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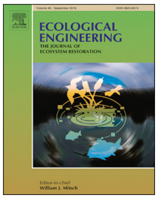

Investigating the time evolution of a rural landscape: How historical maps may provide environmental information when processed using a GIS

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ABSTRACT

A rural landscape is the result of the interaction among natural elements and human activities which takes place in time and space. It represents a non-renewable resource that can provide incomparable information on the general state of the environment. The rapid transformations that are taking place in the last century push towards the implementation of monitoring actions able to take into account the various components of the land use, including their concurrent time evolution as well.

We performed an analysis of temporal transformations of a rural landscape using an open-source GIS approach that allowed for mainstreaming of the main features of this rural landscape, i.e. land use patterns, naturalness dynamics, landscape diversity and visual quality. These four parameters have been selected since they represent those which most affect the processes at the base of the environmental planning and management of a rural landscape. The survey has been carried out over a period of 138 years, using historical maps, interpretation of aerial photos and implementing digital cartography, that have been retrieved with reference to a study area located in the Basilicata Region (southern Italy), which is considered a territory with an high rural – i.e., both natural and agricultural - landscape value.

This methodology has allowed for the examination of the landscape from different points of view, experimenting the performance of a multi-temporal and inter-disciplinary analysis. The main results show – since the landscape has been completely transformed by man in terms of land use – that the areas covered in the past by forest have been transformed into agricultural areas, as opposed to some areas where re-naturalisation processes have taken place. Starting from this first analysis, the implemented methodology, based on a multidisciplinary approach, has enabled to identify the transformations which have greatly influenced the time evolution of the study area. The resulted assessment of land use patterns, landscape diversity, naturalness dynamics and visual quality of this study area, thus enables suitable strategies for the restoration of the local rural ecosystems.

1. Introduction

A "*landscape*" may be considered as the final result of the effects on a given territory, stratified on time by the interaction among the components of the total environment, i.e. atmosphere, hydrosphere, biosphere, lithosphere and anthroposphere. If specifically considering rural landscapes, the anthroposphere plays a pivotal role, because it strongly influences—being influenced in turn—the other natural components. The environmental changes that occurred during the last decades, mainly caused by human activities and changes in land use, have been dynamic since they "evolved" considering the needs and the socio-economic conditions, but are also influenced by the natural forces and continuous interactions with the surrounding context. Under this approach, a "*rural landscape*" may be thus also defined as the "*System of many concurrent ecosystems, in a bi-univocal correlation with human activities*". It is indeed the holistic result of the evolution of free natural elements and relevant human dynamics of land use, land management practices, agricultural policies and socio-economic modifications imposed by the populations living there (Blondel, 2006).

In the last decades, human activities, while altering the whole structure of ecosystems (Vitousek et al., 1997), have also positively influenced the creation of a high number of landscape typologies with a high ecological, cultural and visual value (Antrop, 2005; López-Martínez, 2017, Schulp et al., 2018). Considering the need to protect it, the rural landscape has been increasingly present in studies involving both natural and cultural heritage (Plieninger et al., 2006). Human activities (especially agricultural activities) have played an important role in the characterisation of different landscapes, but the acceleration

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that has occurred in recent decades has negatively affected ecosystems through irreversible changes in the landscape structure and ecological functions (Jansen et al., 2009; Salvati and Sabbi, 2011). Moreover, these changes have had environmental repercussions, such as a loss of biodiversity, land degradation and habitat fragmentation (Reidsma et al., 2006; Bajocco et al., 2018; de Araujo et al., 2015; Fu et al., 2017; Adhikari et al., 2018; Liu et al., 2018a).

The land abandonment process is a common practice all over the Mediterranean area (Ferrara et al., 2016; Romero-Díaz et al., 2017). If at first this process started taking place only in some mountain areas (McDonald et al., 2000), in recent decades, it has spread even in other areas due, above all, to changes in the EU agricultural policy (Keenleyside and Tucker, 2010; Guerra et al., 2016). Focusing on the mountainous areas of the Mediterranean is an important task, because these are regions in which past agroforestry management has led, during the centuries, to high biological and landscape diversity (Falcucci et al., 2007). This diversity is the result of a co-evolution between natural processes and human activities (Klein Goldewijk et al., 2011), which is yet currently sometimes compromised by the abandonment of the territory. In addition, landscapes can be considered as a valuable heritage, having a cultural value (Statuto and Picuno, 2017a) recognised both by the population and by the UNESCO conservation policies (Van Eetvelde and Antrop, 2009; Ridding et al., 2018). In fact, the need to implement new methods to preserve and, at the same time, enhance landscapes (Cillis and Statuto, 2018) has led in Europe to the formulation of the European Landscape Convention (ELC) (Council of Europe, 2000), which says that the characteristics of the landscape and the mechanisms underlying its dynamics must be analysed by observing the changes in the landscape. It also emphasises a lot about the importance of landscape perception by the people.

To prevent loss of rural landscapes in a typical Mediterranean region, it is necessary to obtain a large amount of data to monitor landscape transformations and develop strategies for a suitable management of natural assets (Pelorosso et al., 2009), with the aim to identify proper landscape planning policies, strategies and actions (Agnoletti, 2014; Statuto et al., 2019b). In general, field data are rarely used because they are spatially limited and have limitations of applicability to very large scales (Gillespie et al., 2008), the most used approaches are those that use Geographical Information Systems (GIS) tools, landscape metrics and remote sensing (Scarascia-Mugnozza et al., 2008; Fan and Ding, 2016; Amici et al., 2017; Badjana et al., 2017). Land use maps are generally obtained from the digitalisation of historical maps (Statuto et al., 2015), incorporating historical statistics and old maps (Fuchs et al., 2015), aerial photographs (Carta et al., 2018) or satellite images (Wohlfart et al., 2017). Anyway, the field of the study of landscape dynamics is vast, and there are many techniques and methodologies that are also very different from each other (Meron, 2012). For example, Liu et al. (2018b) proposed an object-based image analysis to improve the use and integration between historical cartography and aerial photos characterising long-term land-use change and landscape dynamics.

Natural components, landscape diversity and visual quality characterise the rural landscape. The natural components can be analysed through the degree of naturalness of the rural landscape. About the concept of naturalness: there are different definitions, each one of which is differentiated for the purpose and the context in which it is evaluated (Machado, 2004; McRoberts et al., 2012). Because of the problems due to the transition from case studies to a general approach to naturalness, a common methodology for the naturalness assessment has not yet been developed (Winter, 2012). One of the concepts often proposed in the relevant scientific literature (Ode et al., 2010; Martín et al., 2018) is the model proposed by Tveit et al. (2006), in which a landscape visual character was defined by nine key concepts (stewardship, coherence, disturbance, visual scale, historicity, imageability, naturalness, complexity, and ephemera), one of which is naturalness.

