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Assessment of land degradation in Mediterranean forests and grazing lands using a landscape unit approach and the normalized difference vegetation index

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ABSTRACT

Land managers need sound, evidence-based information about land degradation patterns and about the effectiveness of their management responses. Obtaining such information is particularly difficult in Mediterranean grazing lands and forests, where a long history of anthropogenic pressure, high topographical and climatic variability, and frequent disturbances combine to create a highly diverse and unstable environment.

Our study aimed at designing a methodology to provide land managers in three data-scarce drylands in Spain, Greece, and Cyprus with spatially explicit, up-to-date information on the state of their land, the pressures driving land degradation, and the effectiveness of their management efforts using remotely sensed NDVI data. To translate NDVI values into a land degradation assessment, we analysed the variance of the annual average NDVI within different landscape units, which we identified based on land cover, aspect, and slope steepness parameters. After calibrating and validating the land degradation mapping methodology using field observations, we related the obtained land degradation patterns with spatial information about grazing and wildfire, as well as controlled grazing and afforestation practices.

Our methodology proved useful to assess land degradation and management measures in dry, semi-natural ecosystems. It also provided insights into the role of landscape in modulating land degradation. Results indicate that grazing is a significant cause of land degradation even in partially abandoned areas; repeated fires have a negative impact; slope steepness increases the land's sensitivity to grazing; north- and east-facing slopes are less sensitive to fire in the long term than south- and west-facing slopes; and the effectiveness of responses to land degradation is substantially affected by land cover and topography.

The methodology presented can be used to overcome the lack of spatially explicit information on the state of the land in drylands of the Mediterranean and beyond, or as a basis for more in-depth studies to plan restoration interventions.

1. Introduction

Land degradation and desertification are considered major threats to the present (Geeson, Brandt, & Thornes, 2003; Hill, Stellmes, Udelhoven, Röder, & Sommer, 2008) and future (Daliakopoulos et al., 2017) of Mediterranean arid and semi-arid ecosystems. Long-term anthropogenic pressure on forests (Baeza, Valdecantos, Alloza, & Vallejo, 2007) and agricultural land (Kosmas et al., 2015; Santana, Baeza, Marrs, & Vallejo, 2010; Spanos, Daskalakou, & Thanos, 2000), combined with abiotic factors such as high topographical and climatic variability (Scarascia-Mugnozza, Oswald, Piussi, & Radoglou, 2000), but also frequent disturbances such as fires, floods, and droughts (Buma & Wessman, 2011; Zdruli, 2014), create a diverse and unstable environment. This makes it challenging for scientists to achieve valid generalizations and draw

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conclusions about the status, drivers (Pausas, Llovet, Rodrigo, & Vallejo, 2008; Perevolotsky & Seligman, 2011), and trends (Arnan, Rodrigo, & Retana, 2007; Helldén & Tottrup, 2008) of land degradation and desertification.

The main pressures – as defined by the DPSIR framework (Borja et al., 2006) – on Mediterranean forests and rangelands are related to land use activities, such as grazing and logging, and disturbances, such as droughts and wildfires (Scarascia-Mugnozza et al., 2000; Zdruli, 2014). These pressures, first and foremost, degrade the vegetation canopy, reducing the density and diversity of plants, changing the species composition, and thereby limiting the supply of important ecosystem services (Calvo, Tarrega, & De Luis, 2002; Pyke, Herrick, Shaver, & Pellant, 2013). The soil is also negatively impacted: soil erosion, increased evaporation, compaction, and a decrease in soil organic matter (Certini, 2005; Coiffait-Gombault, Buisson, & Dutoit, 2012) all lead to reduced fertility, with a considerable impact on agricultural production and fodder provision. Landscape, defined in the context of this study as the combination of topography and land cover, plays an important role in modulating the impacts of pressures and disturbances. Different land covers imply different vegetation traits, such as water requirement and resistance to disturbance or human pressure (Karamesouti et al., 2015). Topography determines the amount of solar radiation, runoff and deposition patterns, and the erosion potential, thereby changing microclimatic conditions and soil fertility (Ruiz, Renault, Romero, & Beguería, 2012). Scientists have stressed the importance of positive feedbacks between decreases in vegetation density and other types of degradation (soil, water) and between land degradation and ecosystem vulnerability to disturbances (Crépin, Biggs, Polasky, Troell, & de Zeeuw, 2012; Knox & Clarke, 2012; Mayor et al., 2016). Coupled with the limited water availability in dry areas, these feedbacks prevent the spontaneous recovery of ecosystems. This explains the poor recovery rates and persistent vulnerability to land degradation observed in many Mediterranean forests and rangelands even though the anthropogenic pressure on these areas has greatly diminished due to outmigration and subsequent land abandonment (Carmel & Kadmon, 1999; López-Poma, Orr, & Bautista, 2014; Pausas et al., 2008).

