and treeless landscape!" The landscape identity had been formed.

Once characterized by very limited living resources, the sparsely populated landscape has completely changed nowadays: the visual impression is of an extensive forest, interrupted here and there with settlements and fragmented grassland patches. Even at first sight, it could be concluded that the landscape identity has changed.

What, however, is a landscape identity? Landscape identity has been defined from many perspectives: from physical features and spatial morphology, to the cultural heritage or socioeconomic image of the landscape. The perception of a landscape can be strictly personal and emotional, on the one hand, or collective and objective, on the other. The definition of the European Landscape Convention is wide enough: "Landscape is an area, as perceived by the people, the character of which is the result of the action and interaction of natural and/or human factors" (Council of Europe, 2000). Stobbelaar and Pedroli (2011) defined landscape identity as "the perceived uniqueness of a place", a definition which might have weak points, since perceptions among people can differ. The perception of landscape identity frequently raises value judgments among people: everyone seeks the "landscape of his youth" in a constantly changing environment. However, the degradation of landscape in relation to the loss of "landscape beauty" has been studied from many angles (Appleton, 1994; Hunziker & Kienast, 1999; Naveh, 1995; Nohl, 1982). "Landscape aesthetics" (Appleton, 1994; Hunziker & Kienast, 1999; Kaplan, Kaplan, & Brown, 1989), "scenic beauty" (Bishop & Hulse, 1994; Hunziker & Kienast, 1999), and "scenic quality" (Arthur, 1977; Brown & Daniel, 2008; Buhyoff, Hull, Lien, & Cordell, 1986) are the parameters often used to determine at least some components of landscape identity.

Land-use and land-cover are parameters that influence all other assessments, which include values, leading to judgments about a landscape's "beauty" and "quality". The land-cover transitions can be traced by using old cartographic material and aerial photographs. Aerial photographs taken at intervals (e.g. every 10 years), together with environmental data and physical attributes, can be correlated with land cover (Hietel, Waldhardt, & Otte, 2004). An aerial photograph chronosequence can also be successfully used to assess other influences: e.g., the historical nature of a disturbance regime (Hirst, Pywell, & Putwain, 2000). The land cover could be deeply understood by the present field survey of biodiversity: results obtained by various classifications and interpretations of remote-sensing data often require field evaluation. Where the landscape contains a fine-scale mosaic, as in the classic Karst (Kaligarič, Sedonja, & Šajna, 2008), the scale in which, e.g., landscape transitions are demonstrated, should be adopted accordingly. When the remotely sensed data are verified in the field, the mapping resolution is of highest importance: in the Slovenian national program of habitat mapping, the horizontal resolution is defined as 2 meters. Regarding the typology, different approaches are used. Smith and Theberge (1986) emphasize that vegetation communities are the most commonly used spatial unit for assessing diversity. As suggested by Kati et al. (2004), standard habitat typologies predominantly based on vegetation types, according to Devillers and Devillers-Teschuren (1996), Pienkowski et al. (1996) or Stoms et al. (1998), could be used effectively. For verifying the remotely sensed data in the field in this study, the adapted PHYSIS typology for habitat mapping (Jogan, Kaligarič, Leskovar, Seliškar, & Dobravec, 2004) was used, which is a commonly used approach in the Slovenian national program of habitat mapping.

Good historical data sets for vegetation cover (maps, aerial photographs, and habitat mapping) allow us to perceive trends at different temporal intervals in the past and simultaneously enable us to model and predict future land cover. In this respect, artificial neural networks are powerful tools that use a machine learning approach to quantify and model complex behavior and patterns in the landscape (Atkinson & Tatanall, 1997; Civco, 1993; Dadhich & Hanaoka, 2010; Li & Yeh, 2002; Paola & Schowengerdt, 1997; Pijanowski, Brown, Shellito, & Manik, 2002; Wang, 1994). The neural network time-series forecast model or the Multi-Layer Perceptron (MLP) classifier is commonly used for data interpretation and modelling (especially in the field of land-use/land-cover change dynamics), not only for remotely sensed data but also for field-based mapped data (Bayes & Raquib, 2012; Bernetti & Marinelli, 2010; Dadhich & Hanaoka, 2010; De Alba & Barros, 2012; Islam & Raquib, 2011; Leh, Bajwa, & Chaebey, 2011). The use of MLP has increased substantially in recent years, owing to advances in computing performance and the increased availability of powerful, flexible software (Atkinson & Tatanall, 1997; Chan, & Yeh, 2001; Dadhich & Hanaoka, 2010; Li & Yeh, 2002; Paola & Schowengerdt, 1997; Pijanowski et al., 2002; Wang, 1994). In order to understand the natural processes and to simulate land-use/land-cover changes, the Markov model (applied to transition probabilities generated with MLP) is often used in addition, for simulating landscape changes and analyzing land-use/land-cover transitions, trends and the dimensions of changes (Baker, 1989; Eastman, 2012; Huang et al., 2008; Muller & Middleton, 1994; Weng, 2002).

In this study, we aimed to demonstrate combined methods (old maps, remotely sensed data and field survey) for assessing the changed landscape identity (i), to illustrate how and to what extent the landscape identity of the classic Karst has changed from the time when it was perceived by the first cartographers to nowadays (ii), and to produce a reliable, long-term land-cover model that is based on validations of previous models (iii).

2. The study area

The "classic" Karst (238 km^2) within the border of Slovenia (a minor part of it lies in Italy) is actually part of the larger area of the karst plateau (Fig. 1). Its geographical position lies between the Adriatic Sea and the Pre-Alpine region in Slovenia and