The quantification of large-scale landscape diversity is a complex task. Concerning bio-diversity, direct measures, especially for large regions, will never provide a complete list of species, even if they are considered as permanent organisms such as plants. This is partly due to change over time, but also because it is not possible to inspect all individuals in a given region (Ricotta et al., 2003). Landscape metrics can support direct surveys in the field because they can be useful for identifying, for example, biodiversity hot spots (Uuemaa et al., 2009; Walz, 2011). Obviously, the metrics do not replace the measurements of the species, but they can help the researchers to direct the surveys and therefore make them less expensive and more effective. (Botequilha Leitão et al., 2006; Bailey et al., 2007).

The visual quality of landscape, finally, includes the assessment of a number of physical, aesthetic, and psychological aspects (Cañas et al., 2009). The landscape has two realities: one dependent on individual perception and another linked to the physical aspect that is independent of the viewer (Palmer and Hoffman, 2001).

In this paper, the focus was put on some of the most crucial aspects that are being lost in the internal areas of the Mediterranean region and which emerged from the ELC, in terms of analysis of natural environment, rural landscape diversity and visual quality. The aim of this paper is, indeed, to propose a case study in which the dynamics of land changes influencing the rural landscape were quantitatively assessed through several approaches, by the implementation of some historical cartographic information at different chronological levels. Historical cartography, even if complex to be elaborated, represents a fundamental source of information for the quantification of the impact of changes in land use on the environment and in landscape (Corbau et al., 2019). But due to the difficulties in processing and retrieving spatial information from historical cartographies, new approaches and models must always be explored to make the historical land use reconstruction more and more consistent (Yang et al., 2017).

With reference to a rural area located in Southern Italy, some land use maps that were retrieved have been related, within a GIS environment, to other environmental parameters, so as to be able to define the overall dynamics of the landscape and its main characteristics. This overall approach allowed to merge purely ecological aspects – i.e., aspects arising from the composition and configuration of the landscape caused by changes in land use and natural dynamics, triggered by the natural components of the total environment – with those typical of engineering, as integrated planning, design methods, works supervision and technical management of the anthropological components of the total environment. This has contributed to bridge the gap between ecology and engineering, providing innovative technical tools suitable to predict, design, construct or restore, and manage rural ecosystems of special naturalistic, tourist and economic value, so as to integrate the human society with its natural environment for the benefit of both (Mitsch and Jorgensen, 1989). This methodology has been focused onto the following objectives: a) to analyse the *land use changes* over a period of 138 years, enhancing information coming from different cartographic supports (historical cartography, aerial photos and orthophotos); b) to evaluate the degree of *naturalness* of the landscape, linking the dynamics with relevant topographic variables as well; c) to evaluate the *landscape diversity* of the landscape over time through the mapping of a diversity metric of the landscape; d) to analyse how the environmental evolution of the landscape has changed the *visual quality* during the analysis period.

2. Methods

2.1. Study area

The study area, located in the north of the Basilicata Region—Italy (Fig. 1), includes regions of great naturalistic and cultural importance that make this landscape unique in Southern Italy. Specifically, the perimeter of the study area was identified on the basis of the land represented on the historical cartographies used.

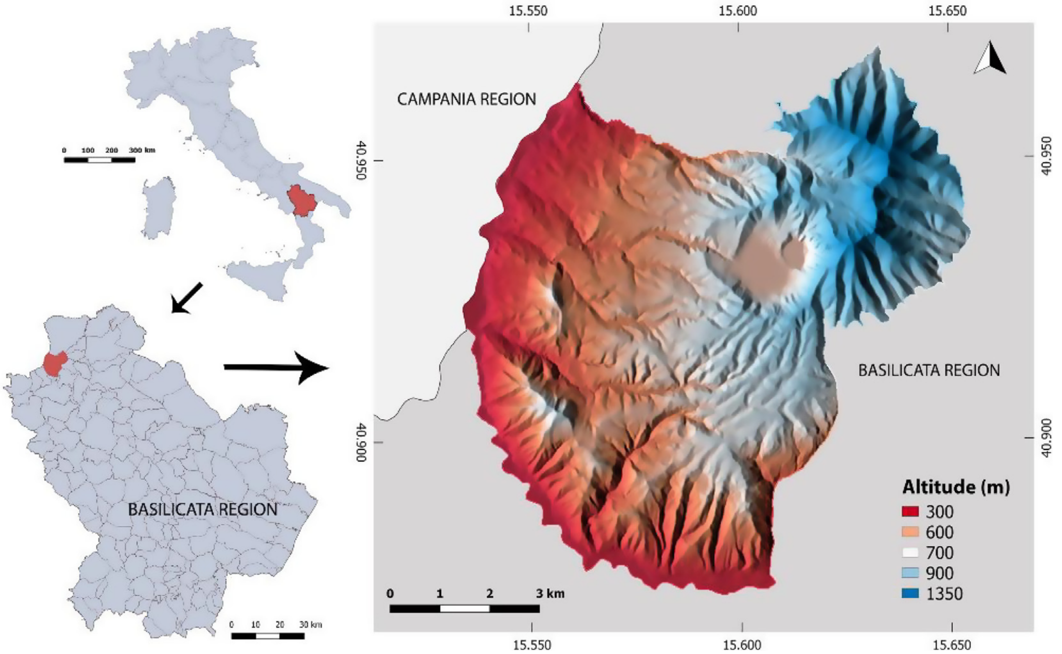

Fig. 1. Location of the study area (centroid: 40°55′18.8″N 15°35′22.6″E, Datum: WGS84).

The landmark of this area is the Mount "Vulture" (1326 m), an extinct volcano which has had a notable influence on the geographic, botanical, zoological and anthropological events of the surrounding natural environment. This is a volcano of Pleistocene age with a complex morphology due to the presence of several eruptive centres and volcano-tectonic structures, surrounded by several quaternary fluvio-lacustrine basins (Principe, 2006). For its geological and geomorphological importance, it has been inserted in the Italian Geosites Inventory (ISPRA, 2015). The northern part of the study area constitutes the Special Area of Conservation (SAC), "Monte Vulture" (Code IT9210210): it includes the "Monticchio" Lakes, formed in the original crater, completely reforested and the top of the volcanic cone, located in the municipal territories of "Atella", "Rionero in Vulture" and "Melfi".

