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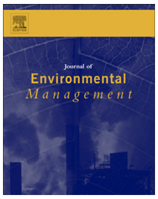

Research article

Assessing the effectiveness of sustainable land management policies for combating desertification: A data mining approach

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A B S T R A C T

This study investigates the relationship between fine resolution, local-scale biophysical and socioeconomic contexts within which land degradation occurs, and the human responses to it. The research draws on experimental data collected under different territorial and socioeconomic conditions at 586 field sites in five Mediterranean countries (Spain, Greece, Turkey, Tunisia and Morocco). We assess the level of desertification risk under various land management practices (terracing, grazing control, prevention of wildland fires, soil erosion control measures, soil water conservation measures, sustainable farming practices, land protection measures and financial subsidies) taken as possible responses to land degradation. A data mining approach, incorporating principal component analysis, non-parametric correlations, multiple regression and canonical analysis, was developed to identify the spatial relationship between land management conditions, the socioeconomic and environmental context (described using 40 biophysical and socioeconomic indicators) and desertification risk. Our analysis identified a number of distinct relationships between the level of desertification experienced and the underlying socioeconomic context, suggesting that the effectiveness of responses to land degradation is strictly dependent on the local biophysical and socioeconomic context. Assessing the latent relationship between land management practices and the biophysical/socioeconomic attributes characterizing areas exposed to different levels of desertification risk proved to be an indirect measure of the effectiveness of field actions contrasting land degradation.

1. Introduction

Land Degradation is a complex phenomenon occurring when specific biophysical, economic, social, cultural and institutional factors act synergistically to produce and entrench desertification over the long term (Reynolds et al., 2011). Unsustainable use of natural resources, weak economic development and policy inaction are relevant drivers of land degradation and reflect the complex relationship between local ecological conditions, socioeconomic dynamics and policy action (Bisaro et al., 2013). Desertification

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results in a progressive decline of land productivity and ecosystem functions, and is a key issue on the global policy agenda (Stringer and Harris, 2014). Desertification has negative impacts on food security, biodiversity and quality of life (Glenn et al., 1998). Abuse or misuse of land drives regional disparities in the availability of natural resources and results in a spatially-unbalanced development (Johnson and Lewis, 2007).

In the last decades, desertification risk has increased in many parts of the world, with land degradation now becoming severe in both emerging and developed countries (Thomas et al., 2012; Izzo et al., 2013; Yang et al., 2013). In the Mediterranean basin, Land Degradation (LD) is the result of the interplay between natural and socioeconomic systems (Wilson and Juntti, 2005). This process involves a number of biophysical attributes of the landscape (topography, climate, soil, vegetation) and conditions deriving from human activity (e.g. land-use transformations, agricultural intensification, land abandonment, population density, settlement distribution, industry and tourism development).

A large part of the Mediterranean region is classified as vulnerable to LD (Hill et al., 2008). While desert land is relatively scarce, areas with semi-arid climate and socioeconomic conditions which negatively impact soil fertility, biodiversity and ecosystem services are rather common. In such contexts, landscapes have lost part of their ecological and economic potential (Basso et al., 2010). LD processes in the Mediterranean basin are highly variable in time and space, closely influenced as they are by the different speeds of changes in environmental and socioeconomic conditions (Ibanez et al., 2008).

Studies that have addressed the most important causes and consequences of LD from a socio-environmental perspective have identified some of the core proximate drivers and underlying factors of change which lead to desertification risk (Zdruli, 2013). Salvati et al. (2015) have proposed an approach to assess the multiple relationships between biophysical variables and socioeconomic factors in a representative sample of Mediterranean sites, identifying diverging spatial patterns for biophysical and human drivers of LD, with higher variability observed for economic and social variables. Gaps in knowledge on the role of system complexity in shaping land vulnerability to desertification, however, have often been underestimated (Briassoulis, 2015). Research often focused on single - albeit important - factors such as soil degradation, whilst diachronic approaches which draw on data at a national or regional scale with an adequate spatial resolution are relatively scarce (Kosmas et al., 2015). Indicator-based approaches have been developed mainly for permanent monitoring of biophysical conditions characterizing LD processes (Ferrara et al., 2012). Whilst development of proper indicators and decision support systems to inform mitigation policies is a research priority (Glenn et al., 1998), further investigation is required to identify a comparative framework for assessing the impact of regional-scale drivers, and enable the importance of biophysical and socioeconomic factors to be ranked (Salvati et al., 2015).

Based on the issues discussed above, rethinking a non-reductionist approach to LD in relation to the characteristic territorial dimensions and the most suitable policy responses is imperative. Mitigation plans should encompass all of the disciplinary perspectives which impact on the problem (Sabbi and Salvati, 2014). Emphasis should be given to the social, demographic, economic, political and cultural processes that shape LD in any given area, and to the responses that society, in that specific local context, is able to implement (Iosifides and Politidis, 2005).

According to Briassoulis (2015), "human response to land degradation can be considered any planned (formal) or unplanned (informal) actions that purport to directly and explicitly tackle it and/or address other individual and collective socioeconomic goals in affected socio-ecological systems". Depending on the prevailing socioeconomic conditions, stakeholders and other actors may have no option but to continue with business as usual (no remedial action), or to engage in more resource-intensive activities (negative responses). Conversely, in some local contexts, stakeholders may be able to undertake actions to mitigate soil and land degradation (positive responses). Positive responses contribute to sustainable development of the local system preserving critical ecological functions and relevant socioeconomic attributes (Kelly et al., 2015).