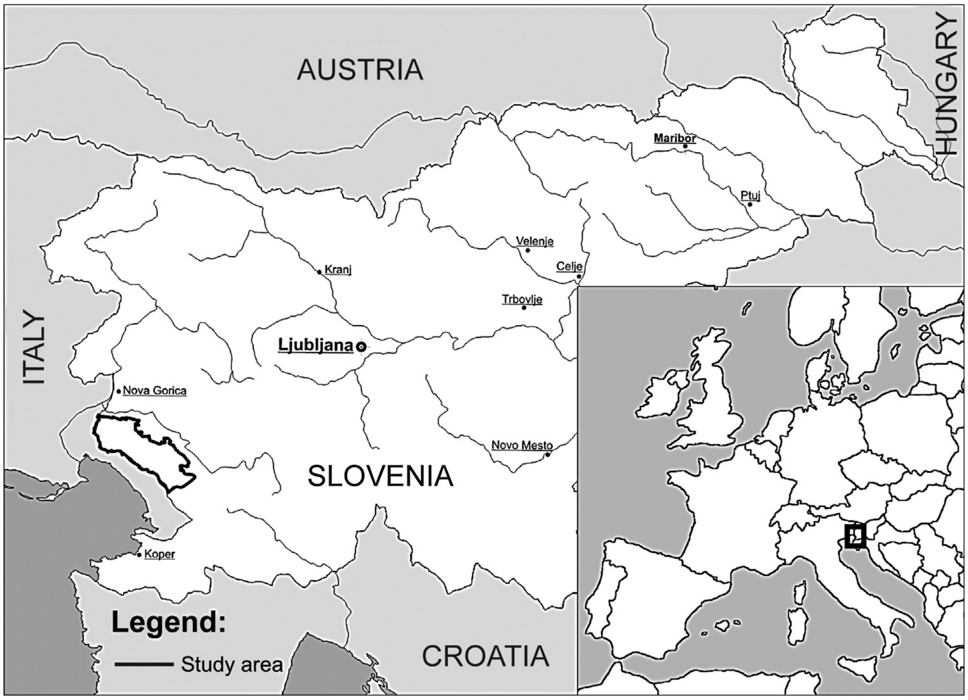

Fig. 1. Geographic location of the study area.

north-eastern Italy (45.77°N and 13.84°E; Fig. 1). It represents the north-westernmost branch of the Dinaric mountain range. The "classic" Karst stretches from 100 to 500 m a.s.l. and is characterized by its geomorphological phenomena (rocks, karst poljes, dolinas, caves, etc.) (Kaligarič et al., 2006).

According to the Köppen-Geiger climate classification, the region around the "classic" Karst is categorized as having a Cfb climate (temperate warm climate with warm summers and adequate rainfall throughout the year, always with a surplus water budget) (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). Poldini (1989) and Ogrin (1995) characterized the climate in the study area as transitional between Mediterranean and continental pre-Alpine, with rainy cool winters and long dry summers. The precipitation amount is around 1400 mm and is almost equally distributed throughout the year (ARSO, 2014). Mean monthly temperatures range from 2.2 °C in January to 20.3 °C in July, with a long-time mean of 11 °C (time interval from 1970 to 2000; meteorological station Godnje, 320 m a.s.l. almost in the center of the study area (ARSO, 2014)). The characteristic, strong bora wind causes desiccation and facilitates erosion in the area. In general, the most common winds are northern, north-eastern, and north-western in direction.

3. Methods

3.1. Cartographic methods and modeling

3.1.1. Spatial databases used

To get a realistic historical view of the study area land cover, Austrian military maps were used; these were designed by engineering officers of the topographic unit of the court war council between 1763 and 1787 on a scale of 1:28,800 and called the Josephinian Cartographical Register (Josephinische Landesaufnahme), the first systematic cartographical documentation of all the Habsburg hereditary lands (except Tirol, Vorarlberg, Italy, and the Vorlande) (Rajšp & Ficko, 1996). Because the maps were not yet based on uniform surveying techniques (triangulation), geo-referencing and digitalization procedures (vectorization) were demanding. For this purpose, ArcGIS 9.3 spatial analyst tools were used (ESRI, 2010). However, four land-cover types were extracted (fields, vineyards, and orchards; forest; grasslands and settlements). In order to retain the thematic resolution of the old cartographic material, current data (remotely sensed agricultural land use maps and a field-based habitat map) were generalized to make them comparable.

For future land-cover prediction, the agricultural land-use digital map was used; this was derived from the remotely sensed data (created on the basis of aerial photos) owned by the Ministry of Agriculture and Environment of Slovenia (GERK, 2012a) and available for the years 2002, 2007, 2009, and 2012. The land-use classification was verified in the field in a large series of randomly selected samples in each available time window (supervised classification technique) (GERK, 2013).

Additionally, a comparison between the agricultural land-use digital map for 2007 and the field-based habitat map for 2007 was performed (IRSNC, 2012); this was developed according to the PHYSIS typology of habitats based on the Palearctic classification (Devillers & Devillers-Teschuren, 1996) and modified for use in Slovenia (Jogan et al., 2004). This was an important step in ensuring the qualitative use of the freely available, remotely sensed data. The high degree of matching between those two maps (92%) enabled future land-cover modeling on a satisfactory level.

3.1.2. Land-cover change modeling

Predictions about future land cover in the study area were developed using several GIS tools and IDRISI SELVA's Land Change Modeler (LCM) and followed four sequential steps: identification of significant land-cover type transitions (1), multivariate analysis of future potential localization (2), modeling future land-use/land-cover by the Markov chains method applied to transition probabilities (3), allocation of the demand for change in order to define the geographical localization of transitions and, finally, verifying the predicted land cover with the actual-real map using image similarity indices (4). The mathematical background for each step is described and explained in Bernetti and Marinelli (2010) and Eastman (2012). LCM is a macro-level land-use change approach that was proposed by Eastman, Van Fossen, & Solorzano (2005) and Eastman (2006).

In the *first step*, the transition matrix was calculated between the old historical military map which illustrates the land use in 1763/1787 and the remotely sensed agricultural land-use map for 2002. Thus, the main or significant land-cover transitions that occurred over this long time period were identified. To be able to realistically predict present land-cover change trends, we continued our analysis with the remotely sensed agricultural land-use map (time windows 2002, 2007, and 2009).

The transition matrix analyses was then repeated, using the 2002 and 2007 time windows of the land-use map in order to reveal representative land-cover transitions, later used to predict land cover in 2009. This was performed exclusively for model validation (see *step four*). Future land-cover predictions were finally based on the 2002 and 2012 land-use time windows, in order to consider the latest recorded land-cover status and to provide a reliable time span which represents a realistic measure of the speed of recent land-cover change.

