Satellite analysis of vegetation cover for the enhancement of natural areas

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Satellite analysis of vegetation cover for the enhancement of natural areas

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Abstract. Sustainable tourism is a precious resource especially for mountainous and hilly areas of high naturalistic value. If correctly implemented, it can induce positive environmental and socio-economic impacts on the involved areas. In this context a continuous and accurate monitoring of vegetation can be a precious support both for protecting natural resources and for promoting tourism. This study is inserted in the project "Ospitalità dei borghi", funded by Campania Region (Italy) for encouraging tourism development in inland hilly and mountainous municipalities. NDVI-MODIS satellite time series (2000-2010) were used to obtain an overall picture of the investigated area in terms of temporal stability of vegetation productivity and a Landsat TM image (August 2011) was analysed for evaluating spatial anomalies of photosynthetic activity. According to our results, the examined natural areas are characterized by a stable distribution of NDVI values with some local increase phenomena in the vegetation activity. In some man managed areas we observe instead slight and confined decreases in photosynthetic activity, presumably due to specific land use practices and local biogeographical contexts rather than to ongoing degradation processes. The good picture emerging from our analysis can be efficiently exploited to publicize the healthiness of the investigated zones and to promote tourism plans and activities. Our approach can be fruitful for evaluating tourism sustainability in valuable and fragile sites generally characterized by inaccessible zones that require expensive and time-consuming field campaigns to be held in check.

Keywords. Natural areas, tourism development, MODIS, LANDSAT, Campania region.

1. Introduction

Sustainable tourism can generate a wide range of positive impacts on mountain/hilly environments of high naturalistic value, fostering pride in culture tradition, averting risk of degradation in marginal areas, and revitalizing local economies [1]. This is true especially for mountain and marginal environments located outside the most popular tourist destinations, often containing unique habitats threatened by changes in land use and climate [2], and whose potential is only partially considered for tourism exploitation. Here, the high naturalistic value is the main tourist attraction and contemporaneously a central focus for the correct planning of tourism sustainability. In these cases a continuous, spatially extended, and efficient monitoring of the local ecosystems is essential to maintain and enhance the attractiveness of the areas. In particular, the assessment of the vegetation cover status, as a direct expression of the local environmental conditions, is crucial to gain qualitative and quantitative information on possible degradation phenomena and accidental, detrimental events (fire, pollution, etc.).

In such a context, both spatial and temporal patterns of vegetation have to be considered to carry out early screenings of the most vulnerable areas. These vegetation properties are heavily influenced by anthropic factors (agriculture, concentration of industrial/mining activities, demographic growth, etc.) and the possible changes can have negative feedback on soil vitality and climate [3,4]. This work concerns the assessment of vegetation cover healthiness in hilly and mountainous municipalities of Campania (Southern Italy), within the context of a project aiming to promote tourism in the area (Ref. "Ospitalità dei borghi" project funded by Campania Region).

Satellite data, usually adopted to assess vegetation conditions over large areas at different temporal and spatial scale [5,6,7], offer further advantages for investigating mountainous areas. In fact, these are generally characterized by inaccessible zones (highly variable aspect and slope) requiring expensive and time-consuming field campaigns to be held in check [8]. In particular, in this study we exploited the optical properties of vegetation, by using specifically devised vegetation indices that synthesize vegetation activity trends and spatial distribution. More specifically, we focused on the evaluation of NDVI (Normalized Difference Vegetation Index) percentage variations and spatial distribution derived from data at moderate and high resolution respectively, to obtain an overall picture of the vegetation cover stability in the last decade and to single out possible spatial anomalies of the vegetation activity.

2. Methods

The analysis was performed in several municipalities belonging to Campania, one of the regions of Southern Italy (Fig.1).

