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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 2003) 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