In the *second step*, multivariate analysis of future potential localization was performed. The neural network time-series forecast model or the Multi-Layer Perceptron classifier (MLP) was used for this purpose (Bayes & Raquib, 2012; Bernetti & Marinelli, 2010; Dadhich & Hanaoka, 2010; De Alba & Barros, 2012; Islam & Raquib, 2011; Leh et al., 2011). Neural networks are nonlinear multivariate methods that simulate the way a human brain analyses complex issues (Bernetti & Marinelli, 2010). One of the main advantages of this technique is that it is distribution-free, i.e., no underlying model is assumed for the multivariate distribution of the class-specific data in the featured space. The explanatory variables listed below were selected using Cramer's V method and inserted as layers in the MLP classifier for each transition of each land-use class to another class, such as the transition from grassland to forest during 2002 and 2012 (Dadhich & Hanaoka, 2010; Vanacker et al., 2003; Van Den Eeckhaut et al., 2006). However, the incorporation of data such as political, social, and economic factors is limited by the lack of spatial data and the difficulty of integrating socioeconomic factors with biophysical factors (Veldkamp & Lambin, 2001). For this study, three groups of explanatory variables were considered: (1) morphometric (elevation, slope, and aspect (as nominal category)—derived from a digital elevation model in a spatial resolution of 5 m—all considered as static) (GURS, 2012); (2) climatic (average annual precipitation in the 1971–2000 interval, average mean air temperature in the 1971–2000 interval, and average mean wind speed in the 1971–2000 interval—all considered as static) (ARSO–Agency for Environment of the Republic of Slovenia, 2012); (3) anthropogenic (distance from infrastructure) considered as the dynamic and empirical likelihood of change between 2002 and 2007 within land cover in 2002 (for model validation) and the empirical likelihood of change between 2002 and 2012 within land cover in 2002 (for future land-cover prediction). The MLP was used for each transition among classes of land use to locate areas of transition potential by integrating these explanatory variables (Dadhich & Hanaoka, 2012). All variables had a statistically significant impact ($p < 0.05$) on the transition potential locations and were included in the model to obtain a satisfactory accuracy rate (over 0.75) of the MLP. Because MLP does not work well with small-area transitions (Bernetti & Marinelli, 2010; Eastman, 2012), we filtered out those minor transitions (<80 m^2) that could be the result of map error or that might be considered insufficiently significant for the purpose of the study.

The *third step* involved modeling future land-use/land-cover by the Markov chains method applied to transition probabilities. A Markovian process is one in which the state of a system can be determined by knowing its previous state and the probability of transitioning from each state to another state (Dadhich & Hanaoka, 2012). The earlier and later land-cover maps were used in the Markov process. This helps in establishing exactly how much land would be expected to transition from the later date to the simulation date, based on the transition potential for the future (Bell, 1974; Dadhich & Hanaoka, 2010, 2012). Moreover, in our case, the transition potential area prepared using MLP was used in the Markov model to simulate future land cover. This resulted in two output maps (soft and hard predictions of land cover). If a hard prediction is a commitment to a specific scenario and results in a land-cover map with the same categories as the inputs, then the soft prediction identifies vulnerability to change, and in general provides more meaningful maps (De Alba & Barros, 2012; Eastman, 2012).

In the *fourth and last step* (model validation), we produced a hard predicted land-cover map for 2009 and compared this with the agricultural land-use map for 2009. Both maps followed the thematic resolution of the old cartographic material (four land-cover classes). On the soft prediction map for 2009, a quantitative assessment was carried out using receiver operating characteristic (ROC) statistics. This is an excellent method for assessing the validity of the model that predicts the location of the occurrence of a land-cover class by comparing a suitability image depicting the likelihood of that land-cover class occurring (i.e., the soft prediction map) and a Boolean image showing where that land-cover class actually exists (i.e., the reference image = real land-cover map). For hard land-cover prediction, the VALIDATE module was used. This module calculates specialized Kappa measures that discriminate between errors of quantity and errors of location between two qualitative maps. This was performed by the IDRISI Selva software (Eastman, 2012). Only if the overall Kappa index of agreement (KIA) reached a value over 0.85, were we sufficiently accurate to repeat the whole procedure with the time windows 2002 and 2012. The main goal was to predict grassland cover in the study area for the years 2025, 2050, 2075, and 2100. To determine where the predicted changes in grasslands mainly occur, the ninth-order polynomial spatial trends (the most complex one that IDRISI Selva software could provide) between each of the predicted temporal windows were calculated. Spatial trend analysis is an effective way of visualizing or geolocating the general trend of change, based on the observed change between two land-cover maps (De Alba & Barros, 2012).

4. Results

4.1. 250 years of change

Grasslands, as the habitats with the highest diversity in temperate regions, have generally declined in Europe, mostly due to abandonment and changed land-use driven by socioeconomic and political agents. Continuous change over a large area of 238 km^2 of the "classic" Karst, previously almost completely deforested, has resulted in a total change in the landscape identity (Fig. 2).

Comparison with the 250-year-old map of the area shows a grassland surface 3.3 times larger than on a recent land-use map. Grasslands mainly transitioned back to forest (in >60%) and therefore declined in area cover from 82% to almost 20% in 2012 (Fig. 3). Forest area, mainly consisting of pioneer thermophilous oak forest, consequently increased from 17% to the present level of 73%. In the last 10 years, the process of grassland overgrowing has remained dominant and intensive; 47 km^2 of the covered area remains persistent, 12 km^2 transitioned mainly (>60%) to forest, and in less than 10%, to fields and settlements. Fields, vineyards, and orchards increased from 0.4% to almost 5% of the area by 2002 but subsequently remained constant until 2012. Most of the transitions are oriented towards forest. Settlements increased from 1.6 km^2 in the past to 3.2 km^2 in the present. Some new settlements occurred,

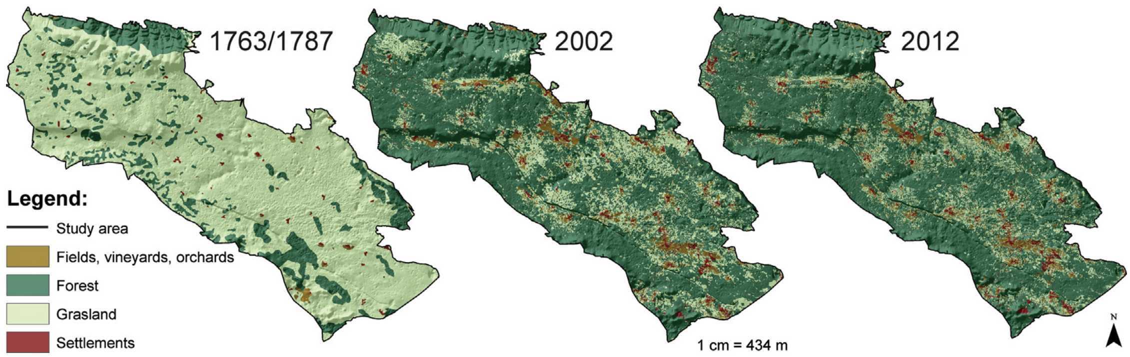

Fig. 2. Robust categories of land use on the "classic" Karst in the years 1763/1787, 2002, and 2012.

but the main pattern is enlargement of existing settlements. They have occupied a considerable area of fields, vineyards, orchards, or grassland during the last 250 years (Fig. 3).

