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A satellite-based green index as a proxy for vegetation cover quality in a Mediterranean region

Sofia Bajocco a,*, Antonella De Angelis a, Luca Salvati b

a Italian Council for Research in Agriculture, Unit of Climatology and Meteorology applied to Agriculture (CRA-CMA), Viale del Caravita 7a, I-00186 Rome, Italy
b Italian Council for Research in Agriculture, Centre for Plant-Soil Relationships (CRA-RPS), Viale della Navicella 2-4, I-00184 Rome, Italy

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To preserve land quality and mitigating land degradation represent an important task for regional planning and environmental management of the Mediterranean region. Since land cover dynamics directly affect the landscape characteristics, remote sensing represents an effective tool for land quality assessment at large scale. In particular, the use of satellite-based vegetation indices, like the NDVI (Normalized Difference Vegetation Index), can provide important information when evaluating Vegetation Cover Qual- ity (VCQ) patterns in terms of vegetation productivity and status, which represents one of the most sensitive landscape component to environmental degradation. This paper proposes an approach for the large-scale assessment of VCQ by means of an NDVI-based (functional) indicator using freely available MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery. As a case study, a complex semi-arid Mediterranean landscape (Attica, Greece) experiencing drought, land-use changes, increasing human pressure, and high vulnerability to degradation was chosen. As VCQ indicator, the NDVI-based vegetation cover classification was produced by means of unsupervised multivariate statistical techniques and compared with ancillary cartographic layers, statistical indicators, and field data related to land-use management observed in the study area. Results demonstrate that the obtained remotely sensed land characterization can be effectively considered as a proxy of the VCQ status of the examined region, especially for studies of actual land degradation. Due to the large availability over time and low cost of satellite images, the proposed approach can be applied to wider regions, e.g. covering the whole Mediterranean basin, to monitor diachronically vegetation quality and indirectly control land degradation.

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1. Introduction

Land conservation has become an increasing matter of concern in recent years, because of the growing human pressure on soil, water and vegetation by expanding population and economic activities (Salvati and Bajocco, 2011). This requires maintenance of the productive potential of these resources as a fundamental element in sustainable land-use management (Pieri et al., 1995; Bindraban et al., 2000; Bajocco et al., 2011). Drastic changes in vegetation cover have taken place all over the Mediterranean basin and are expressed by chaotic urban growth, litoralization, land abandonment, and forest fires, which are progressively consuming cropland and forests, and degrading high-quality natural resources (Basso et al., 2000; Salvati and Zitti, 2007; Munafò et al., 2010). These changes determined loss in land quality in terms of both environmental performances and productivity (Tannervermis, 2003; Simeonakis et al., 2007; Lavado Contador et al., 2009). In the light of the increasing concern about land resource conservation in Mediterranean countries, a number of attempts has been made over the last thirty years to evaluate land quality and map land degradation risk (Salvati et al., 2011).

As far as land quality monitoring is concerned, two approaches have been proposed: (i) the assessment of land capability, e.g. with the aim of soil erosion control (Thomas and Squires, 1991; Squires and Bennett, 2004) and (ii) the assessment of land suitability, e.g. with the objective of defining the potential productivity of land for defined crop or semi-natural covers (Ahamed et al., 2000; Joerin et al., 2001; Kalogirou, 2002). These approaches often produced assessments of (agricultural) land quality at regional or national scales. However, their ability to meet more general environmental and policy needs in terms of landscape functionality is limited (Pieri et al., 1995). Furthermore, they are neither comprehensive in their geographical coverage nor uniform in their methodology (see also EEA, 2006).

The concept of land quality refers to the combined resources coming from water, soil and vegetation, that jointly determine land productivity: the less a landscape is exploited and degraded by human pressure, the higher is the land quality of that territory,
and vice versa (Dumanski and Pieri, 2000). Since the vegetation cover of a territory (e.g. in terms of productivity) is the most sensitive factor to landscape degradation in the Mediterranean basin (Xu et al., 2002; Pettorelli et al., 2005), this paper focuses on the evaluation of the vegetation cover quality (VCQ) as a proxy for the ‘green’ component of land quality and the related potential degradation. VCQ refers to the condition or ‘health’ of vegetation in terms of biomass production, and specifically to its capacity for a sustainable land-use since it is particularly sensitive to human pressure and climate stresses, especially in highly anthropogenic environments (Roerink et al., 2003). The preservation of VCQ represents a major concern for regional planning, and needs to be considered when developing strategies for the sustainable development of environmentally sensitive areas in southern Europe (Portnov and Siefriel, 2004; Christopoulos et al., 2007; Simeonakis et al., 2007; Polyzou et al., 2008; Ioannidis et al., 2009).