Close to the SAC "Monte Vulture", in the south of the study area, near the border of the Campania region, in the municipalities of "Rionero" and "Atella", the SAC "Grotticelle of Monticchio" (Code IT9210140) is located: it includes the State Nature Reserve "Grotticelle", established in 1971 to protect the habitat of the moth *Acanthobrahmaea europaea*, the world's first example of a protected area created for the protection of a moth. "Grotticelle" is basically a hill, on which numerous lithotypes emerge, basically marly clays of red-greenish and grey colour, in chaotic order and intensely deformed even in showy calanchiferous phenomena. The southern extension of the SAC is superimposed on part of a large Important Bird Area (IBAs), named "Fiumara di Atella". The volcanic complex of "Vulture" has differences in respect to all other Italian Quaternary volcanoes both from a geological-geographic point of view and considering a geochemical-geodynamic aspect (La Volpe and Rapisardi, 1977; Giannandrea et al., 2006; Schiattarella et al., 2005). The ancient volcano craters are occupied by two lakes that represent about 14% of the catchment area and these are fed by groundwater. The largest lake has a maximum depth of 36 m while the average depth is about 8.9 m. The smallest lake is 38 m deep; it has an average depth of 17.9 m.

The "Vulture" area presents—due to the number of peaks, the variety of slopes and exposures, the microclimate and the presence of two lacustrine formations—multiple landscape patterns (Fascetti and Spicciarelli, 2001). During the monitoring activities of the area of the past, numerous plant and animal species were highlighted, which are significant for the protection and conservation aspects. Here, areas in which the control of the territory by man is almost total coexist with areas with an almost total naturalness (area of the summit of Monte Vulture and some slopes) (Basilicata Region, 2015). Moreover, a part of the study area has been declared as a landscape of notable public interest by Italian Law (DM 04 May 1966—GU No. 125 of 23 May 1966).

In the area surrounding the lakes, the presence of man is dominant. This portion of the territory has a strong tourist attraction that, over the years, has changed the landscape on many occasions (Olišarová et al., 2018). There are numerous tourist-receptive facilities, both old and new, in many cases close to the banks of the lakes. Therefore, since the natural and cultural heritage of this area is of considerable interest, it is crucial to implement suitable integrated monitoring techniques useful for landscape planning.

2.2. *Cartography*

The first operation carried out has been the preparation of the land use maps of the 4 different time steps (years 1875, 1955, 1988, 2013) that have been considered, which provided the basic datasets for all subsequent operations (Fig. 2). The availability of free land use data covering last 30 years, such as Corine Land Cover (CLC) project datasets, allows for several large-scale and repeated analyses over time (Díaz-Palacios-Sisternes et al., 2014), but considering the need for better spatial accuracy than the data, it was preferred *ex-novo* build the datasets. Preliminary steps and all the subsequent operations were performed with an open-source GIS tool (QGIS Development Team, 2018) together with some other open source tools able to guarantee an effective analysis of landscape dynamics (Statuto et al., 2019a). The statistical analysis has been performed through R software (R core team, 2014).

2.2.1. *Year 1875*

The historical dataset of 1875 was based on the combination of three historical cartographies that were made in the same period, which allowed for the extrapolation of various information concerning land cover classes. The first is a topographic map created by the Italian Military Topographical Institute (currently converted into the Italian Military Geographical Institute) and preserved in the State Archives of

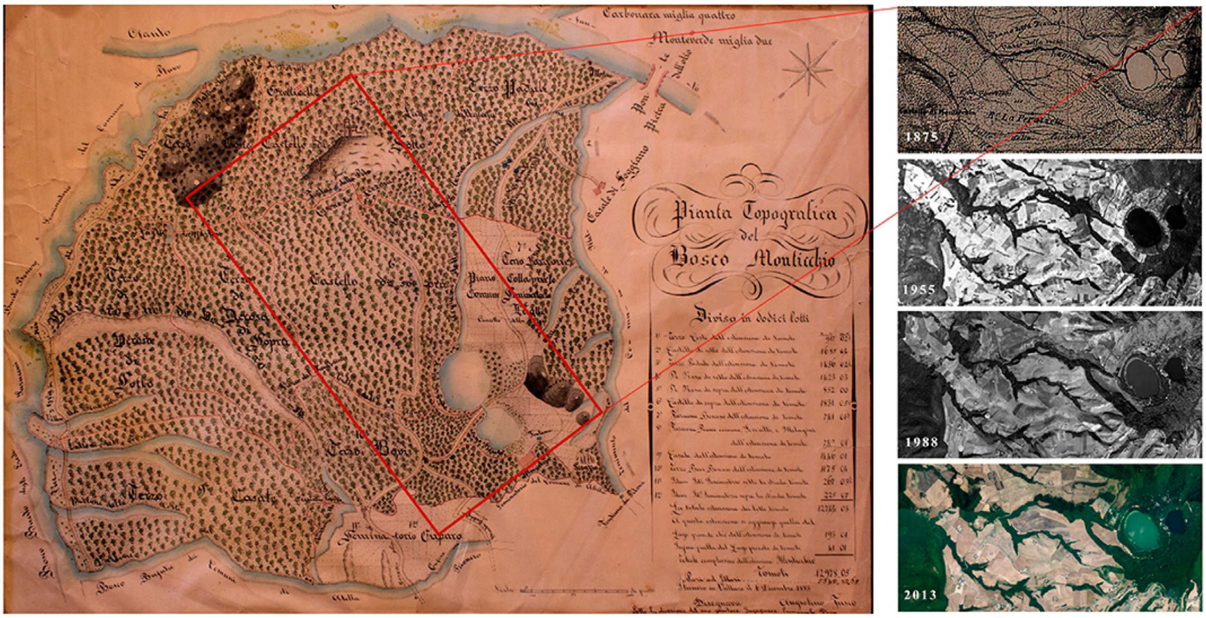

Fig. 2. Extract of a part of the study area (6 × 2.5 km) in the 4 main maps and position with respect to a secondary historical cartography used (*Topographic Map of "Bosco Monticchio"*).

the City of Potenza.