However, in overall, a total land-use change of 43% (KIA = 0.5627) between the temporal windows 1763/1787 and 2002 was detected. In the last 10 years, the area has become very dynamic compared to the 1763/1787 to 2002 interval; overall, 10% (KIA = 0.8974) of land use has changed.

Because there is a clear trend to grassland overgrowing, the focus was on the landscape dynamics in this category. Fig. 4 shows change dynamics according to gains, persistence and loss of grassland area, and the spatial trend of change between the historical map, and the 2002 and 2012 temporal windows. 75% of former grassland was occupied in 2002 by other land-use categories (mainly forest), 23% did not change and 2% expanded to new areas (previously not grassland).

The most intensive changes occurred in the NW part of the area, followed by the SE and the central part (Fig. 4C). Considering only changes in the grasslands category, 18 km^2 or another 31% of grassland area disappeared during the last 10 years, mainly transitioning

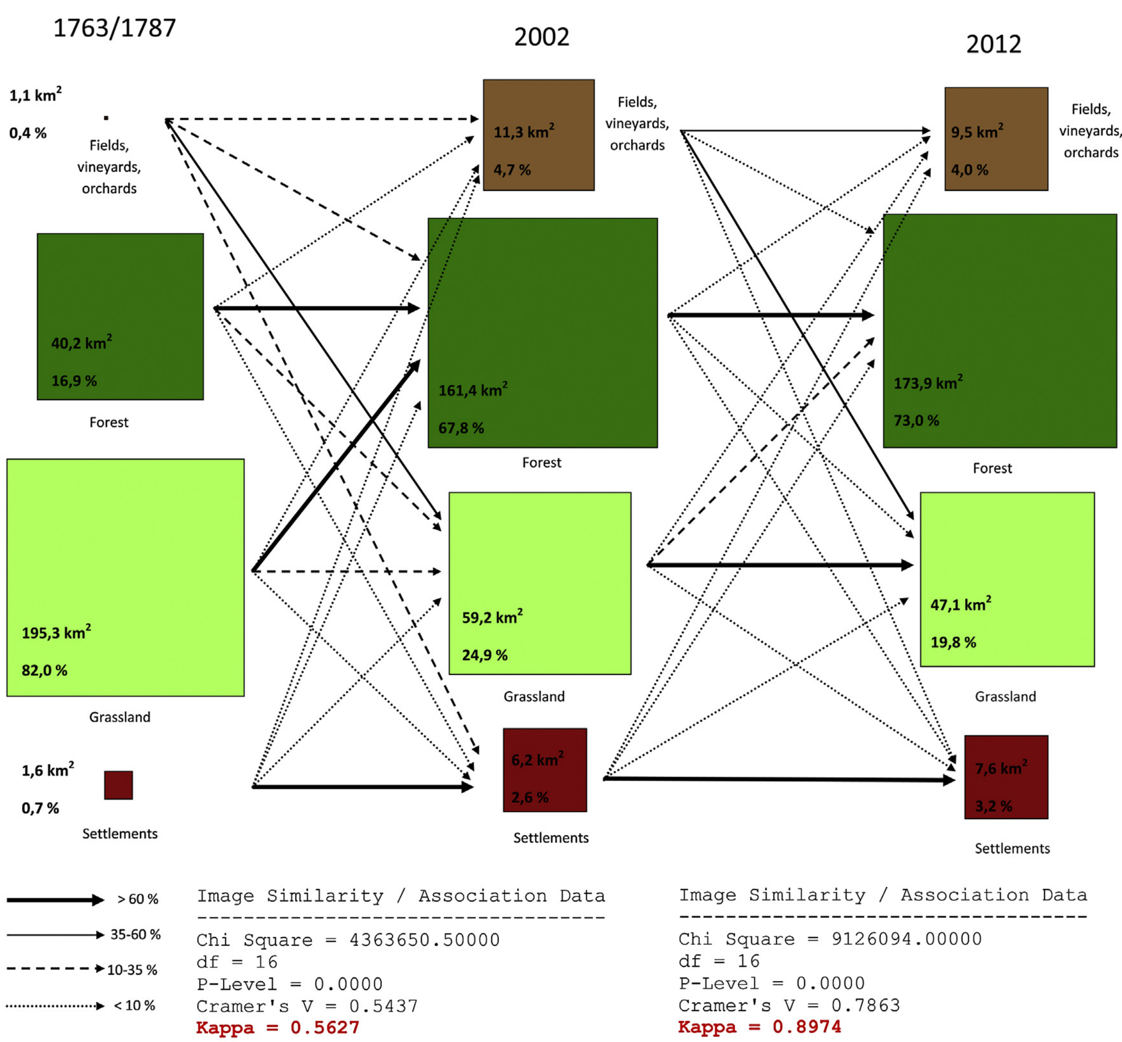

Fig. 3. Transition matrix between the temporal windows 1763/1787, 2002, and 2012 for the same land-use categories.