Among several approaches quantifying the level of vulnerability to land degradation and desertification in the Mediterranean basin (e.g. Feoli et al., 2003), VCQ was assessed in the framework of the MEDALUS indicator system by way of the Vegetation Quality Index (VQI). This approach, originally proposed by Kosmas et al. (2000), evaluates four different components of the vegetation quality concept (i.e. degree of vegetation cover, fire risk, protection from soil erosion, drought resistance of vegetation) quantified on the basis of a weight depending on the different land-use types. The CORINE Land Cover (CLC) maps were extensively used to calculate the VQI at both national and European scale (Kosmas et al., 2003; Lavado Contador et al., 2009; Salvati and Bajocco, 2011). However, the VQI should be regarded as a ‘structural’ indicator of vegetation quality and is not suited to quantify its functional characteristics and its changes over time due to possible environmental stressors. Since this aspect is crucial for understanding the spatial patterns of land vulnerability to degradation, there is a definite need for quantifying VCQ dynamics by means of objective and comprehensive indicators, able to take into account both ‘structural’ and ‘functional’ aspects of vegetation cover. Such methodology upgraded through time could represent an effective early-warning approach for monitoring land degradation at large scale.

In this view, satellite images can provide useful information in a timely and cost effective fashion. As an example, the analysis of the spatial patterns of NDVI (Normalized Difference Vegetation Index) data derived from high temporal resolution satellite images like MODIS (Moderate Resolution Imaging Spectroradiometer) represents a successful tool for monitoring the functional response of vegetation to environmental stresses (Stoms and Hargrove, 2000; Peters et al., 2002) and for quantifying vegetation cover dynamics (Etic and Daniels, 1997; Morawitz et al., 2006; Lunetta et al., 2006).

This study aims at exploring the potentiality of remote sensing techniques to provide a VCQ indicator by identifying landscape categories on the basis of their VCQ patterns over time and space. The intent is to go beyond the traditional use of NDVI as biomass proxy (focusing on the single pixel value) and demonstrate that it can be used as a basis to properly summarize information about the VCQ of a region (focusing on a group of pixels characteristics), especially in land degradation studies, overcoming the limits of standard ‘structural’ vegetation quality indicators.

The Attica region (Greece) was chosen as study area because it is characterized by a dry climate, poor soil quality, human pressure, and an increasing susceptibility to land degradation (Weber et al., 2005; Ioannidis et al., 2009; Chorianopoulos et al., 2010). Interestingly, these are environmental conditions commonly observed in the Mediterranean basin and suggest that results obtained in our study site can be inferred to other regions and possibly to the whole basin. We compared the NDVI-based functional classification of the study area with structural layers about VCQ related to the land management and elevation of the investigated area (both components being expression of the ‘artificiality’ or ‘naturality’ of the territory), and to its MEDALUS-like VQI distribution (linked to the land use/cover of the territory). Results demonstrate the potentiality of the NDVI-based land classification indicator to monitor VCQ dynamics over time and space, and especially to quantify its patterns along artificial-natural gradients. Due to its versatility, the proposed indicator can be included in methodological frameworks assessing the level of land vulnerability to degradation (Salvati and Bajocco, 2011).

2. Study area

The study area covers the large part of the Nuts–2 region of Attica including the urban conurbation of Athens for a total surface area of nearly 3000 km² (Fig. 1). All mainland municipalities belonging to Attica, including Salamina and Egina islands, were considered in this analysis. The remaining islands (Poros, Iдра, Spetses, Kithira) and some continental municipalities belonging to the Pireaus prefecture but geographically located in the Peloponisos region were excluded from the analysis due to the considerable distance from the urban area. The investigated area was subdivided in 115 municipalities of which 58 form the urban area (427 km²). It mostly consists of mountains bordering the urban area of Athens which occupies a relatively flat territory. Three coastal plains are located outside the strictly urban area: the Messoghaia plain, the Marathon plain, and the Thriasio plain. Climate is typically Mediterranean, with average annual temperature of 19 °C and low rainfall (400 mm in the urban area of Athens) mainly concentrated in autumn and winter.

