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A new view on EU agricultural landscapes: Quantifying patchiness to assess farmland heterogeneity

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ABSTRACT

Mapping and assessment of ecosystem services in agricultural landscapes as required by the EU biodiversity policy need a better characterization of the given landscape typology according to its ecological and cultural values. Such need should be accommodated by a better discrimination of the landscape characteristics linked to the capacity of providing ecosystem services and socio-cultural benefits. Often, these key variables depend on the degree of farmland heterogeneity and landscape patterns. We employed segmentation and landscape metrics (edge density and image texture respectively), derived from a pan-European multi-temporal and multi-spectral remote sensing dataset, to generate a consistent European indicator of farmland heterogeneity, the Farmland Heterogeneity Indicator (FHI). We mapped five degrees of FHI on a wall-to-wall basis (250 m spatial resolution) over European agricultural landscapes including natural grasslands. Image texture led to a clear improvement of the indicator compared to the pure application of Edge Density, in particular to a better detection of small patches. In addition to deriving a qualitative indicator we attributed an approximate patch size to each class, allowing an indicative assessment of European field sizes. Based on CORINE land cover, we identified pastures and heterogeneous land cover classes as classes with the highest degree of FHI, while agroforestry and olive groves appeared less heterogeneous on average. We performed a verification based on a continental and regional scale, which resulted in general good agreement with independently derived data.

1. Introduction

Agro-ecosystems are the result of human activities aimed at producing food, feed, fibres and energy. This primary output of agriculture is classified in the ecosystem services frame (MA, 2005) as provisioning ecosystem service. Alongside with agricultural biomass production, farming practices also impact on the capacity of agro-ecosystems to supply regulating and cultural ecosystem services, some of which directly support agricultural production (i.e. soil fertility, water availability, pollination, pest control, soil erosion mitigation) (Bommarco et al., 2013). Farmland biodiversity is hosted to a varying degree in all agricultural landscapes, being the result of thousands of years of agricultural practices. It is generally enhanced and maintained by extensive practices and threatened by intensification (Benton et al., 2003). In particular fragmentation and conversion of natural habitats, removal of landscape elements (e.g. hedges, tree lines, ridges) increase of field size and reduction of crop diversity have contributed to species decline (Donald et al., 2006), including species that are functional to agricultural production (Haenke et al., 2014; Le Féon et al., 2010). From the European policy side, the supply of ecosystem services and biodiversity conservation within farmland is fostered by the EU Biodiversity Strategy to 2020 (European Commission, 2011) and the Common Agricultural Policy (CAP) with its so-called Greening measures (European Union, 2013).

Several studies have tried to assess and/or map the degree to which selected agricultural land characteristics support biodiversity and ecosystem service provision (Billeter et al., 2008; Donald et al., 2006; Herzog et al., 2006; Overmars et al., 2014; Roschewitz et al., 2005). The ecological role of habitat diversity and field edges as source and sink of farmland biodiversity (including functional biodiversity) has been demonstrated by several authors (Gabriel et al., 2006; Jentsch et al., 2012; Kaule and Krebs, 1989; Marshall and Moonen, 2002; Wagner et al., 2000). Recognized important features playing an important role in this respect are linear landscape elements, such as ditches, hedge and tree lines, and grass margins (García-Feced et al., 2015; Van der Zanden et al., 2013). An enhanced supply of regulating ecosystem services and biodiversity

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maintenance is linked to the spatial arrangement of (such) features that increase habitat availability, individual movement and species dispersal when distributed across the landscape with sufficient density and connectivity (Landis et al., 2000; Wiens et al., 1993). The importance of the landscape scale in the regulation of biodiversity processes has been underlined by several authors (Ernoult et al., 2003; Hamer et al., 2006; Tscharntke et al., 2005); however, a lack of information on the spatial configuration of the agricultural landscape on the EU scale limits the possibility of assessing its ecological value at the continental level. An existing assessment (Paracchini et al., 2008) in fact relies on CORINE land cover data (EEA, 2007) which, due to its inherent degree of generalization, does not fully capture the complexity of agricultural landscapes. Recent studies (García-Feced et al., 2015; Van der Zanden et al., 2013) provide information on the presence of landscape features but information on other structural parameters such as field size or patch distribution is still missing. An indicator is therefore needed to fill this gap and to increase the detail of spatial characterization provided by land use maps. This proxy needs to (i) be robust (e.g. insensitive to comparable sensors) and repeatable to be monitored in time, (ii) be detailed enough to account for local particularities and (iii) cover areas of continental extent at the same time. Moreover, the approach of proxy derivation should be (iv) consistent across the whole area, and (v) economically feasible (preferably with no or minimal cost, e.g. based on free available source data). Multispectral remote sensing images fulfil most of these requirements, being suited in particular for the detection of changes in reflectance between spectrally homogeneous features and are thus particularly effective in the detection of field edges and habitat boundaries.