The Bonne projection was chosen, already used in other cartographic works, in order to standardise the map. This map was drawn, for the continental part, between 1869 and 1875, and to make the materials usable in the shortest time, the drafts were printed with a photographic process within a few years. The map is in 1:50,000 scale with level curves at an equal distance of 10 m. The main land use categories, listed points and toponyms were represented (Alisio and Valerio, 1983; Valerio, 1993). The second and third cartographic support are iconographic maps entitled "Topographic Map of the Bosco Monticchio" and "Topographic Map of Vulture mountain", which are kept respectively in the municipal library of the town of "Rionero in Vulture" and the State Archive of Potenza. These maps were realised in the same period and have a similar representation scale as the previous one, so it was possible to use them to extrapolate some information on the land use classes that could not be recovered from the previous one. These historical maps have a lot of information, but their accuracy must be properly assessed to be able to use them correctly from a geographical point of view (Blakemore and Harley, 1980; Mastronunzio and Dai Prà, 2016), so it has been necessary to apply new approaches to transform the maps from simple archive documents with geographic datasets (Balletti, 2006). After scanning and converting the two historical maps to a digital format, they have been geo-referenced. The iconographic maps, "Topographic Map of the Bosco Monticchio" and "Topographic map of Vulture mountain", were geo-referenced with a methodology already used for similar maps in a previous study (Statuto et al, 2017b). The quality of geo-referenced map was assessed by overlapping the historical maps with the Regional Technical Map (CTR) of Basilicata region of 2013 with a scale of 1:5000. In some cases, due to the characteristics and realisation techniques of historical maps, changes of the landscape since the time of the mapping, and in consideration of the land roughness of the study area, the root mean square (RMS) value was over 100 m. To reduce it, the second order polynomial was used, which made it possible to reach an RMS value around 20 m (Brovelli and Minghini, 2012) and also allowed a visual accuracy assessment, thus validating the georeferencing (Podobnikar, 2009). In this way, it was possible to use the two secondary historical maps as a basis to improve the accuracy of the thematic classification of ITM cartography. The software used is *MapAnalyst* (Jenny and Hurni, 2011). Instead, the ITM cartography was geo-referenced using a different approach. By analysing the techniques used to make the cartography used (Mori, 1903), the main meridian on which the geographic grid was constructed was identified, so it was possible to re-structure the map on the basis of the datum used in this study (UTM/WGS84 33N—EPSG: 32633). In this way it has been possible to speed up the geo-referencing of entire sheets, improving their accuracy as well.

2.2.2. *Year 1955*

To process land use in 1955, five grey-scale aerial photos in 1:33,000 scale of the Italian Military Geographic Institute (IGMI) have been used (Statuto et al., 2016). Each photo has been acquired in digital format and imported into the GIS. Subsequently, they were geo-referenced and ortho-rectified with a Digital Elevation Model (DEM); the topographic map was geo-referenced too. Finally, the aerial photos were mosaicked on the basis of the common overlap area.

2.2.3. *Year 1988*

For the year 1988, the ortho-photos supplied by the Italian Ministry of the Environment (WMS service) have been used. These ortho-photos are in 1:10,000 scale.

2.2.4. *Year 2013*

For the year 2013, the ortho-photos were downloaded in GeoTIFF (.tif) format from the Geographic Database of the Basilicata Region (under Italian Open Data License 2.0). These ortho-photos are in 1:10,000 scale.

2.3. *Land use classification*

The raster images were converted into vector maps through a manual procedure finalised to digitise the polygons relative to the land use classes and subsequently re-transformed into raster maps. Conversion from vector to raster errors were calculated for each land use class as the ratio of the difference between the area of classes in vector format before rasterisation and the area of classes in the raster dataset after rasterisation to vector map (Liao and Bai, 2010). After several tests starting from pixel resolution of 1 m, the value used which provided a lower rasterisation error value between the different land use classes (less than 1%) without the file being too large for post processing operations, is that of 5 m. Furthermore, the choice of this

Table 1
Land use class, acronym and description.

Land use class	Acronym	Description
Built up areas	BUILT	Artificial surfaces realised by man (buildings, industrial areas, roads, etc.). In particular, only roads with a significant surface and an important traffic flow and paved roads were considered. All typologies of minor rural roads have been excluded.
Arable lands	ARAB	Cultivated land with different crops and orchards (i.e., in this study: cereals, legumes, fodder crops, olive groves and vineyards).
Forest area	FOR	Area occupied by forests and woodland with a pattern composed of native species.
Afforested area	AFFOR	Area with exotic conifers and allochthonous species planted by men.
Transitional woodland	TRANS	Bushy or herbaceous vegetation with scattered trees. It can represent either woodland degradation or forest regeneration/colonisation. Class representing natural development of forest formations, consisting of young trees species, dispersed solitary adult trees and herbaceous vegetation.
Natural grassland	GRAS	Low productivity grassland. Often situated in areas of rough, uneven ground. Frequently it includes rocky areas, briars, heathland and occasional grazing.
River zone	RIV	Area consistent to the bed of the “Atella” River and the riparian vegetation existing along the river.
Lakes	LAK	Area corresponding to “Monticchio lakes”.
Chestnut forest	CHES	Forest surfaces consisting of chestnut trees. It was separated from the forest area because “chestnut forest” is a characteristic element of the study area. They have an artificial origin, but over time they have become a semi-natural habitat; in fact, they are part of the habitat 9260 of the Natura2000 network.

resolution guaranteed the possibility of comparing with terrain data used subsequently.

Land cover temporal transition analysis and assessment ware performed using the MOLUSCE (Modules for Land Use Change Simulations) plugin, a user-friendly and intuitive tool based on QGIS which makes it easier to perform modelling and simulation in land study applications (Gismondi et al., 2014).

Concerning the reliability level of the survey methodologies based on historical cartography, the manual digitisation shows some uncertainty about polygon shapes and information attributes; it is clear that they may contain errors of different types, as illustrated also by Geri et al. (2010a). This is however the only possible methodology to retrieve dated information, describing the structure and dynamics of the landscape.

Land use and coverage classes are shown in Table 1.

2.4. Naturalness assessment

Based on the definition given by Tveit et al. (2006) that is generally used to describe the natural environment, the perceived naturalness can be different from ecological naturalness. These authors indicated the potential indicators to assess naturalness; in particular, vegetation intactness, percentage area with permanent cover, presence of water, percentage of water area, presence of natural feature, lack of management, management intensity (type and frequency), naturalism index and degree of wilderness. In this study, a methodology that takes into account the indicator of the percentage area with permanent vegetation cover was implemented. For this reason, the naturalness of the landscape has been evaluated through the persistence of the forest vegetation before expanding the survey to the entire study period and not to a specific year, as proposed by some other authors (Martín et al., 2016). In the permanent vegetation, the natural grasslands were not included because their condition of naturalness should be evaluated separately because of their high dynamism. Through the overlay procedures between the land use maps of different years, an image cross-classification was produced with the MOLUSCE plugin, in which the areas showing an intact and permanent forest vegetation (forest and chestnut classes) are shown during the 138 years of analysis (conservation area). Furthermore, the areas in which natural and artificial re-naturalisation processes are being carried out (afforestation area) and areas where naturalness has disappeared due to deforestation processes (deforestation area) have been compared.