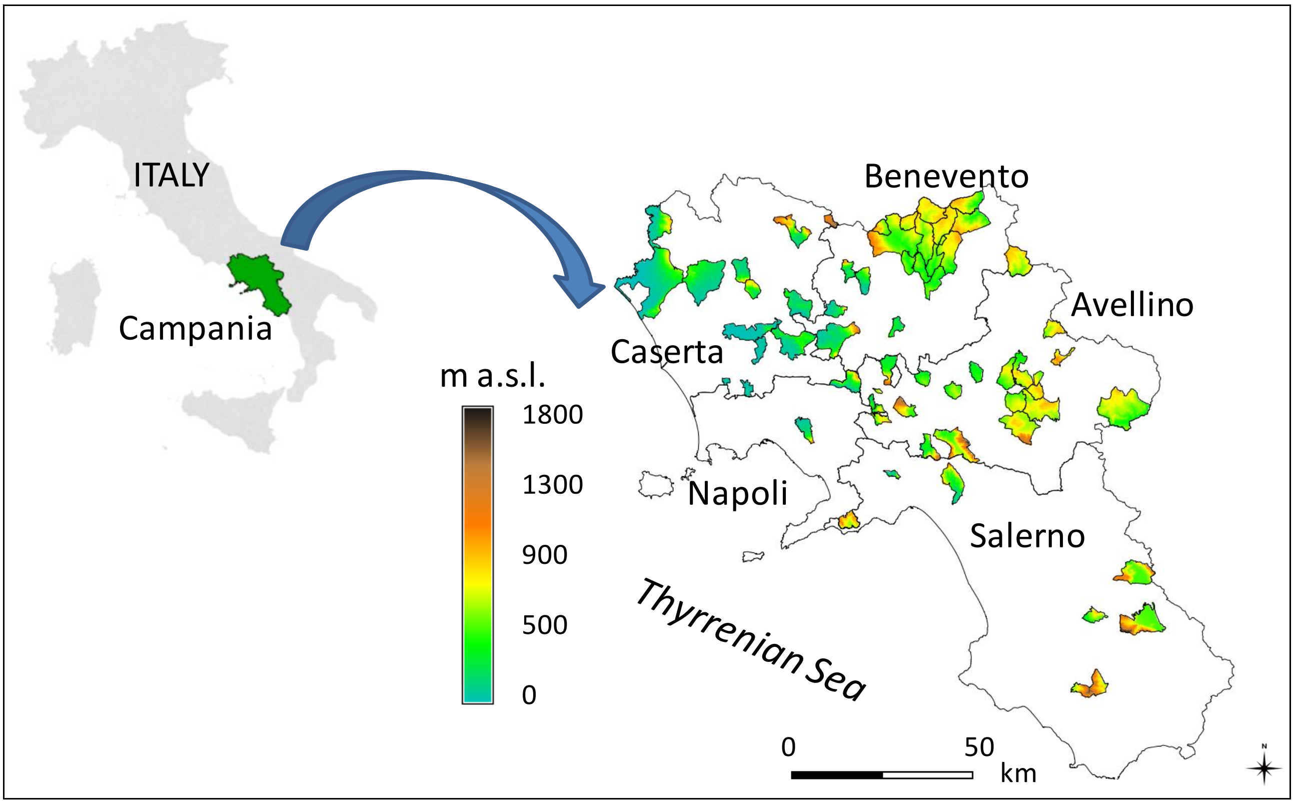

Figure 1. Study area consisting of 62 municipalities belonging to the five provinces of the Campania region. Municipal areas are delimited by black contours and filled by DEM (Digital elevation Model) with a spatial resolution of 20m (source - Ministry of the Environment of Italy).

The study area, extending approximately 2000 km2, consists prevalently of hilly and mountainous areas (the mean elevation is around 500 m above sea level) placed especially in the provinces of Caserta, Benevento and Avellino (corresponding to NUTS level 3 in European Union). The Mediterranean climate and the wide presence of fertile soils favor agriculture also in elevated areas (fruit tree cultivation and arable land). Furthermore, these environments comprise some of the most enjoyable mountainous landscapes of Campania (Picentini, Sannio, Irpinia Mountains, etc.) characterized by a rich faunal and vegetation biodiversity often preserved in protected areas (SIC and ZPS of Natura 2000 Network). Nevertheless because of the presence of thin horizons on steep slopes, geo-mineralogical features of material involved, and intensive anthropogenic activities, landslide events and degradation phenomena are also present in the region [9,10]. In order to evaluate the general vegetation conditions in the study area and indicate potential hot spots of degradation, we used NDVI-MODIS (Moderate Resolution Imaging Spectroradiometer) satellite time series available as 16-day composite from the NASA LPDAAC dataset and a Landsat TM image available from USGS archives. MODIS and Landsat data are commonly recognized as reliable sources for carrying out studies on degradation processes [see e.g., 11,12].