Three key issues should be considered when effective responses to LD are proposed. First, a policy response or the implementation of a policy instrument does not always result in the intended impact in every context. Second, responses may have multiple impacts on the target environment and third, a holistic approach (as opposed to a target-specific or process-specific approach) is required in order to cope with a complex and multifaceted phenomenon such as LD (Salvati et al., 2015). The non-linear, highly-diversified nature of LD processes justifies the implementation of responsive and locally-adaptable policy instruments that are suitable to address place-specific environmental patterns (Wilson and Juntti, 2005). Previous studies have also suggested that the lack of relevant policy, due to *lassez-faire* practices or weak decision-making processes can be considered as tangible policy implementation, although inaction costs have been insufficiently acknowledged and investigated (Ferrara et al., 2012). As a consequence, policy implementation is a relatively fuzzy decision-making spectrum of (more or less) integrated measures, instead of a clear process of well-informed and locally-specific decision-making (Briassoulis, 2005).

In fact, to be effective on the ground, responses have take account of diverse components which are operating at various spatial scales and temporal speeds, and their effectiveness will therefore depend on their ability to respond to the relationships amongst these components. An integrative approach based on the concept of 'response assemblage' was recently proposed with the aim of identifying various types of interventions to combat LD (Briassoulis, 2015). Response assemblages reflect the need for humans to use natural resources sustainably to satisfy societal needs and are intended as "geographically and historically unique, provisional, open, territorial wholes, complex compositions emerging from processes of assembling biophysical and human components" (Briassoulis, 2015). A response assemblage operates at multiple spatial scales and is characterized by specific environmental attributes, land-use regimes and socioeconomic profiles.

Apart from the contribution mentioned above, frameworks identifying responses to LD are still relatively scarce (Thomas et al., 2012; Zdruli, 2013). Understanding place-specific LD processes, and identifying the spatial relationship between drivers of LD at different geographical scales, have allowed designing more effective mitigation strategies (MacDonald et al., 2000; Gellrich et al., 2007; Koulouri and Giourga, 2007; Corbelle Rico et al., 2012). Since place-specific factors and socioeconomic changes at multiple spatial and temporal scales have major impacts on LD responses (Sluiter and De Jong, 2007; Weissteiner et al., 2011; Kairis et al., 2014), stakeholder participation in the design of mitigation responses (e.g. a sustainable land management strategy) is crucial in the fight against desertification (Briassoulis, 2005). Iosifides and Politidis (2005) investigated the local context and its impact on individual stakeholder decision-making, and highlighted the importance of an integrated analysis of biophysical and socioeconomic drivers of change in order to identify and understand responses to LD. An in-depth knowledge of the latent relationship between LD drivers and components of the specific local human-biophysical system is an essential baseline when implementing sustainable land management (SLM) strategies (Zdruli, 2013). Sabbi

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and Salvati (2014) introduced a comprehensive approach to the analysis of the spatial relationship between biophysical and socioeconomic components of a socio-ecological system based on data mining techniques. This framework was applied to a number of rural districts in southern Europe exposed to different levels of desertification risk and allows us to quantify the main environmental and socioeconomic impacts on land. Based on this information, mitigation policies and adaptation strategies for locally-based LD processes have been proposed (Kosmas et al., 2015).

The study reported in this paper contributes to this research frame by illustrating an exploratory framework based on data mining techniques applied to a number of indicators that assesses biophysical and socioeconomic conditions at 586 field sites exposed to variable levels of desertification risk, and where different responses to LD have been implemented. Data were derived from sites in five Mediterranean countries (Spain, Greece, Turkey, Tunisia and Morocco). Eight candidate responses to LD were studied (terracing; grazing control; prevention of wildland fires; soil erosion control measures and soil water conservation measures; sustainable farming practices; land protection measures; and financial subsidies) and correlated with the local context profiled using 40 biophysical and socioeconomic indicators.

The aims of this study were (i) to investigate the spatial occurrence and intensity of 8 candidate responses to LD identifying 'response assemblages' at the field scale, (ii) to correlate the occurrence and intensity of 'response assemblages' with the level of desertification and (iii) to identify spatial relationships between 'response assemblages' and the socioeconomic context at both the local and regional scale. The study contributes to the identification and classification of practical actions and policy measures intended as responses to LD using a statistical procedure which is robust, simple and adaptable to different environmental and socioeconomic conditions. Data mining is a promising tool for ascertaining the spatial configuration of factors shaping desertification risk (Salvati et al., 2015) and allows for an indirect evaluation of the effectiveness of candidate land management actions in the mitigation of LD.

2. Materials and methods

2.1. Study area

A total of 586 field sites were selected in five study areas in the Mediterranean basin. Two of the study areas are situated in European Union member states (Greece and Spain) and three study sites are in countries which are not part of the EU (Turkey, Tunisia, Morocco). Specifically, the study sites are: (i) Crete island, southern Greece, (ii) Guadalentin basin, south-eastern Spain, (iii) Eskisehir plain, Turkey, (iv) Zeuss Koutine, Tunisia and (v) Mamora Sehoul, Morocco. Each study site covers a surface area ranging between 100 km^2 and 150 km^2 and includes a number of individual field sites.

