Science of the Total Environment 569–570 (2016) 973–981

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Lost in convergence, found in vulnerability: A spatially-dynamic model for desertification risk assessment in Mediterranean agro-forest districts

Ilaria Tombolini [a], Andrea Colantoni [b], Gianluca Renzi [a], Adele Sateriano [e], Alberto Sabbi [c], Nathan Morrow [d], Luca Salvati [a,*]

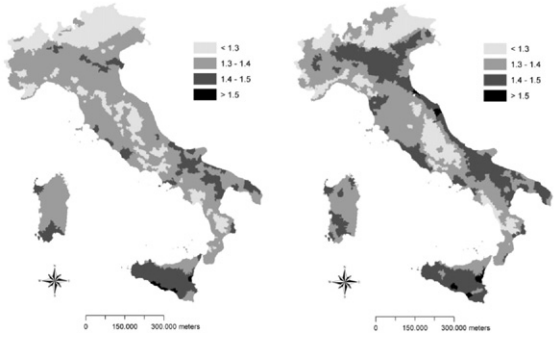
[a] Italian Council for Agricultural Research and Economics (CREA-RPS), Via della Navicella 2-4, I-00184 Rome, Italy
[b] Department of Agricultural and Forestry scieNcEs (DAFNE), Tuscia University, Via S. Camillo de Lellis, I-01100 Viterbo, Italy
[c] Italian National Institute of Statistics (ISTAT), Via C. Balbo 16, I-00184 Rome, Italy
[d] Tulane University, Payson Program in International Development at the School of Law, New Orleans, USA
[e] Via A. Di Tullio 40, I-00136 Rome, Italy

HIGHLIGHTS

- This study illustrates an approach to early-warning assessment of desertification risk.
- We used the ESAI approach to study land vulnerability in Italian agro-forest districts.
- Convergence in Land Vulnerability to Degradation (LVD) was mainly observed in flat districts.
- The average ESAI score converged more rapidly in large districts in respect to smaller districts.
- Spatial convergence in LVD is a key concept in the assessment of land degradation.

GRAPHICAL ABSTRACT

Average score of the sensitivity index to land degradation in Italian agro-forest districts.



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ARTICLE INFO

Article history:
Received 17 April 2016
Received in revised form 8 June 2016
Accepted 8 June 2016
Available online 20 July 2016

Editor: Jay Gan

Keywords:
Land degradation
Environmental indicators
Local districts
Spatial regression
Italy

ABSTRACT

This study illustrates an approach to early-warning assessment of desertification risk in Mediterranean agro-forest districts based on the concept of 'spatial convergence' in Land Vulnerability to Degradation (LVD). We investigate long-term and short-term spatial convergence in LVD across 773 agro-forest districts with different biophysical and socioeconomic traits across Italy. We used the standard Environmental Sensitive Area Index (ESAI) based on climate, soil, vegetation and land management attributes as a proxy for LVD. Latitude, elevation and district size are considered as control variables. Results of the analysis show that more than half districts have experienced an increase in the average ESAI score between 1960 and 2010 and present distinct spatial patterns over three time intervals considered in the study: 1960–1990, 1990–2000 and 2000–2010. Convergence in LVD was observed between 1960 and 1990 especially in flat and highly accessible rural districts of northern Italy. The average ESAI score converged more rapidly in large districts in respect to smaller districts. A moderate convergence in LVD was observed in southern and central Italy during 1990–2000 and 2000–2010 respectively.

* Corresponding author at: CREA-RPS, Italy.

http://dx.doi.org/10.1016/j.scitotenv.2016.06.049

Based on our findings, spatial convergence in LVD is finally proposed as a key concept in the on-going and future assessment of land degradation in rural areas under (increasing) anthropogenic pressure.

1. Introduction

Increased human pressure in dry ecosystems has resulted in a significant expansion of degraded land and a measurable loss of soil quality over the last three decades (Geeson et al., 2002; Montanarella, 2007; Simeonakis et al., 2007). Steep topography, poor soils, low vegetation cover, climate aridity and drought severity, negatively impact land quality, triggering soil degradation processes especially in ecologically-vulnerable areas (Geist and Lambin, 2004; Basso et al., 2012; Bisaro et al., 2014). The negative influence of land degradation on local development, economic performances and social cohesion is also documented, mainly for emerging countries (Glenn et al., 1998), but empirical evidence has been increasingly collected for the wealthiest regions in the world (Juntti and Wilson, 2005; Salvati and Carlucci, 2013; Kelly et al., 2015).

Land Vulnerability to Degradation (LVD) is a dynamic attribute of the landscape (Salvati and Zitti, 2008) and determining the spatial dynamics observed recently at both the global and regional scale requires a continuous monitoring to identify the most relevant contributing factors (Hill et al., 2008). Temporal dynamics and spatial heterogeneity in land degradation drivers are rarely considered together in mitigation and adaptation policies (Gisladottir and Stocking, 2005). By contrast, response interventions to land degradation have been primarily developed with the final objective of reversing (or reducing) the short-term impact of a single factor or a limited set of contributing factors (Sommer et al., 2011). Biophysical and socioeconomic drivers of change have been usually assessed separately (Zdruli, 2014), and therefore policy strategies have also frequently addressed the two dimensions separately (Thomas et al., 2012).