In particular, we performed a multitemporal analysis (2000-2010) using NDVI-MODIS data (250m of spatial resolution). To this purpose, we adopted the NDVI_PV indicator [13] as a suitable tool to monitor long-term trends of vegetation activity, identifying direction and intensity of the analyzed phenomena. This indicator estimates the mean NDVI variation accumulated during the examined period normalizing it with respect to the starting conditions. Normalization is introduced to account for the peculiar type of the considered vegetation cover, resulting in different typical values of NDVI. In this perspective, a same change means a different impact if the area involved is densely vegetated or is characterized by a poor plant cover. Thus, the percentage variation rather than the absolute one, enables a more accurate evaluation of the local degradation severity. In this way, the NDVI_PV, already tested in similar studies carried out in Southern Italy [13,14] is able to indicate increase/decrease of photosynthetic activity and is suitable to detect both slow changes linked to long-term processes (e.g., decline of forests) and drastic changes such as those caused by fires or industrial/urban sprawl. The indicator is calculated as follows:

$$NDVI_{PV} = \frac{\lfloor S_{NDVI} \rfloor}{NDVI_{in}} Y$$

where SNDVI is the slope derived from the linear trend estimation at pixel resolution; Y is the number of considered years; NDVIin is the initial NDVI value at the first year of the examined time series.

This analysis performed in the time domain has been accompanied by an investigation aimed at identifying spatial anomalies of photosynthetic activity using the finer spatial resolution of Landsat data (30m). The examined imagery (August 2011) has been preprocessed (DN-radiance-reflectance conversion, cloud detection) to extract a NDVI map. It is well known that the average NDVI values and the ranges of variations depend on the land cover type. For example, it is intuitive that NDVI values that fall within the range of variability typical of sparsely vegetated areas could be strongly anomalous for a densely forested area. Therefore, it is not possible to establish a general criterion to define anomalous values of NDVI when we perform a statistical analysis on heterogeneous areas since anomalies have to be related to each vegetated cover. To this aim, the level-3 Corine Land Cover map (CLC2006, see http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-2) was used to perform separate statistics for each type of vegetation. On the basis of the statistics carried out for each land cover class, it is possible to identify anomalous areas, for which NDVI values are extreme compared to the average values of the considered vegetation class.

The identification of critical areas can help to early isolate areas with incoming degradation processes and to plan intervention strategies based on appropriate field campaigns. The anomalies Ai(p) of NDVI for the pixel p belonging to the class i are defined as departures from the mean value normalized to the standard deviation of the distribution:

$$A_i(p) = \frac{NDVI(p) - NDVI_i^m}{\sigma_i}$$

where $NDVI_i^m$ and σ_i are respectively mean values and standard deviations of NDVI.

The departure from the mean value is a measure of the dissimilarity of the pixel from areas covered by the same vegetation type while the normalization takes into account the intrinsic variability of the analyzed vegetation cover. In this work, Ai values falling in the range ± 3 (three-sigma rule) are considered statistically compatible with the distribution of characteristic values of the examined area.

3. Results

Figure 2a shows the NDVI_PV map covering the examined municipalities (whose boundaries are indicated by black lines); the corresponding land cover classes are reported in figure 2b. Figure 2c shows the same indicator aggregated in different classes to better highlight the levels of stability/variation in the analyzed areas.