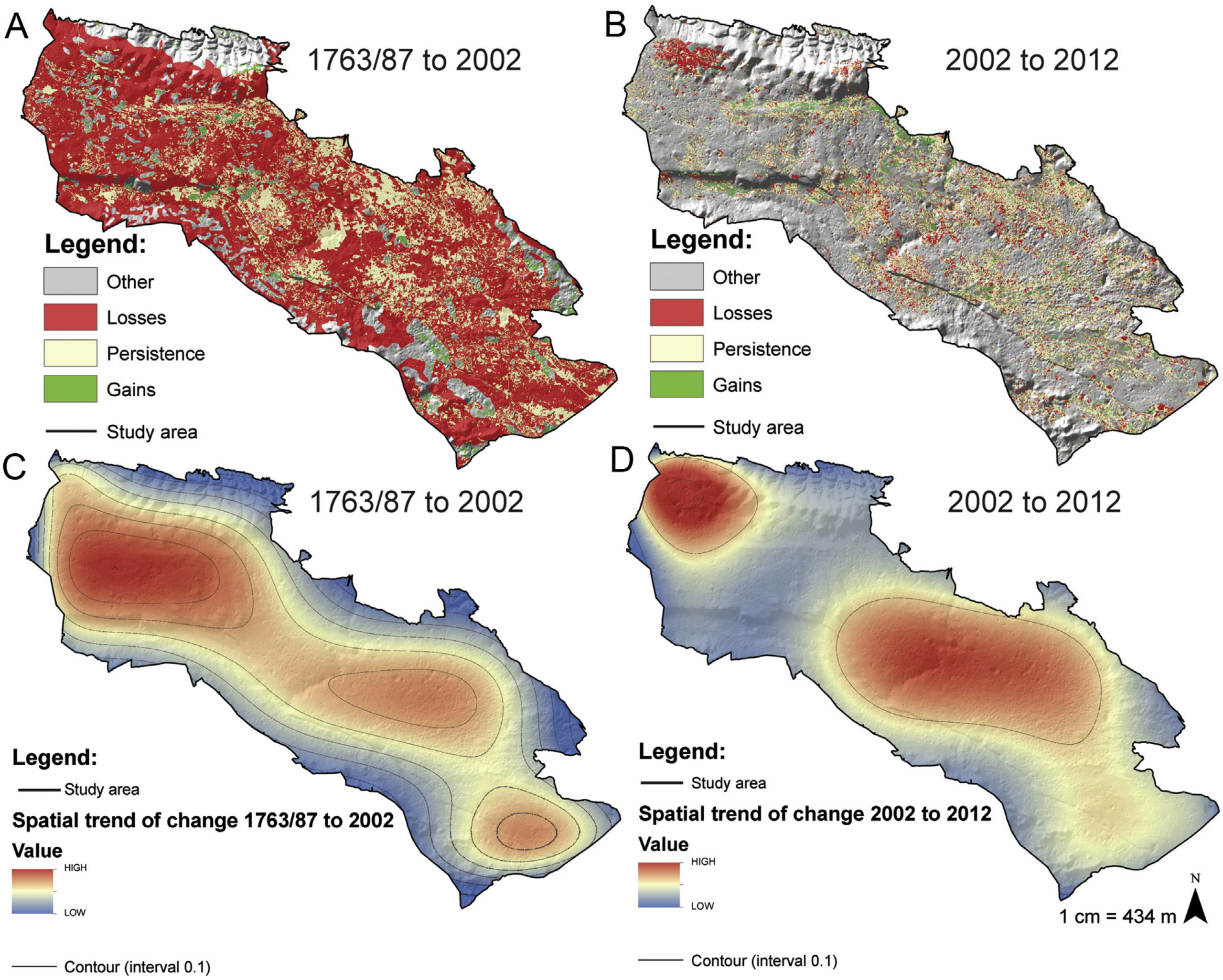

Fig. 4. Change dynamics according to gains, persistence, and loss of grassland area (A and B) and the ninth-order polynomial spatial trend of change between the historical map, the 2002 and 2012 temporal windows (C and D).

to forest, as mentioned before; 56% persisted and 13% expanded to a new category, previously under other land use, resulting in an overall area of 47 km^2 in 2012 (Fig. 4B). Changes were intensive only in the outermost NW part and the central part of the study area (Fig. 4D).

4.2. Model validation

In order to test if the MLP model and the Markov chains method were correct or sufficiently accurate to predict grassland area (the most dynamic category) and its spatial distribution, a predicted land-use map for 2009 was produced and then compared with the actual one. Fig. 5 shows correct predictions (hits) and incorrect predictions (misses).

Image similarity statistics indicate that the two compared images are 89% similar (KIA = 0.8982). The spatial location or distribution of predicted grasslands agrees in 98% of locations (Klocation = 0.9817). A quantitative assessment of the soft prediction was also carried out, using receiver-operating characteristic (ROC) statistics. The result of the ROC analysis was 0.904, which is a very strong value and indicates that the soft prediction was very accurate (the MLP learning process reached an accuracy rate of 0.88). Based on these results, further future prediction were then made with 2002 and 2012 land-use temporal windows in order to consider the latest recorded land-cover status and a reliable time span which represents a realistic measure for the speed of land-cover change.

4.3. The future of grasslands on the “classic” Karst

The results of the land-use change simulation in the categories showing the most change in the study area, grassland, and forest, are shown on the four maps in Fig. 6A (year 2025, 2050, 2075, and 2100) and can be compared with the actual status in 2012 and the past status in 2002. It is clearly visible that grasslands will continue to lose area. The prediction estimates that grasslands will cover 18 km^2 less in 2025 than today and will then shrink to just 6 km^2 in 2100 (Fig. 6B).

The decline can be represented by an exponential function $y = 1\text{E} + 153x^{-45.86}$ ($R^2 = 0.98$), which indicates that the speed of grassland overgrowing is about 2.2 km^2 per year. On the other hand, the simulation shows that forest will gain in area. It is estimated that the lost grassland area will be directly replaced by forest by 2025. Forest area will be expanded by 18 km^2 (or by 7%) and will cover 81% of the study area (compared to 2012, when the forest cover is 73%). From 2025 to 2050, another 14 km^2 (6%) of grassland area will disappear. In 2075, forest will cover 88% of the whole study area, and will reach 90% in 2100 (Fig. 6A). Thus, the proportion of grasslands will decline from 12% in 2015 to 7% in 2050, to 5% in 2075, to only 3% in 2100. The increase in