In accordance with the methodology presented by Geri et al. (2010a) and by Amici et al. (2017), the cross-classification map has been superimposed on the 5 m Digital Elevation Model (DEM) of the Basilicata Region in order to evaluate the relationships between the dynamics of naturalness and some topographic parameters, i.e. *slope* (maximum gradient angle for each pixel in degrees, based on first order derivation estimation); *altitude* (height above sea level); *aspect* (exposition for each pixel, in degree) and *global irradiance* ($\mathrm{Wh\,m^{-2}\,day^{-1}}$). The variables were calculated with the QGIS Raster Based Terrain Analysis Plugin and the module of GrassGIS, r.sun (Hofierka and Súri, 2002). Then, the statistics and box-plot of slope, elevation, aspect and global irradiance versus naturalness classes were elaborated to assess the separateness of native classes with respect to topographic variables (R software—R core team, 2014). This approach can be useful for identifying the areas that have maintained a certain level of naturalness and which may be the cause that led to the non-alteration of these areas compared to the others, and understanding the areas in which a certain degree of naturalness is being recreated.

2.5. Landscape diversity assessment

In this study, a diversity landscape metric used was calculated on the basis of the land use maps using the Fragstats 4.2 free software (McGarigal et al., 2012) to evaluate the multi-temporal patterns changes of the landscape structure (Turner et al., 2001; Cushman et al., 2008). The calculated metric is the *Shannon diversity index (SHDI)*. This diversity index was applied in many studies in which landscape diversity was evaluated over time (Olsen et al., 2005; Liu and Weng, 2013). Using a moving-window approach in FRAGSTATS, a window, with a shape and size chosen by the user, moves through the land use raster one cell at a time, computing the chosen landscape metric within the window, then returning that value to the centre cell. From the elaborated raster, each cell represents the “local neighbourhood structure” of landscape inside the window (McGarigal and Cushman, 2005; McGarigal et al., 2012). To perform the calculation, a window has been used with a radius of 500 m, according to other studies carried out in similar study areas for data resolution and extension (Kong et al., 2012; Modica et al., 2012). To minimise the boundary effect (negative values for cells placed close to the edge of area), an expansion strip of 500 m around the edge of study area was added (McGarigal et al., 2012). The maps obtained with this procedure show the spatial distribution of landscape structure based on the results of the selected metrics. Furthermore, to highlight even more the variations in landscape diversity, a change detection was made with a simple arithmetic difference comparing, between themselves, the SHDI maps in the intervals: 1875–1955, 1955–1988 and 1988–2013.

The SHDI measures the ecological diversity in a community, but it can also be applied to the landscape in order to correlate in value SHDI to plant diversity (Herbst et al. 2007; Burton and Samuelson, 2008). There is not diversity when a landscape contains a single patch (in this case, its value is equal to zero); as the number of different patches and their spatial distribution increase, diversity also grows. The numerical

Table 2
Visual quality values assigned to each land use class. For land use classes acronyms, see Table 1.

Land cover class	Value
BUILT	1-2-4-8*
ARAB	4
FOR	7
AFFOR	5
TRANS	6
GRAS	5
RIV	7
LAK	8
CHES	6

*A value equal to eight has been assigned to buildings of historical and cultural importance protected by the Italian Code of cultural heritage, while industrial zone = 1, new buildings = 2 and old buildings and farm = 4.

value is ≥ 0, without limit (as the value increases, the complexity of the landscape also increases). The diversity of land cover patches may indicate the multi-functionality of the area; it can also be an indicator of the high sensitivity of the area to changes in its structure and function. Low diversity of coverage suggests stability and durability of the land use structure. Chmielewski et al. (2014) suggest that SHDI can be interpreted only against the background of a current land cover map. High values of SHDI prove the increase of diversity of landscape patches, but only together with the analysis of the current land cover structure is it possible to assess whether these changes are natural (e.g. development of patches of scrub communities resulting from natural succession); otherwise, they are the result of human activities (development of built-up areas and roads, changes in the way of agricultural use, etc.).

The calculation of the metrics, and in this case of the SHDI, cannot represent a direct calculation of the estimation of biological diversity, but it can allow the individuation of hotspots of landscape diversity in which, subsequently, point evaluations can be made to correlate the two values. Furthermore, carrying out the evaluation over a long period of time can also guarantee a long-term evaluation of the effects of changes in the diversity of ecosystems typical of the studied landscape.

2.6. *Visual quality assessment*

To evaluate the visual quality of the landscape, the approach proposed by La Rosa (2011) was used, adding some elements in order to contextualise it. The definition of visual quality of the landscape is based on three steps: the first part of the evaluation is based on the viewshed analysis, the second on the calculation of the quality of the landscape and the third on the union of these two themes. Visibility and viewshed are strongly dependent on the terrain morphology, but other parameters can influence the viewshed calculation, such as the height of observer and observed objects, the vertical and horizontal observation angles, the presence of different physical features (vegetation, buildings, general obstacles in the view), the curvature of the Earth and atmospheric conditions (Miller, 2001). Viewshed calculations involve the use of a digital surface model (DSM) with a horizontal resolution of 5 m. To perform this calculation, the QGIS plugin “Viewshed Analysis” (Čučković, 2016) has been used, which allows the facilitation of operations in case of it is necessary to set different parameters and work with large amounts of data. The main data are the Digital Surface Model (DSM) distributed by Geographic Database of the Basilicata Region (under Italian Open Data License 2.0) with a pixel resolution of 5 m and 1 m of accuracy of height and a set of points on the ground. Vegetation heights, buildings and other vertical structures are already included in the DSM elevation values, in order to partially mitigate the problem of the alteration of the conditions of visibility from these elements (Sander and Manson, 2007). These points have been extrapolated from the scenic roads that cross the study area, selected by the Italian Touring Club Atlas of Roads (Touring Club Italiano, 2006). A survey was conducted on other local roads in order to include some of them in the panoramic network. Considering that in this study, we have implemented a methodology to evaluate how the visual quality of the landscape has changed over the time, the panoramic road network has been modified on the basis of the different cartographies used to include only the features that are present in all of the four chronological supports used in this analysis. The points considered (498) coincide with the nodes of the panoramic road network polylines. A cumulative viewshed has been calculated from this viewpoint set, and the output of the analysis returns as an integer raster grid in which each cell stores the number of visible viewpoints. Scores rank from 0 to 307, where 0 represents landscape areas that are not visible by any of the panoramic viewpoints, and 307 represents landscape areas that are visible from most of the panoramic viewpoints. With this first operation, it has been possible to extrapolate a map of intrinsic visibility (Wheatley, 1995), that is, the classification of the territory in the study area in contrast to the least visible (Franch-Pardo et al. 2017). As proposed by several authors (Yeomans, 1986; Vouligny et al., 2009; La Rosa, 2011; Martín and Otero, 2012; Vlami et al., 2017), visual quality value is assessed using an integrated expert-based approach, which allows for the evaluation of landscape qualities from different disciplinary fields.