The area showed a drastic population increase during the last fifty years. Population grew at 3% per year in the 1950s, 1960s and 1970s. In 1961, the population living in Attica amounted to nearly two million people. In that period, population density was 669 inhabitants km⁻². Since the 1980s, Athens’ population deconcentrated with a spillover in the surrounding zones. In 2001 the resident population was 3.7 million people (1231 inhabitants km⁻²) and the demographic growth rate fell up to 0.7% per year in the urban area while maintained very high in rural areas (3.0%).

Environmental issues including harsh environmental conditions, forest fires, soil contamination, erosion, sealing and salinization, as well as climate change and habitat fragmentation represent the main threats for the Attic landscape (Economidou, 1993; Chorianopoulos et al., 2010). The multiplicity of the socio-environmental conditions makes this region a paradigmatic example of the landscape complexity typically found in the Mediterranean basin.

3. Methods

3.1. Land cover data and DEM

The land structural characteristics of Attica were identified by using the CORINE (COoRdination of Information on the Environment) Land Cover map of 2000 (CLC00) (Fig. 2) and a Digital Elevation Model (DEM) (Fig. 3). The CLC00 map was produced in 2000 with the aim of obtaining an updated land use classification of Europe at 1:100,000 scale and with a minimum mapping unit of 25 ha (freely available at the web site http://www.eea.europa.eu/themes/landuse/clc-download). The legend distinguishes several land cover classes, landscape- and ecology-oriented, grouped in a hierarchical nomenclature composed of three levels: the first one is characterized by five classes (urban areas, CLC 1; agricultural areas, CLC 2; forests and semi natural areas, CLC 3; wetlands, CLC 4, and water bodies,
Fig. 1. Location of the study area: the Attica region, Greece.

Fig. 2. Distribution of the first-level CORINE Land Cover 2000 (CLC00) classes in Attica: (a) artificial areas (CLC 1), (b) agricultural areas (CLC 2), and (c) forests and semi-natural areas (CLC 3).

Table 1
CORINE Land Cover (CLC00) map legend.

<table>
<thead>
<tr>
<th>CLC00 code</th>
<th>Land cover type</th>
<th>CLC00 code</th>
<th>Land cover type</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>Continuous urban fabric</td>
<td>311</td>
<td>Broad-leaved forest</td>
</tr>
<tr>
<td>112</td>
<td>Discontinuous urban fabric</td>
<td>312</td>
<td>Coniferous forest</td>
</tr>
<tr>
<td>121</td>
<td>Industrial or commercial units</td>
<td>313</td>
<td>Mixed forest</td>
</tr>
<tr>
<td>122</td>
<td>Road and rail networks and associated land</td>
<td>321</td>
<td>Natural grasslands</td>
</tr>
<tr>
<td>123</td>
<td>Port areas</td>
<td>322</td>
<td>Moors and heathland</td>
</tr>
<tr>
<td>124</td>
<td>Airports</td>
<td>323</td>
<td>Sclerophyllous vegetation</td>
</tr>
<tr>
<td>131</td>
<td>Mineral extraction sites</td>
<td>324</td>
<td>Transitional woodland-shrub</td>
</tr>
<tr>
<td>132</td>
<td>Dump sites</td>
<td>331</td>
<td>Beaches, dunes, sands</td>
</tr>
<tr>
<td>133</td>
<td>Construction sites</td>
<td>332</td>
<td>Bare rocks</td>
</tr>
<tr>
<td>141</td>
<td>Green urban areas</td>
<td>333</td>
<td>Sparsely vegetated areas</td>
</tr>
<tr>
<td>142</td>
<td>Sport and leisure facilities</td>
<td>334</td>
<td>Burnt areas</td>
</tr>
<tr>
<td>211</td>
<td>Non-irrigated arable land</td>
<td>335</td>
<td>Glaciers and perpetual snow</td>
</tr>
<tr>
<td>212</td>
<td>Permanently irrigated land</td>
<td>411</td>
<td>Inland marshes</td>
</tr>
<tr>
<td>213</td>
<td>Rice fields</td>
<td>412</td>
<td>Peat bogs</td>
</tr>
<tr>
<td>221</td>
<td>Vineyards</td>
<td>421</td>
<td>Salt marshes</td>
</tr>
<tr>
<td>222</td>
<td>Fruit trees and berry plantations</td>
<td>422</td>
<td>Salines</td>
</tr>
<tr>
<td>223</td>
<td>Olive groves</td>
<td>423</td>
<td>Intertidal flats</td>
</tr>
<tr>
<td>231</td>
<td>Pastures</td>
<td>511</td>
<td>Water courses</td>
</tr>
<tr>
<td>241</td>
<td>Annual crops associated with permanent crops</td>
<td>512</td>
<td>Water bodies</td>
</tr>
<tr>
<td>242</td>
<td>Complex cultivation patterns</td>
<td>521</td>
<td>Coastal lagoons</td>
</tr>
<tr>
<td>243</td>
<td>Land principally occupied by agriculture, with significant areas of natural vegetation</td>
<td>522</td>
<td>Estuaries</td>
</tr>
<tr>
<td>244</td>
<td>Agro-forestry areas</td>
<td>523</td>
<td>Sea and ocean</td>
</tr>
</tbody>
</table>
3.2. Vegetation Quality Index data