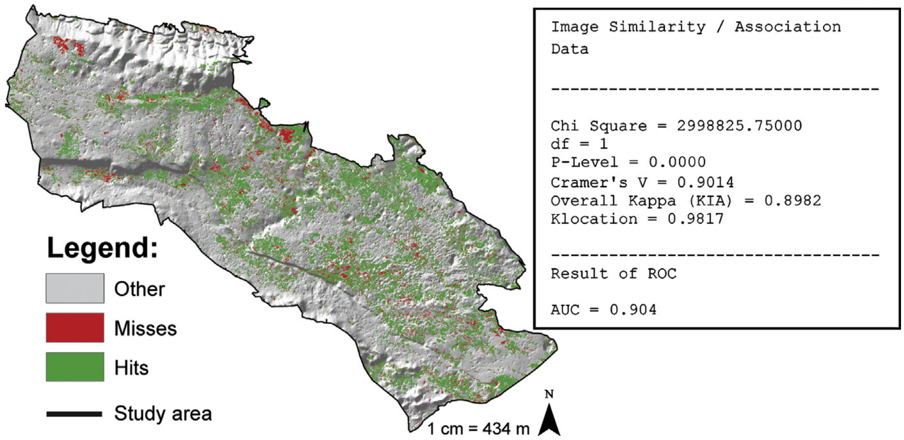

Fig. 5. Comparison between real and predicted grassland cover for 2009, image similarity statistics parameters, and receiver-operating characteristic (ROC) statistics output.

forest area can be represented by a third-order polynomial function ($y = 7E - 05x^3 - 0.4675x^2 + 972.07x - 673650$; $R^2 = 0.97$), which indicates that the area covered with forest will be approaching its maximum value in 2100.

Calculation of the spatial change trend for grasslands enabled the determination where in space the overgrowing process will occur during each of the predicted periods (Fig. 7). To 2025, most grassland overgrowing will be concentrated in the NW and N part of

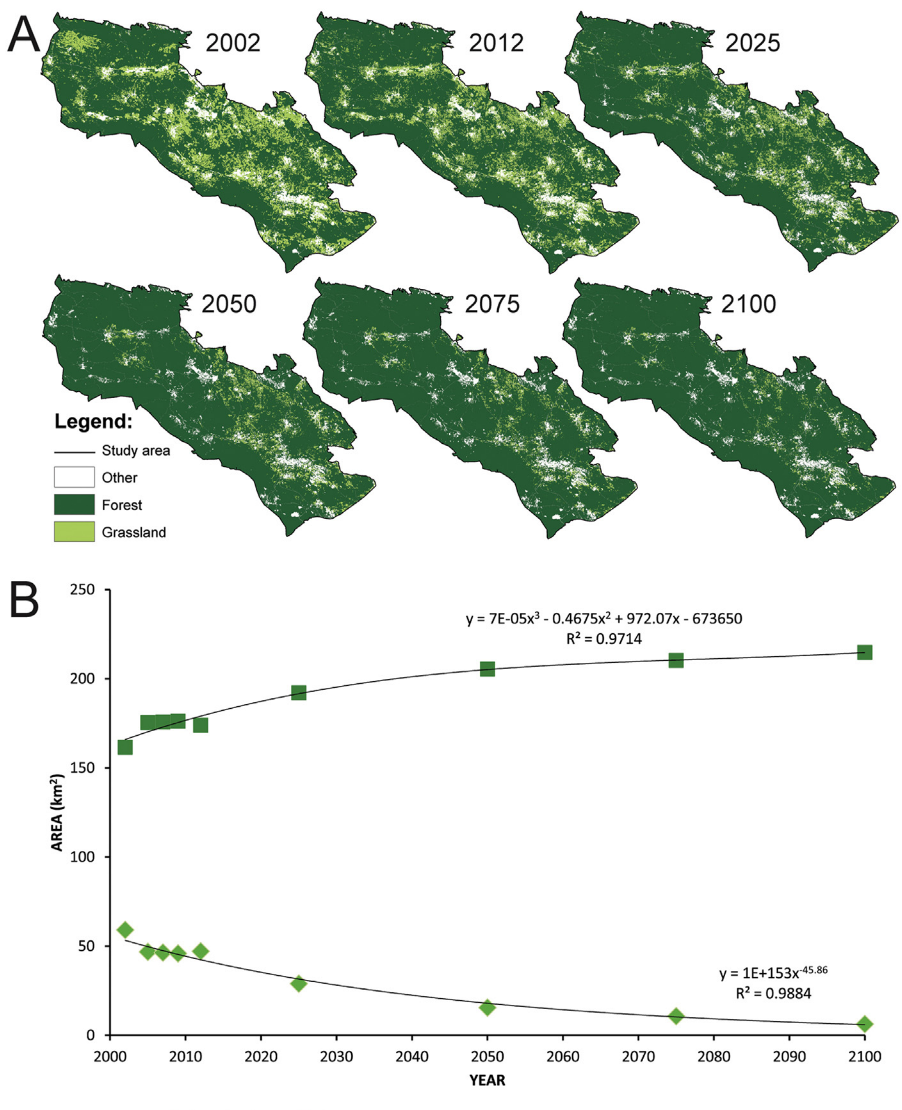

Fig. 6. Real (2002 and 2012) and predicted (2025, 2050, 2075, and 2100) grassland and forest spatial distribution on the "classic" Karst (A) and future trend lines (B).

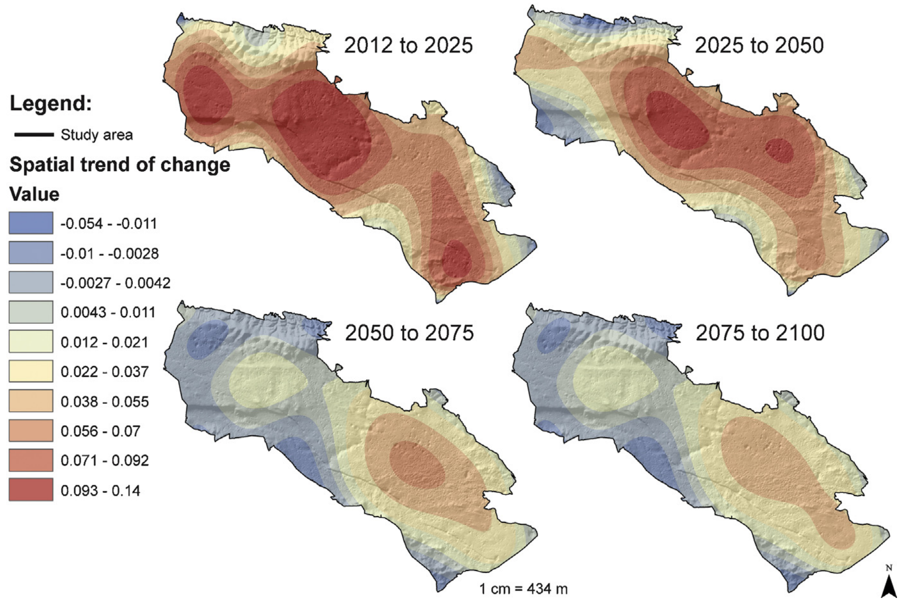

Fig. 7. Ninth-order polynomial spatial trends of change in the grassland category for four predicted temporal windows.

the study area, followed by the S part. In the next 25 years, grassland succession will shift to the central and southern part of the study area. This process will be less intensive. By 2075, most of the N and NW part of the area will be completely reforested. In 2100, grassland fragments will be found only in the central and southern parts of the study area.