A spatial assessment of the impacts of human activities in natural and semi-natural environments is a crucial step for understanding land degradation processes (Middleton & Thomas, 1997; Schwilk et al., 2009) and monitoring the effectiveness of responses (Plummer & Armitage, 2007; Schwilch et al., 2011). Remote sensing has been applied in a number of studies with the aim of mapping land degradation in a cost effective way, be it at regional scales (Garcia-Gomez & Maestre, 2011; Hill et al., 2008; Norman et al., 2014; Prince, De Colstoun, & Kravitz, 1998) or at the global scale (Bai, Dent, Olsson, & Schaepman, 2008; Bridges & Oldeman, 1999; Gibbs & Salmon, 2015; Zucca, Della Peruta, Salvia, Sommer, & Cherlet, 2012).

The most challenging aspect of such exercises consists in translating the multidimensional phenomenon of land degradation into simplified and spatially explicit information suitable for mapping. In order to take into account the diverse factors influencing land degradation, researchers have combined remotely sensed information with data on ecological features (e.g. soil type and depth, erosion, biodiversity) and socio-economic variables (e.g. land tenure, population density, land use history) to create multi-criteria indexes of sensitivity of land to degradation or desertification (Ladisa, Todorovic, & Liuzzi, 2010; Salvati, Sabbi, Smiraglia, & Zitti, 2014; Salvati, Salvati, Corona, Barbati, & Ferrara, 2015). Such methodologies enable a qualitative understanding of processes that might trigger land degradation, and they link the socio-economic and ecological factors concurring with land degradation. Their main shortcoming is that they require spatially explicit information over long periods of time, as well as the use of complex mathematical methods to analyse relationships and trends among such a large number of variables.

At the global scale, or in cases where detailed information about ecosystems was lacking, researchers working with remote sensing have tried to capture the complexity of land degradation using just a small number of variables. The normalized difference vegetation index (NDVI) (Tucker, 1979) has gained particular recognition in the scientific community as a good proxy indicator of vegetation degradation and – given the importance of the vegetation canopy in preventing land degradation in drylands – of general land degradation (Bai et al., 2008; Eckert, Hüsler, Liniger, & Hodel, 2015; Haberl et al., 2007; Thomasson, 1992; Wessels et al., 2007; Yengoh, Dent, Olsson, Tengberg, & Tucker, 2014) and the effectiveness of sustainable land management (Herrmann, Anyamba, & Tucker, 2005; Skidmore, Bijker, Schmidt, & Kumar, 1997) in drylands. The NDVI has been used widely for global assessments (Bai et al., 2008; Bridges & Oldeman, 1999; Thomasson, 1992) due to good data availability and the relative simplicity of statistical analyses involved. However, results from NDVI analysis are difficult to interpret, because NDVI values do not distinguish signs of degradation/conservation from impacts of adverse/beneficial natural processes (Gibbs & Salmon, 2015). Differences in topography, soil characteristics, water availability, and land use all have an influence on NDVI-based assessment of land degradation. To reduce the weight of these factors, most studies concentrate on regional to global assessments covering fairly long periods (10–20 years). This seldom matches the needs of land users and managers: They are more interested in local processes (at scales between 1:10,000 and 1:30,000) and in impacts of disturbances, pressures, or land management in the short to medium term (over 1–10 years).

The overall aim of our study is to design a method to provide land managers in data-scarce Mediterranean drylands with spatially explicit, up-to-date information on the state of their land, the pressures driving land degradation, and the effectiveness of management. Our methodology addresses three shortcomings of existing remote-sensing-based land degradation assessments by fulfilling the following criteria: (1) consistent detection of land degradation across different landscapes using the NDVI as a proxy indicator; (2) successful disentangling of the impacts of present-day anthropogenic pressure from the historical degradation inherited from previous land uses; (3) reliable and consistent evaluation of the effects of land management practices implemented.

To meet these criteria, we compile and validate degradation maps of three Mediterranean dryland study sites in Spain, Greece, and Cyprus using an innovative threshold methodology. We analyse the relationship between pressure and degradation patterns, discuss key results on the relationship between degradation, pressures, and land management practices in the study sites, and offer relevant insights into how topography influences degradation in Mediterranean dry areas.

1.1. Study sites

We focus on three study sites in Mediterranean Europe that each comprise a variety of healthy and degraded areas and face the risk of further land degradation. They are characterized by several risk factors for land degradation that are common to many Mediterranean drylands: limited water availability, shallow soils, a long history of anthropogenic pressure with repeated cycles of farming and land abandonment, as well as a low economic value of land and thus a lack of resources for land management. At the same time, the study sites differ in their degrees of aridity, ranging from sub-humid to semi-arid, and in the ratio between shrubland and