The structural information on VCQ was derived according to the Environmental Sensitive Area (ESA) approach developed in the framework of MEDALUS projects (Kosmas et al., 2000), starting from the available land cover map (CLC00). According to such approach, the VCQ of the different land cover types of the study area was evaluated through four vegetation components: resistance to fire (FR), soil erosion protection (SE), resistance to drought (DR), and vegetation coverage density (VC) (Basso et al., 2000). Statistical analysis was performed for each variable in order to define (i) the correlation of the variable to the measuring target, (ii) the correlations within the data matrix, and (iii) the contribution of each variable to the estimation of land use quality (Basso et al., 2000). To evaluate each component, a weight was attributed to each CLC00 class according to Kosmas et al. (2003), in order to obtain a characterization of the territory based on the degree of VCQ showed by the different land cover types (Brandt, 2005). Scores were derived from the abovementioned statistical analysis results and from additional information gathered from the available literature (e.g. Kosmas et al., 2000) (see Table 2). A composite index (the so-called VQI, Vegetation Quality Index) was then calculated by the geometric average of the values of the four components indicators (Lavado Contador et al., 2009) as follows (Fig. 4):

\[
VQI = (FR \times SE \times DR \times VC)^{1/4}
\]

The VQI was classified into classes defining the quality of land use with respect to possible processes of land degradation, including forest fires, soil erosion and drought, among others. Since the weights of each indicator range from 1 (high quality) to 2 (low quality), also the VQI ranges from 1 (the highest vegetation quality) to 2 (the lowest vegetation quality). Scores equal to zero indicate compact urban areas.

3.3. MODIS NDVI data and processing

In order to derive a functional classification of the study area comparable with the available land cover map (i.e. CLC00), we used MODIS (Moderate Resolution Imaging Spectroradiometer) NDVI (Normalized Difference Vegetation Index) images of a three-years period going from 2000 to 2002. The used images, freely downloadable from the webpage https://wist.echo.nasa.gov, have a spatial resolution of 250 m and a daily temporal resolution composited over a 16-day period. For this study, we downloaded a total of 69 NDVI images, i.e. twenty-three images per year per three years.

The MODIS products include spectral bands that are specifically designed for land monitoring, like RED and Near-InfraRed (NIR) that are used to obtain NDVI (Running, 1990; Myneni et al., 1995; Bajocco et al., 2011). This vegetation index is calculated as the ratio of (NIR − RED) to (NIR + RED), and it ranges between 1 and 1. For the positive part of the index, an empirical quasi-linear relationship with the fraction of photosynthetic active radiation absorbed by vegetation (fAPAR) has been found by many authors (Hatfield et al., 1984; Asrar et al., 1983; Maselli et al., 2006). NDVI can thus be considered as a proxy to quantify vegetation primary...
productivity (Ricotta and Avena, 1998; Boelman et al., 2003; Bro-Jørgensen et al., 2008) and plant biomass (Running, 1990; Myneni et al., 1995), to estimate vegetation performance change (Anyamba and Tucker, 2005; Olsson et al., 2005), and to assess land degradation dynamics at large scale (Bai et al., 2008). Time series of MODIS NDVI data have been mainly used for their potential to measure vegetation dynamics (Zhang et al., 2003; Beck et al., 2006; Ahl et al., 2006; Maselli et al., 2009; Pérez-Hoyos et al., 2010).