5. Discussions

5.1. Formation of landscape identity and change: a historical perspective

Transitions to farming occurred as early as in the Neolithic era, ca. 5000 BC (Andrič & Willis, 2003) in this part of Europe. During the Bronze Age, the situation changed radically: population density increased, forests were cleared for fields and to provide timber for construction and for ore smelting (Kranjc, 2008). As in many countries of southern Europe, the development of open habitats was associated with Roman civilization, which accelerated the pastoral system and agriculture in general. Anthropogenically derived clearances in the karst landscape were necessarily associated with soil erosion, especially on slopes, where they consequently created a drier and warmer microclimate, which enabled colonization by eastern steppe and Mediterranean grassland species (Pipenbaher, Kaligarič, & Škornik, 2011; Poldini, 1989).

The pattern described above is one of the most common pathways that have transformed landscapes during the last millennia—primary vegetation (mainly forest) was transformed into agricultural and urban land. This pattern is currently still present elsewhere and has even accelerated in the third world nowadays, where large areas of tropical forest are cleared for timber production or communications construction (De Alba & Barros, 2012). In those areas, the landscape identity, having been originally perceived as “wild” and “natural” decades ago, rapidly changes into something very different, what we call a “degraded landscape”. However, the situation in many cases is reversing: landscape which was substantially disturbed by prehistoric human settlement regenerated once the populations moved on or died out (e.g. the ancient civilizations of Central America or the Indo-Malayan area). This suggests that, given sufficient time, even tropical rainforest that has been disturbed by modern human activity may be able to regenerate (Willis, Gillson, & Brncic, 2004). In the same way as the perception of a tropical island is of a “jungle forest”, the perception of the “classic” Karst is actually one of a “degraded landscape”, exactly what was seen during times when landscape perception was introduced into our society some hundreds of years ago.

The most deforested stage in nearby Istria occurred in the late Middle Ages, during the Venetian government (Beug, 1977), and the same can be stated for the Karst, although this area was predominant part of the Austrian Empire (Kaligarič et al., 2006). For various reasons, the karst grasslands in the study area became over the centuries one of the most diverse grassland habitats in that part of Europe (Horvat, Glavač, & Ellenberg, 1974; Horvatić, 1973; Kaligarič & Poldini, 1996; Kaligarič & Škornik, 2002; Pipenbaher, Kaligarič, & Škornik, 2008; Poldini, 1989; Škornik, Vidrih, & Kaligarič, 2010), comparable to those reported from Estonia (Kull & Zobel, 1991), the Czech Republic (Wilson, Peet, Dengler, & Pärtel, 2012), or Romania (Dengler et al., 2009, Wilson et al., 2012), which have been recognized as the richest plant communities worldwide within a spatial grains between 10 and 50 m^2. Thus, the general decline of semi-natural grasslands in many parts of the world is considered to be one of the major threats to plant diversity (Critchley, Burke, & Stevens, 2004; Wallis DeVries, Poschlod, & Willems, 2002) and other organisms. While in many parts of western and northern Europe conversion of grasslands to fields is mostly the case, in the Karst area, by far the most important driver of decline in the grassland landscape is land abandonment. When management ceases, grassland changes to forest, considerably reducing species richness (Cousins & Eriksson, 2002). Thus, many types of semi-natural grasslands (e.g. wooded meadows) have disappeared over the last few centuries in many European regions. There is an estimate that 6% (on average) of semi-natural grasslands remain in agricultural areas (Fuller, 1987 after Cousins, 2009). In that regard, the present status of grasslands (almost 20% of the territory) is still high, although having been reduced by almost four times in the last 250 years
.

It should be emphasized at this point that the “classic” Karst lies on the edge of the Mediterranean basin bordering Central Europe. In the Mediterranean climate, secondary succession after abandonment is much slower, delayed because of lower precipitation and summer hydric stress. Thus, the areas, e.g. the Northern Adriatic islands of Croatia, are still “stony desert” to a large degree. The main clue is the climate: while in the Mediterranean the annual precipitation does not exceed 600–800 mm/year, in the "classic" Karst the precipitation reaches 1400 mm/year. The climate facilitates the secondary succession with its much more humid conditions in the air and mesic conditions in the soil. The dynamics of spontaneous reforestation are therefore similar to those in Central Europe.

5.2. Predictions for the future

The "classic" Karst area, of which the landscape identity has changed drastically, impelled ecologists 35 years ago to study the natural reforestation process (Feoli & Feoli Chiapella, 1979; Feoli & Scimone, 1982; Feoli, Feoli Chiapella, Ganis, & Sorge, 1980; Lausi, Pignatti, & Poldini, 1979), at which time the first predictions were made. One of the earliest models ever published of forest progression on account of abandoned grassland was done by Favretto and Poldini (1986). They forecasted that the Trieste Karst area (the Italian portion of the "classic" Karst) would be "completely covered by bush" by the year 2013. The assumption was that in the past the grasslands under consideration were completely free from bush encroachment, which is, of course, not the case (and they were aware of this). Our results show that this calculation did not predict the real situation that we witnessed in 2013. In 2012, there was still almost 20% of grassland present, even though losses over the previous 10 years (2002–2012) constituted another 5%. Poldini and Favretto strongly based their model on the fact that, in only 32 years (from 1950 to 1982), the grassland decline had been greater than 40%. However, the pace of bush/tree encroachment can differ from case to case. Many studies have pointed out that grassland transformation into forest is not homogenous; an overall decrease in the rate of secondary succession over time was perceived by Myster and Pickett (1994), Pueyo and Begueria (2007), and Myster and Malahy (2008), who concluded that the main reason for this could be occupation of the most suitable sites during the first stages of colonization. However, the opposite was the case in a study from Central Italy (Bracchetti, Carotenuto, & Catorci, 2012); their results indicate a strong increase in the transformation rate in the second period of succession. The explanation could lie in further facilitation of recruitment of woody species under the canopies of newly established bush/tree patches. In our prediction model, based on the time interval 2002–2012 (with validation in 2009), a light increase in sheep farming, stimulated by EU subsidies, that occurred after the accession of Slovenia to the EU in 2004, is detected, and the trend of grassland succession between 2002 and 2012 is affected by this phenomenon. This socioeconomic factor could be considered as a latent variable (a proxy) which is hidden in the land-cover transitions between 2002 and 2012 and is therefore an important added value to the modelled outputs. However, in general, the incorporation of political and socioeconomic factors into environmental models is a difficult task (Veldkamp & Lambin, 2001), especially because of the lack of spatial data and the complexity of biological systems in the constantly changing environment, frequently triggered precisely by anthropogenic interference.