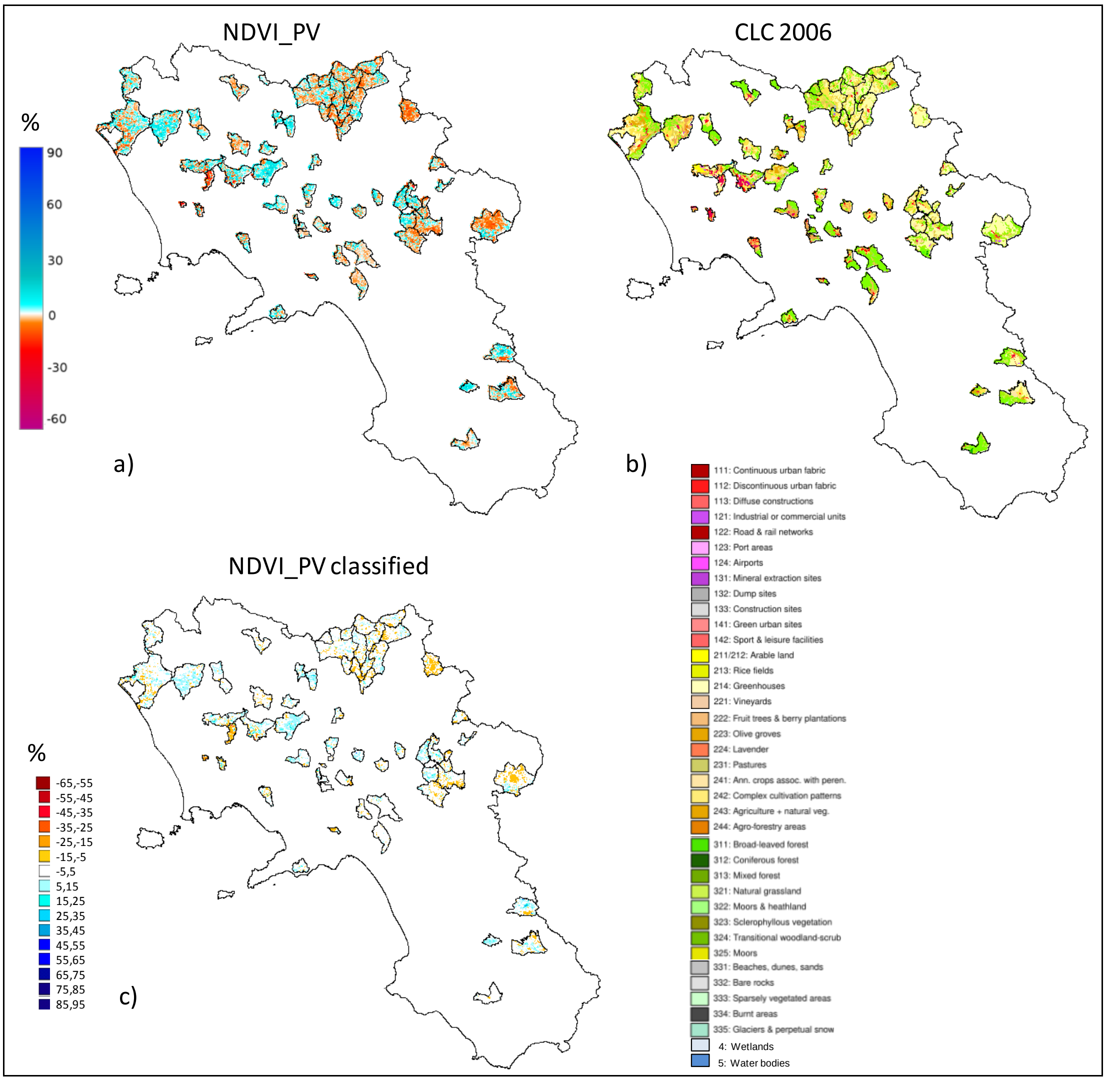

Figure 2. a) Map of the NDVI_PV indicator estimated for the study area at 250m of spatial resolution; b) Corine Land Cover map 2006; classes belonging to wetlands and water bodies have been aggregated; c) NDV_PV indicator classified in different classes. All the estimations are expressed as percentage.

The distribution of these classes is reported in Figure 3.