In order to derive a land cover characterization capable to quantify the VCQ spatial patterns of the study area both in structural and functional terms (Lunetta et al., 2006; Reed et al., 1994; Pettorelli et al., 2005), we summed, on a pixel basis, the 23 NDVI values (∑NDVI) recorded for each year (2000–2002) and computed the three-years average obtaining the mean annual ∑NDVI.

The mean annual ∑NDVI represents a surrogate for the total annual biomass production of the investigated area (Bai et al., 2008). By quantifying the functional performance of the actual vegetation on a one-year basis, this indicator estimates VCQ taking into account the environmental conditions that affects biological productivity, and its deviance from the local average may be taken as a measure of land degradation or land quality improvement (Bai and Dent, 2009).

An unsupervised classification technique of the three-years mean ∑NDVI image was then performed on the image statistics without training samples or a priori knowledge of the area. k-Means unsupervised classification calculates initial class means evenly distributed in the data space then iteratively clusters the pixels into the nearest class using a minimum distance technique. Each iteration recalculates class means and reclassifies pixels with respect to the new means. All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified, in which case some pixels may be unclassified if they do not meet the selected criteria. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached (MacQueen, 1967). The k-means clustering procedure was used to classify the vegetation of the study area into k homogeneous groups in terms of spectral behavior and therefore characterized by the same annual vegetation productivity range and VCQ level. The number of k was selected according to the parsimony criterion by running the k-means algorithm for several possible solutions (i.e. number of clusters) ranging from 3 to 10. Diagnostics such as the pseudo F statistic and the highest value of the cubic clustering criterion were considered to identify the best cluster partition, i.e. the number of clusters which allows the most significant discrimination among areas with different levels of annual vegetation productivity (Salvati and Zitti, 2009). The final choice of five clusters (i.e. five k-means classes) adopted in this paper was also compatible with the moderate spatial resolution of the MODIS NDVI images (250 m). The NDVI-based VCQ (NDVCQ) map obtained (Fig. 5), due to its construction, involves an intrinsic character of functionality associated to each composing pixel, related to its annual vegetation performance.

3.4. Conceptual framework

VCQ is a complex concept that cannot be evaluated by single, unique measurement; it is an integrated sum of variables, like productivity, plant coverage, landscape structure, environmental conditions, fragmentation, etc. In this perspective, our working hypothesis is that, at regional scale, the mean annual NDVI of a territory (i.e. its status territory in terms of vegetation performance) can be regarded as a proxy of the VCQ, because it summarizes all the abovementioned variables, providing synthetic information of a landscape. In order to characterize the obtained NDVI-based (functional) classification in terms of structural properties of VCQ, we compared it with (independent data) layers that can provide some ‘structural’ information about VCQ in terms of land management, ‘naturalness’ gradient, and degree of vegetation cover sensitivity to land degradation.

3.5. GIS and statistical analysis

By using GIS (Geographic Information Systems) tools, we intersected the NDVI-based VCQ classification with the CLC00 map, the ASTER GDEM layer and the VCI map; we then analyzed (and tested) the percentage of each NDVCQ class by CLC type, elevation range and VC and VCI class.

For the comparison between the NDVCQ and the CLC00 classes, we focused on the most representative (>10% of the investigated area) land use types (third-level CORINE) in at least one of the five k-means classes, which correspond to: (i) urban areas: continuous (CLC 111) and discontinuous (CLC 112) urban fabric; (ii) agricultural areas: complex cultivation patterns (CLC 242) and land principally occupied by agriculture with significant areas of natural vegetation (CLC 243); (iii) forest and semi-natural areas: coniferous forest (CLC 312), sclerophyllous vegetation (CLC 323), and transitional woodland–shrub (CLC 324). These CLC00 classes well depict the degree of urbanization versus ‘naturality’ in the Mediterranean landscape. Such information can be considered as a proxy for the VCQ status of a territory, also providing useful indications about the spatial transition from urban to...
3.6. Visual and field assessment

The ability of the proposed index to discriminate among different levels of vegetation cover quality was also tested in two ways: (i) a qualitative comparison of the produced NDVI-based VCQ classification with existing land use maps and (ii) a field assessment.