5.3. Which landscape identity is more highly appreciated?

Today, we have both subjective/emotional criteria ("landscape of our grandparents", "landscape beauty") and objective criteria (high biodiversity, species rarity, endemism) for evaluating positively the treeless landscape of the "classic" Karst. On the other hand, wood is always considered "good" for nature and biodiversity, not taking into consideration birds and other animals, including charismatic mammals. Woodland is also an ecosystem representing natural wilderness and is beneficial for the microclimate. The importance of grasslands may be overestimated: their ecosystem functioning is weak, owing to changes in land-use and abandonment, habitat fragmentation and weak connectivity, all of which result in negative genetic consequences, which then in turn affect population and plant species viability (Kaligarič et al., 2008).

Also, from the ecological point of view, the abandonment of land and subsequent reforestation is a gain in terms of a lowered input of pesticides and fertilizers (Hunziker & Kienast, 1999). However, the concurrent loss of the patchy land mosaic is often linked to the loss of biodiversity (Burel & Baudry, 1995; Dale, Pearson, Offerman, & O'Neill, 1994; Naiman, Decamps, & Pollock, 1993; Ruzicka, 1993). From the landscape-aesthetics point of view, it can be assumed that partially reforested landscapes are what most people prefer visually; completely overgrown areas, however, are likely to receive a lower level of approval (Hunziker & Kienast, 1999). It should be mentioned that attempts to interfere actively in the balance between forest and grassland in the karst area have a long-standing history. During the period of severe deforestation, the remaining forests represented a positive value (timber for ship-building in Trieste, a protection zone against the Turkish raids, etc.). The first act to protect the forest around the city of Trieste (our research area) was introduced in 1150; in 1583, an armed guard was organized to protect local forests—even grazing in the forests was prohibited and banned (Kranjc, 2009). However, these administrative measures were not sufficiently successful to prevent expansion of grasslands at that time, so the planting of trees (first acorns and then black pines) started in 1842. The success of this strategy was unexpectedly high, so in 1885 a reforestation act was adopted, which systematically regulated the process of planting black pines, especially along the railway and in the vicinity of settlements (Kranjc, 2009; Poldini, 1989). Systematic reforestation continued until the mid-twentieth century. From today's point of view, the planting of alien tree species, despite preventing further soil erosion, is considered an inappropriate measure by most ecologists and many foresters. Only one hundred years later, the outlook has changed completely, and we consider the vegetation of dry grassland as having new value: dry grasslands are considered as an endangered and strongly declining habitat type in Europe, one which attracts special consideration from nature conservancy (Kaligarič et al., 2006). The karst grasslands within the "classic" Karst have been recognized as a Natura 2000 habitat. Natura 2000 is an ecological network of areas designated by the European Union member states: wild plants and animals and their habitats that are rare or endangered in Europe require protection. Thus, the main objective of the network is to conserve valuable habitats in a favorable state for future generations. Virtually the entire study area, the "classic" Karst within the borders of Slovenia, is under the protection of a Natura 2000 area (except for two larger urban areas inside the area). Consequently, maintaining the favorable status and original extent of karst grasslands is required as a state obligation. However, it is readily evident from this study that since 2002 (the "classic" Karst area was declared a Natura 2000 site in 2004), 12 km^2 (or an additional 5%) of grasslands in total were lost by 2012, mainly due to forest progression. For that reason, it is very important to determine the baseline or "reference" conditions that existed before recent times and how thresholds can be determined beyond which specific management plans should be used (Willis & Birks, 2006). The conservational goals, grounded in Annex II of the Habitat Directive (EC, 1992), which include maintaining a favorable status for habitat type 62A0 "Eastern Sub-Mediterranean dry grasslands (*Scorzoneratalia villosae*)" are therefore not in accordance with our prediction, which assumes that by 2100 only 3% of the grasslands will survive. This incongruous situation should be overcome by careful landscape planning and coordinated management direction between sectorial policies (nature conservation, forestry, hunting, and agriculture). However, the power of the Natura 2000 network in Slovenia in still vague and uncertain for the time being. For that reason, it is realistic to expect that the most likely projection lies somewhere between the two possibilities.

We can also consider the spontaneous reforestation that has happened in recent decades as positive for biodiversity conservation. We can share this view with that of Bracchetti, Carotenuto, and Catorci (2012) for the montane area of the Central Apennines, where an increase was perceived in the population of many vertebrates (birds, bats, wolf, wildcat, and brown bear) that are associated with mature forest and rare at regional and national scales. It is, however, extremely important to keep the share of grasslands within the area above at a certain threshold (at least 15%), which would enable sufficient connectivity between grassland fragments. In that regard, the long-term availability of subsidies is inevitable, because only through subsidies will the proper (extensive) management be assured—if controlled by inspections and regular monitoring. In that way, the persistence of the remnants of past "grassland landscape identity" would be assured.

6. Conclusions

Our study has demonstrated that the combined methods of using old maps, remotely sensed data and field surveys clearly show historical trends in vegetation coverage and enable us to assess the changing of a "classic" Slovenian Karst landscape identity. An almost treeless stony grassland landscape was converted to a forest-dominated landscape in only 250 years. Furthermore, the methods enable reliable predictions such as a long-term land-cover model based on the validation of previous models. The predictions show the overgrowing speed of 2.2 km/year, which would result in an 88% forest coverage of the area in 60 years. Active landscape planning incorporating financial support for breeding cattle and sheep is required in order to keep the remnants of the traditional "classic" Karst grassland landscape identity and to fulfill the legal obligation to preserve the Natura 2000 grasslands habitats, which have already declined by 5% since the Slovenian accession into the European Union in 2004.

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