Generally, landscapes that have topographically high and uneven areas are preferred to those that have plain surfaces, especially if water is present, and the vegetation dominates the area, particularly when trees are more numerous than scrubs. Landscapes with wide diversity or with a mosaic structure are valued more than those homogeneous ones, being characterised by a monotonous appearance (Martínez-Graña et al. 2017).

In particular, using a methodology based on a panel of experts assessment (Otero et al., 2007; La Rosa, 2011; Martín and Otero, 2012), a score between one and eight was assigned to each land use class (Table 2). Scores do not express absolute values.

Even if in some studies (Taylor Perron and Fagherazzi, 2012, Martín et al., 2016; Martínez-Graña et al., 2017) relevant landform factors have also been considered (altitude, slope, lithology, sinuosity etc.), as the present study aims to highlight how the visual quality of the landscape has changed over the time, they have not been computed, assuming the fact that the morphology of the territory has not changed radically over the years. Furthermore, the diversity of the landscape was also considered, including the metric SHDI. In fact, some studies show a correlation between the aesthetic quality of the landscape and its diversity (Franco et al., 2003; Dramstad et al., 2006). The SHDI maps of the different years of study elaborated in the previous phase, have been reclassified with values from 0 to eight, where 0 corresponds to the values of lowest SHDI and eight for the highest values.

Finally, all the layers (landscape visual value and SHDI maps) were summed using map algebra, attributing to every grid the same weight, by creating landscape value maps named Landscape Value Scores (La Rosa, 2011). In the last step, according to this author, an *Index of Visible Landscape Value* was calculated. From the point of view of landscape planning, it is important to distinguish not only which areas are most visible from the scenic roads, but also how much their connected value is. A single index able to consider both visibility and value, as well as to quantify “how much” and “what” landscape can be seen from a series of points of view (the road network in this case), has been defined. This index represents the intensity of the landscape values that can be observed from the panoramic road network. Operationally, this index is obtained by the overlay of rasters of viewshed and landscape value score which have been previously calculated. They are arithmetically multiplied to create a new grid. This index was calculated for the four different chronological levels of the present analysis.

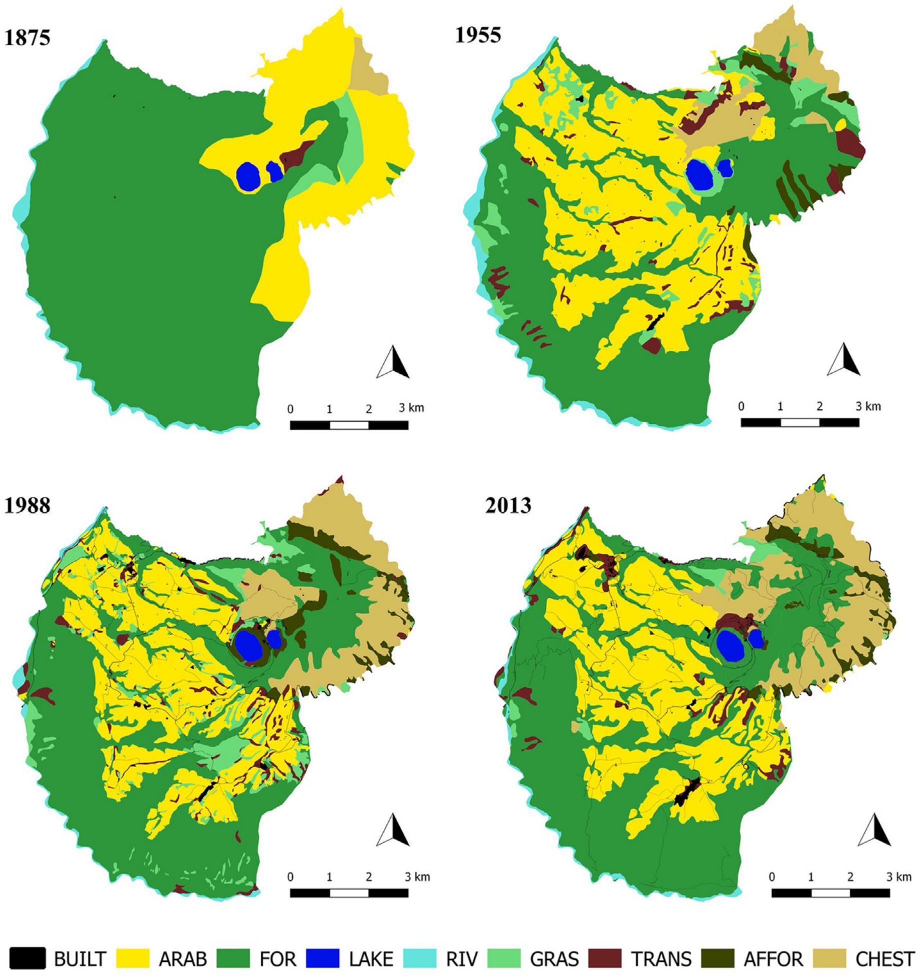

Fig. 3. Land use maps derived from the classification of the different cartographies for the 4 years which have been analysed. For land use classes acronyms, see Table 1.

3. Results

3.1. Land use

The land use maps produced for the four different time steps, in which the surfaces relevant to each land use class were summarised (expressed in ha and in %), are shown in Fig. 3. These data are also reported in Table 3, in which the net change for each time-lapse has been calculated for the whole period of 138 years as well. The analysis that has been enabled through identifying the general dynamics of the study landscape, shows that some areas have radically changed during the whole considered time period. Indeed, the western part of the study area appears to have the most part transformed into an agricultural area, while the volcanic cone of Mt. Vulture (eastern part) has been almost completely reforested.

From a quantitative point of view, considering the whole period, there has been a strong decrease in forest area (about −1735 ha), counterbalanced by an increase in the arable land (about 616 ha) and chestnut forest (around 767 ha). In addition, the largest increase, in percentage terms, occurred, as evident, for the built-up area (+109 ha, with the highest increase in the period 1955–1988).

With the aim to enable a more detailed analysis, a contingency

Table 3
Total surface for each land use class (in ha and %) and net change (ha) over the years. For land use classes acronyms, see Table 1.