Due to the long-term interaction between nature and man, traditional agro-forest systems dominate Mediterranean landscapes and preserve biodiversity, natural resources, aesthetic and cultural values (Salvati and Ferrara, 2015). Forms of sustainable agriculture were frequently practiced in these districts and provided some protection from land degradation (Biasi et al., 2015). Agro-forest systems are increasingly seen as buffer zones containing soil degradation and desertification risk in vulnerable areas (Bajocco et al., 2015). Agro-forest districts are therefore seen as an appropriate scale for assessment of LVD in Mediterranean Europe (Salvati et al., 2015a). Past experience shows that multidimensional analysis of landscape and socioeconomic transformations in agro-forest systems prove to be relevant evidence base for the development and implementation of integrated land degradation management strategies (Salvati and Zitti, 2009). Additionally, in-depth understanding of complex environmental dynamics in agro-forest systems at the spatio-temporal scales considered in this study contribute essential information for the design of sustainable land management policies (Le Houérou, 1993).

'Convergence' in a given condition or process is a regional system modeling approach commonly applied to indicators of economic growth or income but also used more recently to model a wider variety of sociological and ecological phenomenon (Barro and Sala-i-Martin, 2004). The 'convergence' notion denotes a negative relationship between changes over time in the studied variable and the level of the same variable at the initial observation time (Arbia and Paelinck, 2003). Convergence compares the average change over time to the initial value for an indicator under the implicit assumption that those units with the lowest value will change at a faster rate to those units already near (or above) the mean. If it is assumed that the indicator is rising across the observed units, then there should be a negative relationship between more recent measurements and previous measurements. Then more negative this relationship, the more certainty that values across all units are in fact converging around the mean.

Spatial convergence in economic, demographic and social indicators is well documented in regional and country level assessments (Quah, 1997; Giannias et al., 1999; Manca et al., 2014), but relatively fewer studies focus on convergence of environmental pressure, governance and policy indicators (Iosifides and Politidis, 2005; Aldy, 2006; Ezcurra, 2007). Notwithstanding the relative novelty of the approach, there exists a great demand for research on spatial convergence in ecological (or socio-environmental) variables as a potential evidence base to design policies for the mitigation of land degradation processes driven jointly by biophysical and socioeconomic factors (Bajocco et al., 2015). Spatial convergence is also suggested as a possible early-warning indicator of environmental risk in complex ecological contexts (e.g. Neumayer, 2001).

Salvati and Zitti (2008, 2009) first applied the concept of convergence to LDV and then provided empirical evidence on spatial convergence in LVD at the country scale by identifying the most relevant factors determining convergence among selected ecological and socio-economic factors in Italy. Salvati et al. (2013) demonstrated that a given territorial system may undergo different (or even contrasting) patterns of land vulnerability (improvement, worsening or stability) in the long-term, amplifying sometimes the heterogeneity in the spatial distribution of land resources (Salvati et al., 2015a). Processes causing spatio-temporal convergence in LVD have been hypothesized to represent a signal of desertification risk (Salvati, 2014). Convergence in LVD may also be used as an organizing concept when developing socio-environmental scenarios for policy implementation (Thornes, 2004). Although a number of candidate indicators, composite indexes and decision support systems assessing desertification risk have been proposed at both global and regional scales, early-warning approaches increasingly require a reduced number of variables and simplified analytical techniques (Salvati et al., 2011).

Meeting these requirements, spatial convergence in LVD is proposed as a promising approach to on-going and future assessment of land degradation in rural areas under (increasing) anthropogenic pressure (Salvati and Zitti, 2009). Convergence or divergence of LVD may prove useful in the assessment of adaption capacity of agro-forest districts to biophysical and human pressures as well as inform specific mitigation strategies (Briassoulis, 2011; Kelly et al., 2015; Salvati et al., 2015a). In the present study we investigate the long-term (1960–2010) spatial convergence of LVD in Italy using a composite index of land vulnerability that integrates environmental and socioeconomic variables at the scale of agro-forest districts. The national coverage of our study makes the results potentially more interesting than a pilot study confined to a limited test area. Analysis of areas experiencing spatial convergence in LVD in Italy provides relevant information for the analysis of land degradation across the northern Mediterranean and may contribute to the evidence-based design of place-specific measures for mitigation of desertification risk and adaptation to rapid socio-environmental changes (Salvati et al., 2015b). The novelty of the approach presented in this study lies in the integration of a widely-used land degradation monitoring system (such as the ESA) into a statistical model incorporating space and selected context variables as relevant predictors of local-scale changes in the level of LVD. Finally, we discuss the relevance of spatial convergence in LVD as an early-warning signal of increased desertification risk at the local scale.