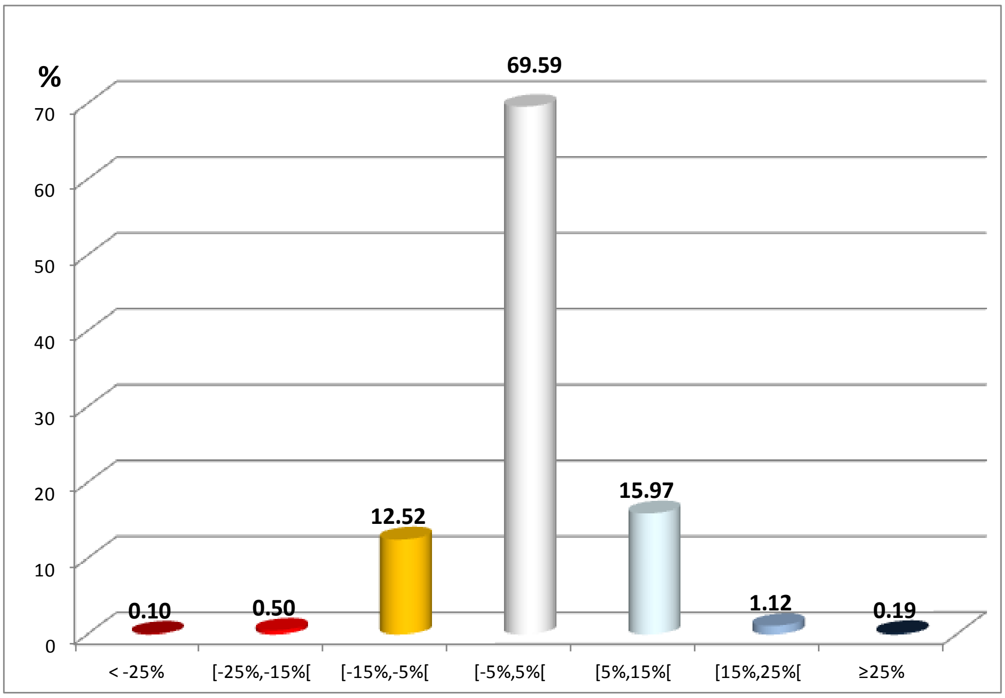

Figure 3. Bar graph of NDVI_PV values aggregated in different classes.

On the whole, this analysis focused on temporal variations of the NDVI in the period 2000-2010 at 250m resolution evidences the global stability of the investigated area. In fact, about 70% of pixels exhibit variations whose magnitude is less than 5% and most of the variability is confined in the 15% range. Such variations, mainly observed in the presence of heterogeneous land use, are consistent with vegetation activity fluctuations linked, as an example, to meteorological fluctuations (variability in temperature, changes in rainfall amount, increasing occurrence of drought episodes, etc.) that cause different responses in different vegetation covers due to local bio-geographical factors. In addition to this, it is noticeable that the percentage of areas experiencing positive variations is comparable with the percentage of areas where negative variations are found, thus confirming a stationary scenario for the last decade, if analyzed as a whole. The comparison with the classes of vegetation cover extracted from the CLC2006 map puts in evidence that areas affected by a greater variability are generally arable lands and heterogeneous cultivations (mainly characterized by negative variations) or broad-leaved forests (mainly positive variations) highlighting differences between natural and man-managed areas.

The positive response of natural areas is particularly interesting because testifies the healthy conditions of these areas, potentially exploitable for tourism purposes. On the other hand, the slight percentage decrement of NDVI in some anthropized zones does not contradict such an evidence since the variation magnitude is small and very likely due to inter-annual fluctuations rather to actual changes in the vegetation status.

The results obtained from the spatial analysis using Landsat data at 30m resolution are shown in Fig. 4 (Fig. 4a depicts the anomaly values; Fig.4b shows them separated in different classes). They substantially confirm what highlighted by the temporal analysis (see Fig. 5. showing the distribution of the identified classes).