Field sites were representative of a variety of biophysical and socioeconomic conditions typical of Mediterranean rural landscapes. Data were collected as a part of the extensive fieldwork carried out through the DESIRE research project, financed by European Commission (see Kosmas et al., 2015 and references therein). The field sites are located in areas affected by variable degrees of land degradation, due to their differing levels of soil erosion, salinization, compaction, sealing, contamination, water stress, overgrazing, wildfires and anthropogenic pressures (population growth, tourism development, industrialization, depopulation, land abandonment). In 80% of the study sites, climatic conditions are characterized as semi-arid or dry with rainfall ranging between 200 and 600 mm. Reference evapotranspiration >800 mm (*sensu* Penman) was also observed in the majority of field sites. Soils are formed mainly on sedimentary and unconsolidated parent materials. Soil organic matter content in the soil surface has been identified as low to moderate (0.5%–1.5%) in most of the study sites. Dominant vegetation cover types include cereals, olives, vineyards, garden crops and cotton. The agricultural holdings are characterized as owner-farmed in 58% of the sites with farm size ranging from less than 2 ha to more than 100 ha, and there is a high degree of land fragmentation (Salvati et al., 2015).

2.2. Data collection

Data were collected at the field scale. Cultivated fields with an area ranging between 0.5 ha and 20 ha and having uniform soil, topography, land-use and management were considered as field sites (Kairis et al., 2014). Some field sites were identified from topographic maps or ortho-photographs in 400 m grids by applying a systematic sampling design. However, this approach was not easily applied throughout the study areas since the presence of the land owner was necessary for the collection of some data related to land management and the socioeconomic context at the local scale (Kosmas et al., 2015). Therefore, the majority of the field sites were described after contacting the owner of the land. The location of each field site was pin-pointed using GPS. A digital questionnaire and guidance notes were compiled defining each variable and describing the assessment methodology with the aim of harmonizing data collection between study sites (see Salvati et al., 2015 and references therein for details on methodology, selected variables and technical details). A total of 49 variables (no missing values) were derived from the collected information.

Values for each variable collected were transformed into a scale indicator (with scores ranging between 1 and 2) describing the (positive or negative) relationship with LD. Increasing scores indicate a higher contribution to land degradation (Kosmas et al., 2015). Existing classification systems (Rubio and Bochet, 1998), reference research frameworks (Lavado Contador et al., 2009) and expert opinion were used to set up the scoring system. Scores are suitable to scale and homogenize the values of the studied variables to a comparable range allowing comparison across space or between different research dimensions (Ferrara et al., 2012).

2.3. Indicators

A comprehensive set of 40 indicators assessing biophysical and socioeconomic conditions was prepared according to Kosmas et al. (2015) and Salvati et al. (2015). The indicators (Supplementary Materials, Table 1) were classified into 9 dimensions (4 dimensions assessing biophysical aspects and the remaining 5 dimensions quantifying socioeconomic factors): (a) climate (4 indicators), (b) soil (10), (c) vegetation (3), (d) water runoff and fires (3), (e) agriculture (5), (f) cultivation practices and husbandry (6), (g) land management (10), (h) water use (2) and (i) demography and tourism (4). Additional indicators (land protection intensity, terracing, grazing control, fire prevention measures, farm subsidies, sustainable farming practices, soil erosion control measures and soil water conservation measures) were used to assess 8 specific land management practices or policy actions with a (supposed) positive impact on LD (Sabbi and Salvati, 2014). These practices are considered as important interventions against LD in the studied areas (Salvati et al., 2015). However, other practices/actions can be taken as relevant in other territorial contexts. The overall level of desertification risk in each site was derived according to the Environmentally Sensitive Area (ESA) approach (Lavado Contador et al., 2009), originally produced by the MEDALUS research project funded by European Union (Ferrara et al., 2012).

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Candidate indicators were selected by (i) reviewing the existing literature (Rubio and Bochet, 1998; Wilson and Juntti, 2005; Basso et al., 2010; Kairis et al., 2014; Kosmas et al., 2015), (ii) consultation with stakeholders (land users and managers, local politicians and research groups working on LD issues at both national and study site levels) and (iii) using scientific, technical or planning reports, including the National or Regional Action Plans to Combat Desertification. Candidate indicators included (i) state indicators monitoring specific territorial contexts, (ii) pressure indicators describing conditions where remedial interventions are required to prevent land degradation and desertification, and (iii) response indicators focusing on actions undertaken for sustainable land management, landscape conservation or environmental quality protection.

2.4. Statistical analysis

A data mining strategy incorporating Principal Component Analysis, Spearman correlations, step-wise multiple regression, non-parametric Mann-Whitney inference and Canonical Correlation Analysis was carried out using the full sample size (n = 586 observations). The multivariate techniques considered here are intended to (i) assess the variety of local socio-ecological systems, (ii) to identify indicators associated with the level of desertification risk and the spatial relationships among them, and (iii) to characterize the most relevant responses to LD. The indicators involved in each statistical analysis are listed in Table 1.

A Principal Component Analysis (PCA) was run on the data matrix constituted by the 8 indicators assessing candidate responses to LD at each of the 586 field sites. The PCA was aimed at exploring the spatial relationship between the 8 response indicators with the aim of identifying (formal or informal) response assemblages. Significant components were selected according to the eigenvalue extracted by the PCA. Components with absolute eigenvalue >1 were extracted and analyzed. Non-parametric Spearman rank tests were run with the aim of correlating pairwise response indicators and biophysical/socioeconomic indicators profiling field sites. Significance was set up at $p < 0.05$ after Bonferroni's correction for multiple comparisons.

A multiple linear regression model was run to identify the response indicators most associated with the level of desertification risk in each field site. The model was developed using a forward stepwise approach with response indicators as predictors and the level of desertification risk as the dependent variable. Predictors were included in the model when the *p*-level associated to the respective Fisher-Snedecor test was below 0.01. Results of the regression model were illustrated using standardized coefficients and tests of significance for each variable (an overall Fisher-Snedecor's F-statistic testing for the null-hypothesis of non significant model and a Student's *t*-statistic testing for the null hypothesis of non significant regression coefficient). A Durbin-Watson statistic testing for the null hypothesis of serially uncorrelated errors was applied separately to regression residuals.