The qualitative visual comparison was carried out with independent land use maps including those provided by European Environment Agency (e.g. the urban atlas map covering the whole investigated area at 1:10,000 scale). The field assessment (sensu Salvati et al., 2011) of the NDVI-based VCQ indicator was carried out at 50 field sites homogeneously distributed in all five NDVCQ classes with sample size determined according to the proportion of each class surface area (Fig. 6). Each site was geo-referenced and the vegetation characteristics were briefly described within a 100 m circle plot centered on the coordinates of each point (Salvati et al., 2011). All field data and pictures were stored into a database organized as a check-list. Fig. 6 illustrates the location of selected plots where a visual evaluation of the VCQ level was performed. While urban areas were mainly represented by NDVCQ class 1, degraded, pastures and shrubland land at the urban fringe mainly fell in NDVCQ class 2. Shrublands, pastures and wood fragments were the vegetation association mainly recorded in NDVCQ class...
3. Finally, open woodlands with Mediterranean maquis and close forests dominated, respectively in NDVQ classes 4 and 5.

The visual assessments we performed did not have the intent to “validate” the classification, but to give a concrete information of what we derived NDVQ classes can correspond to. Field validations of VCQ can test only one composing variable at a time, while the proposed NDVI-based VCQ classification wants to be a synthetic information indicator.

4. Results

Going from NDVQ class 1 to class 5, the level of vegetation productivity associated increases (Fig. 5). The NDVQ class 1 covers about 16% of the whole study area, like NDVQ class 4. The NDVQ classes 2 and 3 represent the most important categories covering about 36% and 22% of the study region, respectively, while NDVQ class 5 is the less represented category occupying roughly 11% of Attica (Table 3).

4.1. Comparing the NDVI-based VCQ classification with reference layers

The comparison between the five NDVQ classes and the reference (structural) layers (i.e. CLC00 and DEM) identified a VCQ gradient associated to the produced NDVI-based map from low quality (class 1) to high quality (class 5). The results of the correlation between the functional NDVQ classes and CLC00 (Table 4) showed that the NDVQ class 1 was mainly represented by urban areas, in particular continuous (18%) and discontinuous (21%) urban fabric (CLC 111 and CLC 112), with inclusion from complex cultivations (about 14%) (CLC 242). By contrast, the NDVQ class 2 was dominated by complex cultivations (30%) (CLC 242), with some intrusions from discontinuous urban fabric (CLC 112), agriculture mixed with natural vegetation (CLC 243) and sclerophyllous vegetation (CLC 323) (for a total land proportion amounting to 37%). The NDVQ class 3 mainly included transitional woodland–shrub (CLC 324) and sclerophyllous vegetation (CLC 323) which, together with agriculture mixed with natural vegetation areas (CLC 243) land cover class, represent almost the 60% of the total NDVQ class surface area. The NDVQ class 4 was mostly represented by sclerophyllous vegetation (about 24%) (CLC 323) and transitional woodland–shrub (34%) (CLC 324), while the NDVQ class 5 was dominated by coniferous forests (42%) (CLC 312). The percent distribution of third-level CLC land cover classes was significantly different among the five NDVQ classes (median test, chi-square = 11.77, p = 0.019, df = 4).

The analysis of the relationship between the NDVI-based land classification and the elevation (Table 5), confirmed the abovementioned evidences. NDVQ classes 1 and 2 mostly corresponded to lowland zones (0–200 m), with respectively 87% and 67% of the total class surface area; however 27% of the NDVQ class 2 was also represented by territories at elevations ranging from 200 to 400 m (Fig. 7). NDVQ class 3 mainly occupied zones from 0 to 400 m (about 80% totally), while the majority of NDVQ class 4 extended on the 200–400 m (about 36%) and the 400–600 m (about 26%) elevation belts. Finally, the NDVQ class 5 was mainly located between 400 and 600 m (about 34%), however nearly 80% covered the elevations ranging from 400 to 1000 m. The percent distribution of elevation class surface was significantly different among NDVQ classes (median test, chi-square = 9.96, p = 0.041, df = 4).

Table 3
Number of evaluated pixels and surface area by NDVQ class in Attica.