	Surface (ha)				Surface (%)				Net change (ha)			
Land use	1875	1955	1988	2013	1875	1955	1988	2013	1875–1955	1955–1988	1988–2013	1875–2013
BUILT	0.7	11.6	79.1	110.1	0.0	0.2	1.2	1.6	10.8	67.5	31.0	109.4
ARAB	1388.3	2323.7	1861.1	2004.6	20.7	34.7	27.8	29.9	935.4	−462.6	143.5	616.4
FOR	4895.2	2968.9	2958.5	3160.4	73.0	44.3	44.1	47.1	−1926.3	−10.5	201.9	−1734.8
AFFOR	0.0	143.8	256.3	162.7	0.0	2.1	3.8	2.4	143.8	112.5	−93.6	162.7
TRANS	30.4	271.8	215.5	181.8	0.5	4.1	3.2	2.7	241.4	−56.3	−33.7	151.4
GRAS	137.2	383.6	442.4	97.0	2.0	5.7	6.6	1.4	246.4	58.8	−345.3	−40.2
RIV	120.0	164.8	73.6	81.4	1.8	2.5	1.1	1.2	44.8	−91.2	7.7	−38.6
LAK	51.8	54.8	55.9	58.2	0.8	0.8	0.8	0.9	3.0	1.1	2.4	6.5
CHEST	82.2	382.8	763.5	849.5	1.2	5.7	11.4	12.7	300.6	380.6	86.0	767.3
Tot	6705.8	6705.8	6705.8	6705.8	100.0	100.0	100.0	100.0				

Table 4/a
Cross-tabulation matrix—1st Period: from 1875 to 1955 [Ha]. For land use classes acronyms, see Table 1.

1875/1955	BUILT	ARAB	FOR	LAK	RIV	GRAS	TRANS	AFFOR	CHEST	Tot 1875
BUILT	**0.11**	0.37	0.18	0	0	0.09	0	0	0	**0.7**
ARAB	0.98	**312**	420.2	7.68	0	125.22	127.98	125.25	268.96	**1388.3**
FOR	10.18	2009.09	**2385.44**	0.51	53.54	229.75	143.78	15.38	47.53	**4895.2**
LAK	0	0	1.58	**46.62**	0	3.58	0	0	0	**51.8**
RIV	0	0.21	7.15	0	**111.27**	1.34	0	0	0	**120**
GRAS	0.11	0	119.48	0	0	**11.62**	0	3.2	2.79	**137.2**
TRANS	0.18	2	28.19	0	0	0	**0**	0	0	**30.4**
CHES	0	0	6.71	0	0	11.96	0	0	**63.54**	**82.2**
Tot 1955	**11.56**	**2323.68**	**2968.93**	**54.81**	**164.81**	**383.55**	**271.76**	**143.83**	**382.82**	**6705.75**

Table 4/b
Cross-tabulation matrix—1st Period: from 1875 to 1955 [%]. For land use classes acronyms, see Table 1.

1875/1955	BUILT	ARAB	FOR	LAK	RIV	GRAS	TRANS	AFFOR	CHEST
BUILT	**14.34**	49.32	24.41	0	0	11.92	0	0	0
ARAB	0.07	**22.47**	30.27	0.55	0	9.02	9.22	9.02	19.37
FOR	0.21	41.04	**48.73**	0.01	1.09	4.69	2.94	0.31	0.97
LAK	0	0	3.05	**90.04**	0	6.91	0	0	0
RIV	0	0.18	5.96	0	**92.74**	1.12	0	0	0
GRAS	0.08	0	87.09	0	0	**8.47**	0	2.33	2.03
TRANS	0.6	6.6	92.81	0	0	0	**0**	0	0
CHES	0	0	8.16	0	0	14.54	0	0	**77.3**

matrix was created. It is a type of change detection obtained through a cross-tabulation analysis, which enables to highlight the changes occurred in time both in qualitative terms—by showing them directly on the map—and in quantitative terms, by allowing for the calculation of the total surface extent of land use change occurred at different times. The operations were carried out by the MOLUSCE plugin and its specific function “Area Changes”. Thanks to this tool, it is possible to elaborate a pixel-based cross-tabulation matrix for each period of analysis and then export the results to a spreadsheet. The created tables show the proportion (hectares or percentage) of unchanged area per each land use class for each time-lapse (on the diagonal), as well as the changes from one land use class to another one (out of the diagonal). The rows indicate changes in land use classes in the analysed period and the columns show the land use class in the first year of analysis, from which another land use class has changed in the following year of analysis. As an example, the 1875–1955 cross-tabulation matrix reported in Table 4/a shows that Arable land for 420.20 ha in 1875 was changed into Forest land in 1955, while, on the contrary, other 2009.09 ha of Forest land in 1875 was changed into Arable land in 1955. In this way, Table 4 (4/a, in hectares; and 4/b, in %) shows, in the 1st Period (1875–1955), that (excluding the surface of the lakes which is the most stable in all three years) the river area class (92.7%), chestnut woods (77.30%) and forest area are the most stable in terms of permanent cover of the surface area. The one which showed most dynamism is, on the opposite, the natural grassland (8.5%), which has been replaced mostly by forest area (about 120 ha). From the comparison with the other tables, it is clear that the period 1875–1955 is the one in which there have been the greatest changes, probably even due to a longer time period.

During the second period, i.e. between 1955 and 1988—reported in Table 5 (5/a in hectares; 5/b in %) it is noted that transitional woodlands and natural grasslands have been affected by important conversion processes. In fact, only 10.2% and 16% remained stable, while the other part of these land use classes has been replaced (in terms of their size) by forests, arable land, as well as also by about 81 ha of allochthonous species planted by men (afforested area) and about 85 ha of chestnut. The built up area, which in this period has undergone the greatest increase compared to other periods, has increased at the expense above all of the agricultural areas (about 45 ha).

Finally, in the third period 1988–2013 (Table 6) (6/a in hectares; 6/b in %), the contingency matrix shows that the landscape has changed less than during the previous time spans. In fact, many classes (in particular the arable land and the forest area) exceed 70% of stability. Also, in this case, the most dynamic classes have been the transitional woodlands and natural grasslands. Furthermore, it is noted that around 44% of the afforested areas were transformed into forest areas. As for the total surface of the river zone, there is a reduction of about 38 ha, following an initial increase, during the first period, of 44 ha, which was followed by a sharp decrease (almost 100 ha at the expense of forest area and natural grasslands) between 1955 and 1988, then by a further increase (+7 ha).

3.2. Naturalness

The naturalness of the study area has been evaluated considering, as a main parameter, the level of conservation of the forest area, in which the presence of woods has remained unchanged during the 138 years of the analysis, compared to the areas in which, during this time span, there have been processes of deforestation of woody areas or, on the contrary, afforestation of other surfaces. From the spatial overlay of land use maps by the MOLUSCE plugin, the fraction with a persistent forest surface (conservation area) has been so extrapolated (Fig. 4—a). This approach overgeneralises the naturalness assessment, and the accuracy of dynamics can be improved in the future by adding other parameters such as presence/absence of vegetation intactness and management. From the spatial analysis and the mapping of naturalness (Fig. 4—b), it emerges that this conservation area with greater naturalness covers only 31.96% of the total study area. In general, even if this area has a high naturalistic vocation, the prevailing socio-economic dynamics have led to the deforestation of the territory (43.26% of the study area). The main naturalisation processes are taking place around the “Vulture” mount, since almost all of the areas of afforestation (27.4%) concerned the slopes of the extinct volcano.