Response indicators were analyzed separately using non-parametric Mann-Whitney U statistics testing for significant differences ($p < 0.05$) in the two EU countries (Greece and Spain) compared with the three Mediterranean countries outside of the EU (Morocco, Tunisia, Turkey). This analysis evaluates the occurrence and intensity of different land management actions and/or practices within and outside the European Union, providing useful elements for the evaluation of the effectiveness of some EU policies relevant to LD (e.g. farm subsidies). A Canonical Correlation Analysis (CCA) was finally carried out with the aim of separately assessing the spatial relationship between the 20 biophysical indicators (or the 20 socioeconomic indicators) and the 8 response indicators at the field site scale. The general objective of the CCA is to combine two sets of indicators (e.g. biophysical indicators *vs* land management actions or socioeconomic indicators *vs* land management actions) into a common structure formed by a restricted number of factors (roots) extracting a high proportion of the matrices' variance. The roots' structure was analyzed on the basis of the correlation coefficients with the input indicators. The final aim of the CCA was to summarize the results derived from previous analysis steps providing a comprehensive overview of the complex spatial patterns within the studied variables, and the spatial relationship between desertification risk, the local context and the candidate responses to LD.

Table 1
List of the indicators used in the data mining approach presented in this study (for a complete description see Table 1, Supplementary Materials).

Variable	Class	PCA	SRC	MLR	MWU	CA
Desertification risk	D		●	●		
Degree of erosion	B		●			●
Major land-use/cover	B		●			●
Vegetation cover type	B		●			●
Rainfall	B		●			●
Aridity index	B		●			●
Potential evapotranspiration	B		●			●
Rainfall seasonality	B		●			●
Rainfall erosivity	B		●			●
Parent material	B		●			●
Rock fragments	B		●			●
Slope aspect	B		●			●
Slope gradient	B		●			●
Soil depth	B		●			●
Soil texture	B		●			●
Soil water storage capacity	B		●			●
Exposure of rock outcrops	B		●			●
Organic matter surface horizon	B		●			●
Plant cover	B		●			●
Drainage density	B		●			●
Runoff water storage	B		●			●
Impervious surface area	S		●			●
Burned area	S		●			●
Farm ownership	S		●			●
Farm size	S		●			●
Land fragmentation	S		●			●
Net farm income	S		●			●
Parallel employment	S		●			●
Tillage operations	S		●			●
Tillage depth	S		●			●
Tillage direction	S		●			●
Grazing intensity	S		●			●
Land use intensity	S		●			●
Period of existing land use	S		●			●
Irrigation percentage of arable land	S		●			●
Tourism intensity	S		●			●
Elderly index	S		●			●
Population density	S		●			●
Population growth	S		●			●
Frequency of tillage	S		●			●
Land abandonment	S		●			●
Farm subsidies	P	●	●	●	●	●
Land protection intensity	P	●	●	●	●	●
Terracing	P	●	●	●	●	●
Grazing control	P	●	●	●	●	●
Fire prevention measures	P	●	●	●	●	●
Sustainable farming	P	●	●	●	●	●
Soil erosion control measures	P	●	●	●	●	●
Soil water conservation measures	P	●	●	●	●	●

D = dependent variable; B = biophysical context variables; S = socioeconomic context variables; P = policy-relevant land management indicators. PCA = Principal Component Analysis (results in Table 2, Fig. 1), SRC: Spearman Rank Correlation analysis (results in , Appendix 1); MLR: Multiple Linear Regression (results in Table 3); MWU = Mann-Whitney *U* test (results in Table 4); CA = Canonical Analysis (results in Table 5).

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3. Results

3.1. Principal component analysis

The PCA run on the 8 response indicators at the field site scale extracted 3 relevant components explaining more than 65% of the total variance (Table 2). Component 1 accounts for 28.5% of the total variance and was correlated positively with soil erosion control measures, soil water conservation measures and land protection intensity. Component 2 accounts for 19.5% of the total variance with positive loadings assigned to terracing and farm subsidies and a negative loading assigned to fire prevention measures. Component 3 accounts for 17% of the total variance and outlines the counter-correlation between sustainable farming measures and grazing control measures since they present significant loadings with contrasting signs along component 3. Fig. 1 illustrates the position of each field site over the factorial plane based on components 1 and 2. Component 1 discriminates field sites mainly within non-EU countries (Tunisia, associated with negative or slightly positive scores; Morocco and Turkey associated exclusively with highly positive scores); component 2 discriminates field sites of EU countries (Greece and Spain, receiving positive scores on average) from sites situated in non-EU countries (receiving negative scores on average).

3.2. Non-parametric correlations

Non-parametric correlations assessing the spatial distribution of response indicators and the local context (biophysical and socioeconomic attributes) are illustrated in Supplementary Materials, Table 2. The level of desertification risk in each field site was correlated positively with the intensity of land protection, fire prevention and grazing control measures. The remaining five response indicators are not directly associated with the level of desertification risk. Fire prevention is the action with the largest number of significant correlations with both biophysical and socioeconomic variables at the field site scale (78%) preceding sustainable farming (68%) and land protection (58%). Indicators totaling an intermediate number of significant correlations with the variables assessing the local context are grazing control (54%) and farm subsidies (49%). Soil water conservation measures (46%), terracing (44%) and soil erosion control measures (42%) totaled a comparatively low percentage of significant correlations in respect to the other actions.