<table>
<thead>
<tr>
<th>NDVQ classes</th>
<th>Number of pixels</th>
<th>Surface area (km²)</th>
<th>%</th>
<th>Cumulated %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (very low)</td>
<td>9039</td>
<td>485.3</td>
<td>16.4</td>
<td>16.4</td>
</tr>
<tr>
<td>2 (low)</td>
<td>19638</td>
<td>1054.3</td>
<td>35.5</td>
<td>51.9</td>
</tr>
<tr>
<td>3 (intermediate)</td>
<td>11948</td>
<td>641.5</td>
<td>21.6</td>
<td>73.5</td>
</tr>
<tr>
<td>4 (high)</td>
<td>8604</td>
<td>461.9</td>
<td>15.6</td>
<td>89.1</td>
</tr>
<tr>
<td>5 (very high)</td>
<td>6020</td>
<td>323.2</td>
<td>10.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>55,249</td>
<td>2966.2</td>
<td>100.0</td>
<td>-</td>
</tr>
</tbody>
</table>

Fig. 7. Average (and standard deviation) elevation by k-means class.

Table 4
Percent surface area of each NDVQ class by CLC00 class (see text for details).

<table>
<thead>
<tr>
<th>NDVQ classes</th>
<th>CLC 00 classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.8</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 5
Percent surface area of each NDVQ class by elevation belt.

<table>
<thead>
<tr>
<th>NDVQ classes</th>
<th>Elevation belts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–200 m</td>
</tr>
<tr>
<td>1</td>
<td>87.1</td>
</tr>
<tr>
<td>2</td>
<td>67.0</td>
</tr>
<tr>
<td>3</td>
<td>37.3</td>
</tr>
<tr>
<td>4</td>
<td>18.2</td>
</tr>
<tr>
<td>5</td>
<td>2.9</td>
</tr>
</tbody>
</table>
Table 6
Percent surface area of each NDVCQ class by vegetation cover score class.

<table>
<thead>
<tr>
<th>NDVCQ classes</th>
<th>VC score</th>
<th>1.0</th>
<th>1.2</th>
<th>1.5</th>
<th>1.8</th>
<th>2.0</th>
<th>Urban areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>4.1</td>
<td>0.5</td>
<td>25.1</td>
<td>23.3</td>
<td>6.8</td>
<td>40.1</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>22.6</td>
<td>0.3</td>
<td>12.0</td>
<td>58.7</td>
<td>1.1</td>
<td>5.3</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>44.5</td>
<td>0.2</td>
<td>6.6</td>
<td>46.2</td>
<td>0.4</td>
<td>2.1</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>79.8</td>
<td>0.1</td>
<td>1.8</td>
<td>26.1</td>
<td>0.1</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>95.0</td>
<td>0.0</td>
<td>0.1</td>
<td>3.7</td>
<td>0.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

* Urban areas were not evaluated in MEDALUS approach.

4.2. Comparing the NDVI-based VCQ classification with standard indicators

The tests performed on the NDVI-based VCQ classification suggest that it may represent a reliable proxy of vegetation cover quality. A visual comparison of the NDVCQ map produced in this study with existing land-use maps pointed out the consistency of the proposed procedure for the identification of areas with different VCQ levels. In all studies, areas with the highest VCQ (highest NDVCQ classes) were found concentrated in undisturbed, mountain areas under environmental protection (Parnitha national park, and, at a lesser extent, Limnos and Pateras mountains) while the lowest VCQ (lowest NDVCQ classes) were recorded in urban and suburban areas, especially at the interface between urban fabric and agricultural land.

A correlation between the NDVCQ indicator and the MEDALUS VC and VQI was also observed. Although some differences between the two indexes could be found at local scale depending on site-specific socio-economic factors (whose quantification is outside the scope of the present paper), the statistical analysis suggests that the NDVI-based classification produces a reliable proxy of VCQ which is also consistent with the standard ESA procedure. Table 6 reports the percent surface area of each NDVCQ class according to the VC indicator scores. It shows that, on average, VC decreased from NDVCQ class 1 to class 5 indicating higher vegetation quality (Fig. 8). As an example, 95% of investigated class 5 land was associated to the highest VC score. Notably, the percent distribution of VC class surface area was significantly different among NDVCQ classes (median test, chi-square = 9.5, p = 0.049, df = 4). Similar results were obtained analyzing the percent distribution of NDVCQ classes by VQI scores (Table 7). By dividing the VQI scores into two classes (VQI < 1.4: high vegetation quality; VQI > 1.4: low vegetation quality), NDVCQ class 1 had only 5% of land surface classified as high vegetation quality while NDVCQ class 5 had more than 95%.