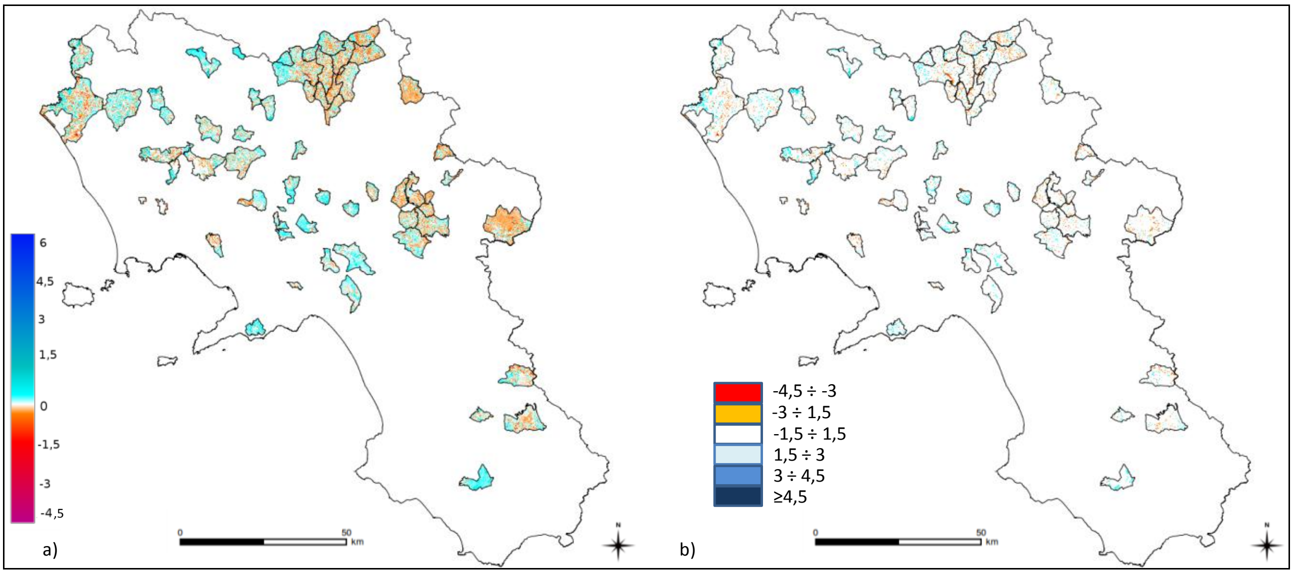

Figure 4. a) Map of NDVI anomalies obtained from Landsat-TM data for different land cover classes; b) anomalies classified into discrete classes to better highlight the presence of possible critical areas.

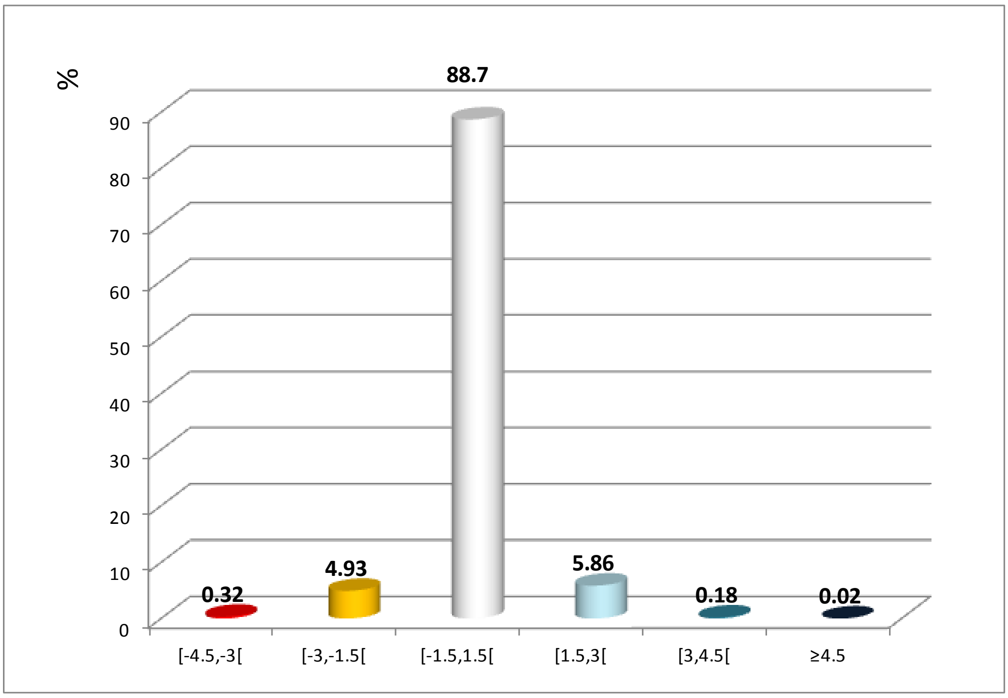

Figure 5. Bar graph of NDVI anomalies aggregated in different classes.

It is clear that there are not large areas affected by anomalous values of NDVI. Small isolated areas, consisting of a few pixels, can appear as anomalous due to very local stresses (e.g. small fires, different times of harvesting, etc.) that are not linked to the general healthiness level of the examined areas.

4. Conclusions

The satellite analysis of the study area provided a satisfactory picture of vegetation conditions, evidencing a rather stable vegetation cover. Within the inherent variability expected for temporal and spatial patterns we do not observe areas clearly labelable as vulnerable to degradation. The main positive result concerns natural areas (mainly broad-leaved forests) that do not show any evident decline phenomena or negative spatial anomaly and in some cases are characterized by small local increases of photosynthetic activity. Slight negative variations, concentrated especially in man managed areas, do not seem to be related to degradation phenomena.

This work, based on temporal analysis and spatial investigations has proved to be precious for highlighting healthy natural areas and suitable to support the development of sustainable tourism activities in zones characterized by high naturalistic value. In such a context, an accurate monitoring based on satellite remote sensing techniques enables continuous diagnostic updates of the ecosystem conditions (assessment of the impact of occurred changes and identification of thresholds in ecosystem responses). Ultimately, satellite data, making this information available for implementation in web-based platforms, can help to support tourism plans and actions as well as to evaluate their sustainability in valuable and fragile sites such as hilly and mountainous environments.

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