Fire prevention measures are more frequently observed in field sites with medium-high population density and positive demographic growth rate, tourism intensity and net farm income. By contrast, the intensity of fire prevention measures is low in areas characterized by semi-arid climate, poor soils and moderate-low plant cover, land fragmentation and farm size. Fire prevention measures are therefore more likely to be applied in wealthier rural contexts with suitable biophysical conditions for cropping. Similar results were found for sustainable farming, which is more likely to be observed in biophysical contexts with relatively good climate conditions and with farms with young owners and high returns. The intensity of land protection measures is related to soil and climate and was found to be higher in local contexts with high soil depth and water storage capacity and medium-high plant cover. A higher level of land protection was also observed in areas with stable or moderately increasing population growth, more sustainable farming (depending, for example, on tillage depth, intensity and direction) and a low rate of land abandonment.

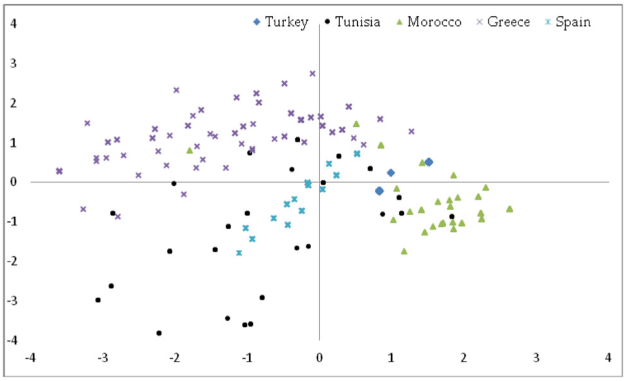

Fig. 1. Principal Component score plot of the 586 experimental sites investigated in the present study by country (PC 1: x-axis *vs* PC 2: y-axis).

Grazing control is a practice more frequently observed in semi-arid and arid land with low-quality soils and in territorial contexts with high grazing intensity, land abandonment and fragmentation. Farm subsidies are linked with biophysical and socioeconomic variables reflecting place-specific factors rather than regional environmental conditions. Soil water conservation measures are especially practiced in rural sites with a young population and where sustainable farm practices are applied. Terracing is mainly observed in semi-arid and arid climate conditions, with intense grazing, high land ownership rates, low tourism intensity and high land abandonment rates. Finally, soil erosion control measures are increasingly observed in areas with high risk of soil erosion, low plant cover, high grazing intensity, parallel employment of farmers in non-agricultural sectors, depopulation and land abandonment.

3.3. Multiple regression model

Results of a step-wise multiple regression model with the level of desertification risk as the dependent variable and the response indicators as predictors are illustrated in Table 3. The best regression model incorporates four predictors with adjusted $R^2 = 0.25$ and a significant Fisher-Snedecor F test. The model's outcomes are in partial agreement with the findings collected from the non-

Table 2
Principal Component Analysis loadings (>|0.5|).

Variable	PC 1	PC 2	PC 3
Farm subsidies		0.50	
Land protection intensity	0.69		
Fire prevention measures		−0.65	
Sustainable farming			0.67
Soil erosion control measures	0.71		
Soil water conservation measures	0.50		
Terracing		0.60	
Grazing control			−0.52
Explained variance (%)	*28.6*	*19.5*	*17.0*

Table 3
Results of the step-wise multiple linear regression with desertification risk as the dependent variable and the eight measures combating land degradation in the 586 plots investigated in the present study as predictors (adjusted $R^2 = 0.248$, $F_{(4,581)} = 49.3$, $p < 0.001$).

Variable	Beta	Std.Err.	*t*(581)	*p*-level
Intercept	0.000	0.030	1.342	0.180
Land protection	0.442	0.038	11.624	0.000
Grazing control	0.277	0.039	7.030	0.000
Terracing	−0.186	0.039	−4.790	0.000
Farm subsidies	0.128	0.039	3.321	0.001

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parametric Spearman analysis (Section 3.2). Intensity of land protection and grazing control are the predictors with the highest regression coefficient observed with the level of desertification risk preceding terracing and farm subsidies. Desertification risk is higher in field sites with extensive terraces and economic subsidies and decreases in areas with protected land and grazing control.

3.4. Non-parametric inference

Results of the pair-wise non-parametric Mann-Whitney *U* test comparing the spatial distribution and intensity of response indicators in EU (n = 276 sites) and non-EU countries (n = 310 sites) indicate that 4 indicators out of 8 were significantly different ($p < 0.0001$) in the two groups of countries (grazing control: adj-Z = 11.5; vegetation protection from fires: adj-Z = 21.5; farm subsidies: adj-Z = −14.1; land protection intensity: adj-Z = 7.1). Sustainable farming (adj-Z = −3.3) and terracing (adj-Z = 3.9) are moderately different ($0.001 < p < 0.05$) between EU and non-EU countries. Two indicators (soil erosion control measures: adj-Z = 0.2; soil water conservation measures: adj-Z = −1.7) show a homogeneous distribution ($p > 0.05$) in both EU and non-EU countries.