Given the ecological importance of structural elements, field size and patch distribution, and further considering the requirements of the indicator, a remote sensing-based indicator-based on edge density seems adequate. Such edges are both positively correlated with the edge density of classically defined patches (see Section 2.2 for definition) that can be detected in a multispectral image. Therefore, in this study we propose a new patch indicator, supposed to deliver a qualitative (related to degree of patchiness) and up to a certain degree a semi-quantitative assessment indicator (related to approximate field size) of the structure of European agricultural areas. The proposed indicator is based on an edge density metric combined with a parallel-derived texture-based measure. Both metrics are combined to a single indicator called FHI or Farmland Heterogeneity Indicator. FHI can be considered an improved Edge Density of patch borders, based on a combination of spectral *and* textural data as promoted by Chica-Olmo and Abarca-Hernández (2000), while improving the spatial extent of similar works (Kuemmerle et al., 2009; Rydberg and Borgefors, 2001) which cover smaller regions.

2. Materials and methods

2.1. Data

As base data for this study we used Image 2006 (Soille, 2008), a pan-European mosaic, providing top-of-atmosphere (TOA) reflectance of four pre-processed spectral bands in the green, red, near-infrared and mid-infrared spectrum, derived from the satellite sensors IRS P6 LISS-III, SPOT 4 and SPOT 5, and centred in the year 2006. A total of 2004 images were mosaicked for the first coverage of the mosaic (COV1), temporally centred in the early period of the vegetation period (spring, early summer), and 1,561 images for the second coverage (COV2) of the mosaic, temporally centred in the later period of the vegetation period (late summer, autumn). Details about data, pre-processing, cloud detection, accuracy, and the mosaicking method are reported by Soille (2008).

2.2. Methods

2.2.1. Farmland Heterogeneity Indicator (FHI) design

FHI aims to express a major part of the above-mentioned cultural and ecological values of landscape. FHI is intended for this purpose as a measure for the frequency of occurring patch variability within a defined area. To achieve this, we (i) performed a segmentation based on homogeneity criteria for spectral data, (ii) quantified patch edge density for a defined area A, (iii) calculated a textural indicator for A and (iv) combined both to create the FHI. A graphical overview of the FHI methodology is shown in Fig. 1. The core of the methodology is the segmentation and the parallel texture module, whose results are then fused: we considered the parallel approach beneficial since it consolidates the final results and enhances robustness. Moreover, following our empirical tests, texture still delivers meaningful results on areas with very small fields where the segmentation already fails. This led us to a complex fusion technique, which takes into account the asymmetry of data confidentiality.

In this work, a patch is defined as a homogeneous plot within the wider agricultural land, which assumes a different (remotely sensed) observable property from its surrounding neighbourhood, and, similar to Forman (1995), assumes an ecological meaning. The patch is detached from any cadastral meaning. According to this definition, patches do not necessarily represent agricultural fields, although most of them do so. A patch can also consist of remnant elements of semi-natural vegetation (forest, trees, hedges, edge of field and/or riparian buffer strips, etc.), small water bodies and wetlands, roads or even single buildings or rocks, which are not masked out by pre-stratification of agricultural areas. These elements, where encountered, are part of the definition of the FHI, intended as an indicator expressing heterogeneity, also taking into account non-typical agricultural elements.

2.2.2. Segmentation

Segments or image objects provide the basis of geospatial object-based image analysis (GEOBIA) (Blaschke, 2010). Out of various object-based image analysis software on the market, we selected the product eCogniton® of Trimble (eCognition Developer, Server version 8.64.1), since it provided a batch processing environment. We prepared 549 tiles with a dimension of 4000 × 4000 pixels and eight spectral bands, four of COV1 and four of COV2 for segmentation. The basic task of segmentation algorithms is the merging of (image) elements based on homogeneity parameters or on the differentiation to neighbouring regions (heterogeneity) (Schiewe, 2002). eCognition's segmentation relies on a bottom-up region merging technique, which aims at minimizing the weighted heterogeneity ($n \times h$) of resulting image objects, where n is the size of a segment and h a parameter of heterogeneity (Baatz and Schaepe, 2000; Benz et al., 2004). In each step, the pair of adjacent image objects (initially a pixel pair) is merged, which results in the smallest growth of the defined heterogeneity. Heterogeneity is defined as heterogeneity of *colour* (spectral data/grey tone) and *shape*, where *shape* heterogeneity can be divided into heterogeneity of *smoothness* and *compactness* of an object. The merging process stops if the growth exceeds the threshold defined by the scale parameter Ψ. The scale parameter is used to determine the approximate size of objects, although in reality the scale parameter Ψ determines the maximal threshold of heterogeneity allowed to grow objects. For segmentation, the user has the option to determine weights for the colour and shape heterogeneity (and for smoothness and compactness).

For the underlying purpose, the *colour* parameter was considered of highest interest, since patch borders are supposed to be placed in locations where the spectral colour of a remotely sensed image changes and creates heterogeneity. The *shape* parameter was