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Research Paper

Mediterranean land systems: Representing diversity and intensity of complex land systems in a dynamic region

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ABSTRACT

In the Mediterranean region, land systems have been shaped gradually through centuries. They provide services to a large and growing population in a region that is among the most vulnerable to future global change. The spatial extent and distribution of Mediterranean land systems is, however, unknown. In this paper, we present a new, expert-based classification of Mediterranean land systems, representing landscapes as integrated social-ecological systems. We combined data on land cover, management intensity and livestock available on the European and global scale in a geographic information system based approach. We put special emphasis on agro-silvo-pastoral mosaic systems: multifunctional Mediterranean landscapes hosting different human activities that are not represented in common land cover maps. By analyzing location conditions of the identified land systems, we demonstrated the significance of both bio-physical (precipitation, soil) and socio-economic (population density, market influence) factors driving the occurrence of these systems. Agro-silvo-pastoral mosaic systems were estimated to cover 23.3% of the Mediterranean ecoregion and exhibited to a certain extent similar characteristics as forest and cropland systems. A reanalysis using data that are available with global coverage indicated that the choice of datasets leads to significant uncertainties in the extent and spatial pattern of these systems. The resulting land systems typology can be used to prioritize and protect landscapes of high cultural and environmental significance.

1. Introduction

In light of recent socio-economic developments and anticipated climate change impacts in the Mediterranean region, there is an urgent need for investigating the capacity of the region to sustain a variety of ecosystem services for a growing population. On one side, the European part of the region is home to high-input intensive agricultural systems significant for regional food production. On the other, the Middle Eastern and North African part is among the regions with the highest population growth, and dependency on food imports – with over half of the population relying on food produced elsewhere (Wright & Cafiero, 2011). The region is extremely vulnerable to fluctuations in food supply and prices, and expected climate change coupled with demographic growth could contribute to further regional instability and conflicts (Evans, 2008; Sowers, Vengosh, & Weinthal, 2010). Potential shocks to the society and economy have also been observed in the European part. The Greek financial crisis reportedly influenced the supply of agricultural products (Pfeiffer & Koutantou, 2015), impacting on land-use and environment.

In order to target policies to prioritize areas for agriculture, landscape conservation and biodiversity protection in the Mediterranean region, the characteristics and distribution of land systems need to be identified (Agnoletti, 2014). This is particularly valid for agro-silvo-pastoral mosaic systems where human influence and ecological conditions are intricately linked. Characteristics of such traditional landscapes are disregarded if represented by a single, dominant land cover type as is common in most current datasets (Turner, Lambin, & Reenberg, 2007; Verburg, Neumann, & Nol, 2011). Moreover, when analyzing changes to these systems, land-use intensity is an important component besides changes in land cover, and has a significant environmental impact (Ellis & Ramankutty, 2008). Existing land cover and land systems mapping approaches are misrepresenting the extent or diversity of agro-silvo-pastoral mosaics (Zomer, Trabucco, Coe, & Place, 2009) and often fail to integrate differences in land-use intensity. Although global and continental attempts to map land systems in the Mediterranean region were made, they focused on generalized cropland and grazing systems (Dixon, Gulliver, Gibbon, & Hall, 2001; FAO, 2011; van Asselen & Verburg, 2012), ignor-

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ing the specific mosaics unique to this region.

As a result of its environmental conditions, extremely long land-use history, and cultural diversity, the Mediterranean region is characterized by a wide variety of land systems that are not easily mapped. A good example is the dehesa/montado system, present in Spain and Portugal, which is highly valuable in the cultural heritage context (Meeus, 1995). In this system different activities, such as gathering of forest products, livestock grazing and cereal cultivation occur simultaneously (Joffre, Rambal, & Ratte, 1999). Using remote sensing imagery, we can receive information on the tree density of these systems, but not on the extent of grazing or crop cultivation below the trees (Plieninger & Schaar, 2008). Attempts to map these multifunctional systems have been made. In the European CORINE land cover data, they are represented as “Agroforestry areas”, however substantial areas are also defined as other classes (Bunce, Pérez-Soba, & Smith, 2008; EEA, 2015a).

In the Mediterranean region, landscapes are subject to two contrasting processes of change: abandonment of rural, mountainous and less developed areas on one side, and intensification and increasing human influence on the other (García-Llorente et al., 2012; Nieto-Romero, Oteros-Rozas, González, & Martín-López, 2014). Soil degradation and water shortages are the main environmental problems in the region, as a consequence of land management and complex biophysical and climatic conditions (Almagro, Vente de, & Boix-Fayos, 2013; Guerra, Metzger, Maes, & Pinto-Correia, 2015). Furthermore, projected climate and socio-economic changes suggest that Mediterranean ecosystems are amongst the most vulnerable to future global change (Schröter, Cramer, & Leemans, 2005). Traditional agro-silvo-pastoral mosaic systems are particularly under pressure, threatening the provision of numerous ecosystem services and biodiversity in general (Zamora, Verdú, & Galante, 2007). A significant number of plant and animals species, a lot of them endemic, are related to extensive management practices and these traditional landscapes. This is why the Mediterranean region was identified as one of the Global Biodiversity Hotspots (Cuttelod, Garcia, Malak, Temple, & Katariya, 2009).