3.5. Canonical correlation analysis

A separate Canonical Correlation Analysis (CCA) was run on the standardized data matrices respectively composed of 20 biophysical indicators (Table 4) and 20 socioeconomic indicators (Table 5), both contrasted with the 8 response indicators observed at the 586 field sites. The CCA analyzing biophysical indicators extracted 7 roots respectively with 59.6% (left variables' set) and 94.2% (right variables' set) of the total variance. Each root identified specific response indicators associated with a restricted number of context indicators. Root 1 (respectively 12% and 21% of the total variance) is correlated positively with fire prevention measures and negatively with farm subsidies. The biophysical indicators correlated with this root are soil texture and soil water storage capacity (positive coefficients), potential evapotranspiration and rainfall erosivity (negative coefficients). Root 2 (13% and 16% of the total variance) is correlated positively with terracing, grazing control, soil drainage and four climate variables (rainfall, aridity index, potential evapotranspiration and rainfall seasonality). The structure of this root suggests that grazing control and terracing are actions strictly dependent on the local-scale biophysical context. Root 3 (12% and 19% of the total variance) is correlated positively with soil erosion control measures and sustainable farming, in turn associated to the overall degree of soil erosion and runoff water storage (positive coefficients) and to rainfall and aridity index (negative coefficients). The structure of root 3 indicates that the application of soil erosion control measures is dependent on the overall degree of soil erosion. Root 4 (6% and 12% of the total variance) is correlated positively with farm subsidies, grazing control and rainfall erosivity. Negative coefficients to root 5 (8% and 13% of the total variance) were assigned to soil water conservation measures and vegetation cover. Root 6 (5% and 6% of the total variance) outlines the association between land protection intensity and the prevailing use of land in each site. A higher level of land protection is associated with priority habitats and natural cover types such as forests, high-biodiversity pastures and crop mosaics. Finally, root 7 (5% and 7% of the total variance) indicates the negative relationship between the overall degree of soil erosion and terracing, confirming that this traditional land management option is an indirect response to

Table 4
Canonical analysis run between biophysical indicators and land measure indicators in the 586 plots investigated in the present study (bold indicates significant correlations with coefficient >|0.5|).

Variable	Root 1	Root 2	Root 3	Root 4	Root 5	Root 6	Root 7
Biophysical indicators							
% variance	*0.12*	*0.13*	*0.12*	*0.06*	*0.08*	*0.05*	*0.05*
Degree of erosion	−0.07	−0.06	**0.52**	0.21	−0.42	0.13	**−0.50**
Major land use	0.08	0.01	−0.17	0.41	0.05	**0.66**	0.23
Vegetation cover type	0.41	0.29	0.47	0.30	−0.11	0.05	−0.14
Rainfall	0.37	**−0.51**	**−0.56**	0.24	−0.14	−0.07	−0.08
Aridity index	0.21	**−0.50**	**−0.54**	−0.21	−0.39	−0.24	0.05
Potential evapotranspiration	**−0.66**	**−0.51**	−0.22	0.13	−0.25	0.00	−0.12
Rainfall seasonality	−0.11	**0.78**	−0.40	−0.15	0.05	0.14	0.21
Rainfall erosivity	**−0.51**	0.30	−0.01	**0.52**	0.25	0.27	0.00
Parent material	−0.19	−0.26	−0.05	0.18	−0.08	0.09	−0.12
Rock fragments	0.12	−0.06	−0.16	−0.14	0.11	−0.16	0.11
Slope aspect	−0.09	−0.06	0.23	0.06	0.16	0.13	−0.42
Slope gradient	−0.43	0.26	−0.06	−0.01	−0.04	0.37	−0.29
Soil depth	0.14	0.04	0.03	0.27	−0.47	−0.02	−0.15
Soil texture	**0.56**	0.16	−0.22	0.21	0.03	0.04	−0.24
Soil water storage capacity	**0.50**	0.25	−0.17	0.00	−0.49	0.33	−0.08
Exposure of rock outcrops	0.30	−0.09	0.12	0.48	−0.10	−0.20	−0.14
Organic matter surface horizon	0.49	−0.29	−0.30	−0.05	−0.20	0.25	−0.04
Plant cover	0.18	−0.36	0.06	−0.05	**−0.53**	0.17	−0.23
Drainage density	0.09	**−0.70**	0.47	−0.03	0.22	−0.01	−0.26
Runoff water storage	0.33	−0.10	**0.71**	0.03	−0.44	0.16	0.24
Response indicators							
% variance	*0.21*	*0.16*	*0.19*	*0.12*	*0.13*	*0.06*	*0.07*
Farm subsidies	**−0.59**	−0.43	0.40	**0.54**	0.10	−0.02	0.03
Policy enforcement	0.48	0.03	0.47	−0.35	−0.16	**0.62**	−0.04
Fire protection	**0.94**	−0.30	−0.02	0.07	−0.12	0.00	−0.03
Sustainable farming	0.10	0.11	**0.80**	−0.43	0.10	−0.31	0.09
Soil erosion control measures	0.16	0.29	**0.67**	0.02	−0.47	−0.14	−0.25
Soil water conservation measures	−0.05	0.40	0.04	0.07	**−0.79**	−0.06	−0.02
Terracing	0.09	**0.54**	0.11	0.33	−0.22	−0.02	**0.68**
Grazing control	0.42	**0.66**	0.13	**0.51**	0.27	−0.03	−0.17

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Table 5
Canonical analysis run between socioeconomic indicators and land measure indicators in the 586 plots investigated in the present study (bold indicates significant correlations with coefficient >|0.5|).