Overall results confirm the general compatibility between the NDVCQ and MEDALUS-like VCQ indicators. In detail, local mismatching demonstrates the there are cases where the actual vegetation cover performance is not aligned with the actual land use: there can be forests (high MEDALUS VCQ) degraded (but still classified as forests) and anthropic landscapes in good ecological conditions (even if classified as urban). This because what affects the VCQ is what actually happens on the territory, notwithstanding its “nominal” use.

5. Discussion

As a result of human pressure and climate changes VCQ is continuously evolving, especially in the Mediterranean region (Kosmas et al., 2000; Simeonakis et al., 2007). In common with other southeastern European regions (e.g. García-Latorre et al., 2001), Attica has shown drastically modified landscape patterns in the last decades because of recurring fires and un-controlled urbanization (Weber et al., 2005; Ioannidis et al., 2009; Chorianopoulos et al., 2010). Characterizing areas with different VCQ levels is crucial to assess the state of the landscape and inform policies aimed at mitigating land degradation in dry areas vulnerable to desertification. Indicators producing land characterization systems that are easy to use, repeatable through time, spatially explicit and universally applicable, like the one presented here, could support land quality monitoring over time and space (Bindraban et al., 2000; Pieri et al., 1995).

Land quality refers to the state or condition of land, including its soil, water and biological properties, and it relates to the capacity of a land to provide economically viable productions and ecosystem services at all observation scales (Dumanski and Pieri, 2000). To promote sustainable land management and inform effective conservation policies, land quality needs to be assessed with respect to the specific functions and types of the actual land cover. Ideally, an indicator of land quality represents a proxy for the functional role of a land, integrating factors and processes that determine its productivity (Bindraban et al., 2000).

In this study we considered an NDVI-based land characterization system as an indicator of the functional characteristics of a territory (Zhang et al., 2003; Bai et al., 2008; Bajocco et al., 2011) and hence as a proxy of its vegetation cover quality (VCQ). The index was intended to monitor VCQ degradation over space and time at regional scale (Budde et al., 2004; Evans and Geerken, 2004; Asner and Heidebrecht, 2005; Helldén and Tottrup, 2008).

The obtained results showed that the proposed methodology identified functional homogeneous zones in terms of remotely-sensed vegetation productivity and highlighted a gradient of decreasing human pressure and increasing VCQ, expressing at the same time the transition dynamics among different land cover types. Interestingly, the NDVCQ class 1, characterized by the lowest NDVI values, reflects the RUI depicting the transition between non-vegetated areas and croplands, but mostly turned toward the urban component. The NDVCQ class 2 covered part of the RUI and part of the WRI, mainly focused on the rural component of the landscape, while the NDVCQ class 3 mainly represents the transition between croplands and the WRI interface. The NDVCQ class 4 reflects the WRI mostly oriented toward the wild-land component and, finally, the NDVCQ class 5, corresponding to the highest NDVI values, indicates that the highest VCQ are mainly associated to structured, semi-natural landscapes, such as coniferous forests. Such results, taken together with the results of the elevation analysis, show how the land characterization system proposed here can be considered as an honest indicator of VCQ that increases from flat areas, where human pressure is high (due to urbanization, tourism, agriculture, industry, etc.) to the upper inlands, where human pressure is reduced.

Finally, this study showed the potential of the proposed NDVI-based methodology to distinguish transition zones with different levels of VCQ and to derive information about the vegetation and land-use dynamics at the urban–agricultural and
agricultural–wildland interfaces in the Mediterranean region. Furthermore, according to the observed relationship between the NDVI-based VQC classes and the elevation range, the obtained classification proved to reflect environmental conditions associated to different vegetation cover status and human-derived pressure.

6. Conclusions

Unlike the standard VQC, the proposed methodology provides a regional characterization of the vegetation cover pattern able to quantify its functional aspects and also to give information about its structural component. Moreover, the NDVI-based VQC classification proved to overcome the VQC constraints, related to the availability of limited land-cover maps and the intrinsic subjectivity of the procedure assigning weights to the thematic indicators composing the VQI with several advantages including low costs, automatic procedure, replicability through time, large scale coverage, detailed spatial resolution, and global data availability. The proposed methodology can thus represent an effective tool for regional planning, sustainable development, and environmental science to evaluate VQC and potential ecosystems degradation under climate, land-use, and demographic change scenarios. Finally, the methodology can be easily integrated in standard procedures (e.g., the ESA approach) to evaluate land vulnerability to desertification in order to provide an integrated functional and structural assessment of the vegetation status and the possible changes of its quality over time and space.

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