In this paper we develop a spatial representation of Mediterranean land systems by integrating information on land management as an inseparable part of these landscapes. By investigating the location factors behind these land systems, we identify how different socio-economic and biophysical factors determine their distribution. At the same time, this study addresses the challenges of data and knowledge differences between different parts of the Mediterranean region. Finally, we evaluate the performance of our classification, by comparing it to existing studies in the region, and by analyzing the uncertainty related to available data.

2. Materials and methods

2.1. Study area

We defined the spatial extent of the Mediterranean region by focusing on areas surrounding the Mediterranean Sea that share similar climatic and other biophysical characteristics. We chose the spatial extent of the Mediterranean ecoregion (Fig. 1), as it describes the approximate extent of representative Mediterranean natural communities (Olson, Dinerstein, & Wikramanayake, 2001). We included the Nile Delta and similar ecoregions within the Mediterranean ecoregion, such as the Apennine deciduous montane forests in central Italy. The total study area covers 2.3 million km^2 in 27 countries. Around 400 million people live within the ecoregion boundaries, and yearly 250 million tourists visit the area (31% of all international tourists), making it among the regions with highest human influence (Cuttelod et al., 2009). The region is characterized by the Mediterranean climate with dry summers and mild winters, when most precipitation takes place. The southern part of the region is predominantly arid and semi-arid, whereas the northern part is semi-arid to dry humid (Zomer, Trabucco, Bossio, & Verchot, 2008). Although the mean annual precipitation of the whole area is around 500 mm, a quarter of the area has below 300 mm of rainfall. This limits rainfed agriculture, particularly in the Middle East and North Africa part of the region.

2.2. Classification overview

We classified combinations of land cover, livestock density, irrigation extent and different intensity proxies (Table 1) using a Geographic Information System (GIS) based approach. By combining land cover with data on land management, we considered the anthropogenic aspects of Mediterranean land systems. This is necessary, as the management of a specific location depends on local combinations of socio-economic and biophysical conditions (Lambin, Turner, & Geist, 2001). Mediterranean land system classes were defined a-priori based on the common types distinguished in the literature.

We operated on a 2 km spatial resolution. Although a 2 km spatial resolution is arbitrary this would hold for any chosen resolution that aims to capture human-environment interactions. The choice of spatial resolution was based on: 1). The continental extent of the Mediterranean region and the spatial detail of available data. Although some of the data were available on a very high resolution (e.g. 25 m tree cover), most of it was available on a 1 km resolution (Table 1); 2). Land systems were defined by the set of activities at the farm or landscape level and not at the level of individual landscape components (Verburg et al., 2002), given the relatively small scale and high spatial variation within landscapes a 2 km spatial resolution was judged to be optimal for capturing variation in land systems; and 3). We aimed to represent global patterns of Mediterranean land systems on a resolution able to capture the spatial variability of human-environment interactions in heterogeneous landscape mosaics (Pickett & Cadenasso, 1995 ;van Delden, van Vliet, Rutledge, & Kirkby, 2011).

2.3. Data

More data and data with higher thematic and spatial resolution were available for the European part of the region (Fig. 1). In contrast to studies that only use data that are consistently available across an entire study area, we used the best data available for different parts of the region. However, we restricted ourselves to data that covered multiple countries. National data were used to train the classification (e.g. by looking at the dehesa/montado extent). The following criteria were used when choosing the data: 1). Highest spatial resolution; 2). Data were as recent as possible; 3). Data underwent validation; 4). The data were not generated by downscaling based on population density. This way we could ensure independence of the data and later analyze how the occurrence of land systems relates to population distributions. All input maps were resampled to a resolution of 2 × 2 km in an Lambert equal area projection.

For land cover variables, we used tree cover (Hansen, Potapov, & Moore, 2013), soil sealing data for Europe (EEA, 2015b), built up areas extent for the remaining part of the region (Jun, Ban, & Li, 2014), cropland extent (Fritz, See, & McCallum, 2015) and the extent of bare areas (Latham, Cumani, Rosati, & Bloise, 2014). For identifying the extent of areas with permanent crops, we used the CAPRI-dynaspat data for the European Union part of the region (Britz & Witzke, 2014), the CORINE land cover permanent crops extent for the rest of Europe and Turkey (EEA, 2015a), and the SPAM data for the MENA region (You et al., 2014).

Livestock distribution was obtained from the Gridded Livestock of the World v2.0 (Robinson, Wint, & Conchedda, 2014). We combined the numbers of bovines, goats and sheep. Livestock distribution was used to identify rangelands and grazing mosaic systems, and to define the intensity of grazing based on an existing grazing systems classification (Dixon et al., 2001; FAO, 2011). We did not consider the distribution of pigs. Pigs are being grazed on a large extent in the dehesas/montados of