Variable	Root 1	Root 2	Root 3	Root 4	Root 5	Root 6	Root 7	Root 8
Socioeconomic indicators								
% variance	*0.15*	*0.14*	*0.10*	*0.06*	*0.10*	*0.05*	*0.02*	*0.02*
Impervious surface area	**−0.69**	−0.32	−0.18	−0.01	0.34	−0.02	−0.08	−0.14
Burned area	−0.27	0.22	−0.27	−0.16	−0.15	0.35	0.29	0.03
Farm ownership	−0.07	0.38	−0.57	−0.08	−0.25	−0.16	−0.01	0.09
Farm size	−0.40	0.30	0.15	−0.30	0.34	0.41	−0.05	0.00
Land fragmentation	−0.44	**−0.67**	0.11	0.14	−0.24	−0.11	−0.21	0.01
Net farm income	−0.01	0.22	0.33	**−0.54**	−0.29	0.08	−0.17	−0.26
Parallel employment	0.40	−0.33	0.41	0.05	−0.28	−0.38	0.02	0.21
Tillage operations	0.20	−0.31	0.34	0.12	0.42	0.28	0.04	0.04
Tillage depth	0.28	−0.38	0.21	0.16	0.25	0.29	−0.26	−0.03
Tillage direction	0.07	−0.45	0.22	−0.05	0.44	0.20	0.22	0.01
Grazing intensity	0.46	0.16	**−0.72**	0.05	−0.19	0.18	−0.02	0.14
Land use intensity	−0.16	−0.49	−0.03	0.04	0.14	0.44	0.04	−0.06
Period of existing land use	0.34	−0.44	0.00	−0.30	0.28	0.02	0.03	−0.31
Irrigation percentage of arable land	0.21	0.39	0.23	0.33	**−0.69**	−0.04	0.02	0.23
Tourism intensity	0.12	0.19	0.23	−0.20	0.17	0.12	−0.13	0.20
Elderly index	**−0.64**	**−0.64**	−0.06	−0.31	−0.13	−0.02	0.01	−0.06
Population density	−0.02	0.30	−0.33	**0.61**	0.46	0.11	−0.12	−0.19
Population growth	**−0.93**	0.07	−0.20	−0.13	0.00	0.10	0.01	0.04
Frequency of tillage	0.09	0.12	0.25	0.05	0.07	0.22	−0.38	0.04
Land abandonment	−0.11	**−0.52**	**0.52**	−0.01	−0.34	−0.08	0.11	−0.25
Response indicators								
% variance	*0.22*	*0.15*	*0.15*	*0.15*	*0.10*	*0.06*	*0.06*	*0.11*
Farm subsidies	**−0.57**	**−0.53**	−0.03	**−0.57**	−0.23	−0.04	0.01	−0.10
Policy enforcement	0.46	−0.26	0.31	0.41	−0.25	**0.53**	−0.33	−0.06
Fire protection	**0.89**	0.10	0.36	−0.18	−0.18	−0.08	−0.02	−0.05
Sustainable farming	0.16	**−0.75**	0.09	**0.58**	0.00	−0.20	0.14	−0.04
Soil erosion control measures	0.24	−0.41	−0.32	0.28	−0.37	−0.31	**−0.58**	−0.14
Soil water conservation measures	−0.07	0.32	−0.24	0.49	**−0.71**	−0.11	0.08	−0.27
Terracing	0.12	0.03	−0.48	0.06	0.11	0.03	−0.04	**−0.86**
Grazing control	**0.55**	−0.09	**−0.77**	−0.09	−0.07	0.19	0.19	0.05

biophysical factors triggering erosion risk.

The CCA analyzing socioeconomic indicators extracted 8 roots respectively with 64.6% (left variables' set) and 100% (right variables' set) of the total variance. Each root identified one-to-three response indicators in turn associated with a restricted number of contextual indicators. Root 1 (15% and 22% of the total variance) is correlated positively with fire prevention and grazing control measures and negatively with farm subsidies. Three socioeconomic indicators correlated negatively with root 1 (impervious surface area, elderly index, population growth). Farm subsidies and sustainable farming measures are negatively correlated to Root 2 (14% and 15% of the total variance), together with three socioeconomic indicators (land fragmentation, elderly index and cropland abandonment). Root 3 (14% and 15% of the total variance) is associated with grazing control measures and grazing intensity (negative coefficients) and land abandonment (positive coefficient). Root 4 (6% and 15% of the total variance) discriminates the impact of farm subsidies (negative coefficient) from that of sustainable farming measures (positive coefficient), with population density associated positively with the root and with the reverse pattern observed for net farm income. A negative coefficient to root 5 (10% and 10% of the total variance) was assigned to both soil water conservation measures and the percentage of irrigated arable land. The intensity of land protection (root 6), soil erosion control measures (root 7) and terracing (root 8) are not correlated with any socioeconomic indicators.

4. Discussion

Research, participatory processes, tools for policy makers and local-scale informal responses are seen as key components of an integrated strategy to fight desertification in the Mediterranean basin (Reynolds et al., 2011). The positive (research) and normative (policy) interest in human responses to LD usually focuses on sectoral policies and single-target measures that are designed to mitigate degradation in affected or vulnerable areas (Omuto et al., 2013). Conversely, actions targeting either the resources impacted and/or the drivers and proximate causes of degradation are considered 'best practices' in strategies designed to mitigate LD. Policy implementation in different socioeconomic and biophysical contexts necessitates responses which support adaptive management and effective local governance (Thomas et al., 2012) because human responses to LD are inevitably context-specific and contingent (Wilson and Juntti, 2005).

The study reported in this paper contributes to the debate on the characterization of candidate responses to LD; environmental legislation, economic incentives, customary rules and SLM practices were considered as candidate responses to LD. While responses have often been intended as a set of distinct actions targeting specific environmental problems or coping with an undesirable condition (Bakker et al., 2005; Strijker, 2005; Sluiter and De Jong, 2007), our approach has tried to identify specific informal 'response assemblages' based on the convergence of different land management practices at the local scale across a range of territorial contexts.

The data mining approach proposed here may contribute to a decision support system to be used by various stakeholders for joint monitoring drivers and candidate responses of land degradation in local contexts characterized by different environmental and socioeconomic conditions. The novelty of the proposed approach is based on the exploratory analysis of a large number of quantitative indicators collected in five study sites identifying apparent or latent relationships among drivers and candidate responses, possibly depending on the intimate characteristics of each examined local

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context. In this sense, our results outline the role of some 'state' variables of a local system assessing e.g. climate dryness, soil quality or vegetation cover, as clearly addressed in previous studies (Basso et al., 2010; Kosmas et al., 2015; Salvati et al., 2015). The evident complexity in the system of relationships between drivers and candidate responses to LD allows distinguishing biophysical factors (often characterized by one-to-one relationships between drivers and responses) from socioeconomic factors (more frequently characterized by relationships among multiple drivers and one response), corroborating the interpretative framework provided in Salvati et al. (2015). Evidences of this study may encourage more refined empirical research applied to the comprehensive analysis of a local system (Stavi et al., 2015) and its evolution in terms of ecological aspects (e.g. soil quality, geodiversity and vegetation) or socioeconomic conditions (e.g. changes in the social and economic base with impact on the produced value added).

Candidate responses to LD were classified as 'broad' or 'narrow' spectrum based on the observed correlation with the local context profile and with the overall level of desertification risk. Fire prevention, sustainable farming and the intensity of land protection were identified as broad-spectrum actions (Kosmas et al., 2015). Grazing control and farm subsidies were classified as medium-spectrum actions since they operate at the farm scale with indirect impact on LD in terms of both economic and environmental sustainability. By contrast, soil conservation measures and terracing practices are intended to cope specifically with soil degradation processes and are correlated primarily with soil indicators. Results of non-parametric inference confirm the local-scale target of soil conservation measures - possibly less relevant in EU policy in respect with actions classified as 'broad-spectrum', such as farm subsidies or land protection, or in national/regional strategies in respect with sectoral measures such as fire prevention, grazing control, sustainable farming or terracing.

Moreover, the candidate responses investigated in this study show distinct spatial relationships depending on the level of desertification risk and the underlying territorial context (Salvati et al., 2015). These evidences may outline divergent responses of the socio-environmental local systems to ecological disturbances, highlighting possible mismatches between single-action responses and the related biophysical conditions prevailing at the time (García-Orenes et al., 2010) For example, our data indicate how effective measures for soil conservation and for soil erosion control were adopted in regions where the overall soil quality is structurally high. Whilst most sites experienced a single-action response in our sample, the analysis of the spatial relationship between responses indicates a diversified set of dominant 'response assemblages' based on the co-existence of different actions with positive (or negative) feedbacks within the local context. Although practices considered in this study are seen as particularly important in the field sites investigated, other practices/actions can be relevant in other territorial contexts. A better knowledge of the latent relationship between the local context and the actions/practices intended as responses to LD is therefore a key issue to inform policy strategies which target desertification (Bisaro et al., 2013).

In this sense, the approach illustrated in this paper may inform the development of practical tools for (i) selecting response indicators from a sample of candidate LD indicators, (ii) assessing spatial relationships among relevant indicators and, based on this information, to characterize candidate responses to LD at both local and regional scales. Data mining is a promising tool to classify both field sites and candidate responses into homogeneous groups according to the level of desertification risk, the specific territorial conditions, and the distinct response assemblages being implemented. PCA results indicate convergence and divergence patterns in the spatial distribution of these response indicators identifying three possible 'response assemblages' in terms of actions/practices coping with (i) soil conservation, (ii) sustainable farm management and (iii) forest/vegetation protection. As a matter of fact, measures containing soil degradation (reducing soil erosion or enhancing soil water conservation) were more frequently observed in sites where land is protected. Measures dealing with farm management (terracing and farm subsidies) are spatially independent from measures protecting soils while being negatively correlated with measures specifically coping with forest degradation (e.g. fire prevention). Finally, measures improving farm sustainability (sustainable farming and grazing control) are uncorrelated with both soil conservation and fire prevention actions. Such a complex correlation pattern may indicate - at least in some territorial contexts - a process of spatial segregation of the different responses to LD, shaping the effectiveness of comprehensive 'response assemblages' at the local scale. These results are in agreement with previous studies from the same authors (e.g. Kosmas et al., 2015; Salvati et al., 2015) and from other scholars (e.g. Weissteiner et al., 2011).

5. Conclusions

Our study suggests how responses to LD based on a set of land management actions/practices are dependent on the local context impacting environmental degradation processes in a (more or less) effective way. Mitigation plans, e.g. incorporating SLM strategies, should promote a policy shift from driver-specific and process-specific targets to a more comprehensive set of practical actions mixing responses adapted to the local context. In this way, research is increasingly required to indicate mechanisms to involve stakeholders in problem analysis and solution-finding for the application of adaptable and context-specific responses to LD. Since stakeholders have different perceptions of desertification risk, establishing (or intensifying) the dialogue between stakeholders, policymakers and the general public will contribute to increasing the positive impact of land management actions designed to address LD. An improved analysis of response indicators and investigation on the effectiveness of joint responses to LD at the local and regional scale is hence essential for identifying appropriate mitigation strategies based on the 'response assemblage' perspective.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2016.09.017.

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