To better interpret the naturalistic dynamics of the studied landscape, box plots have been created for the time periods 1875–1955, 1955–1988 and 1988–2013 (Fig. 5) through a statistical analysis (Table 7) relating these three areas (conservation, afforestation and deforestation) to some topographic variables (elevation, slope, aspect and global irradiance).

In the first analysis period (1875–1955), the forest persisted in

Table 5/a
Cross-tabulation matrix—2nd Period: from 1955 to 1988 [Ha]. For land use classes acronyms, see Table 1.

1955/1988	BUILT	ARAB	FOR	LAK	RIV	GRAS	TRANS	AFFOR	CHEST	Tot 1955
BUILT	**8.7**	1	0.1	0	0	0.3	1.2	0.3	0	11.6
ARAB	45.3	**1690.3**	164.5	0.1	1.1	275.6	85.8	37.1	23.9	2323.7
FOR	12.9	45.7	**2466.7**	0.4	1.1	41.5	37.8	90.6	272.3	2968.9
LAK	0	0	0	**53.8**	0	0	0	1	0	54.8
RIV	1.8	6.7	51.1	0	**70.8**	20.9	13.6	0	0	164.8
GRAS	6.4	74.4	129.2	1.6	0.7	**61.5**	32.8	55.1	21.8	383.6
TRANS	2.9	39.6	77.6	0	0	34.8	**27.6**	25.7	63.6	271.8
AFFOR	0.1	0.5	25.2	0	0	2.3	3.4	**41.2**	71	143.8
CHEST	1	2.9	44.1	0	0	5.4	13.2	5.4	**310.9**	382.8
Tot 1988	**79.1**	**1861.1**	**2958.5**	**55.9**	**73.6**	**442.4**	**215.5**	**256.3**	**763.5**	**6705.8**

zones (conservation area) with elevation of, on average, less than 600 m and with quite high slopes. Comparing to global irradiance, the areas that were most preserved have been those with a higher value of this parameter. The areas that have lost naturalness (deforestation area), on the other hand, are those with high irradiance values (very concentrated around the median value), placed at a higher elevation than the conservation area and especially at lower slopes. At higher elevation and slopes, areas with naturalisation processes are especially concentrated.

Between 1955 and 1988, a greater dispersion of values, especially those related to elevations, is evident. As for the slope, in all these three areas, the values are quite similar. The trend of the global irradiation value is similar to the previous period, and in particular, it emerges that above all, the deforestation process has taken place in areas with high and concentrated values.

Finally, in the last period (1988–2013), the preserved areas follow, in general, the trends of the previous period. On the other hand, as regards the areas that have been re-naturalised, it is noted that this process has also been affected by areas with lower elevation and slope, differently from those that occurred in the past. The aspect is not a significant parameter in terms of the significance dynamics of this survey because, for all three periods, an important dispersion of values is evident and particularly for afforestation and deforestation processes, the areas concerned are those with an exposure from South-East to South-West (range between 150 and 200°).

3.3. Landscape diversity

The variation in the diversity of the landscape during the 138 years of analysis was assessed through the mapping of the SHDI (Supplemental Fig. S1). In these maps it is possible to visually assess how the diversity of the landscape has changed over the whole time period of study. Values range from 0 to 1.9 (highest value recorded in 1988). As expected, in 1875 the landscape was not very diversified, mainly because of the extreme uniformity in the use of the ground. In fact, most of the territory was exclusively occupied by forests, so the rural landscape was certainly environmentally uniform, the only diversity hotspots being represented by the lakes area and the top of the "Vulture" mountain, where the SHDI values are close to the maximum ones.

With the realisation of the maps highlighting the differences in values of the SHDI (Fig. 6), it has been possible to investigate some of these dynamics. The period in which there were major changes within the landscape structure was between 1875 and 1955, which witnessed a massive structural diversification throughout the study area, and that therefore, represents the period in which there was the greatest change of the total environment, with consequent increase in the complexity of the landscape. In 1955, almost everywhere, there was indeed an increase in heterogeneity in land use, especially in the northern side of the volcanic cone. Instead, along the southern side of the volcanic cone, there was a reduction in the value of SHDI. This spread of landscape diversification reached its peak in 1988, when most of the study area showed a value of SHDI $>$ 0. The difference of SHDI between 1955 and 1988 allows for the highlighting of two areas in which the dynamics of diversification of the landscape have been different: 1) the area of the volcanic cone and the south-western forest areas (where an overall reduction of SHDI has occurred) and 2) the central area around the lakes (where the landscape diversity has increased). Compared to 1955, in 1988 the absolute maximum values were recorded around the lake area. Finally, analysing the last period of study (1988–2013), it is possible to note that the values of SHDI generally increase slightly, while a reduction in the central area may be detected, that is a process that results opposite to the previous period.

3.4. Visual quality

Through a preliminary comparison among the various historical cartographies, a path able to retrace the network of panoramic roads within the study area has been identified. From this panoramic road network, the observation points which may be considered for the viewshed analysis have been extrapolated. It emerged that just over 68% of the study area has been visible from the panoramic roads, and the areas with the most visible portion of the landscape (the largest percentage of cells visible from the panoramic road) are the central ones, represented by the lakes and the inner part of the volcanic cone (Fig. 7). Although the scenic roads cover most of the study area, due to

Table 5/b
Cross-tabulation matrix—2nd Period: from 1955 to 1988 [%]. For land use classes acronyms, see Table 1.

1955/1988	BUILT	ARAB	FOR	LAK	RIV	GRAS	TRANS	AFFOR	CHEST
BUILT	**75.2**	8.9	0.6	0	0	2.2	10.5	2.6	0
ARAB	2	**72.7**	7.1	0	0	11.9	3.7	1.6	1
FOR	0.4	1.5	**83.1**	0	0	1.4	1.3	3.1	9.2
LAK	0	0	0.1	**98.2**	0	0	0	1.8	0
RIV	1.1	4	31	0	**42.9**	12.7	8.2	0	0
GRAS	1.7	19.4	33.7	0.4	0.2	**16**	8.6	14.4	5.7
TRANS	1.1	14.6	28.6	0	0	12.8	**10.2**	9.4	23.4
AFFOR	0.1	0.4	17.5	0	0	1.6	2.4	**28.7**	49.4
CHEST	0.3	0.7	11.5	0	0	1.4	3.5	1.4	**81.2**

Table 6/a
Cross-tabulation matrix—3rd Period: from 1988 to 2013 [Ha]. For land use classes acronyms, see Table 1.

1988/2013	BUILT	ARAB	FOR	LAK	RIV	GRAS	TRANS	AFFOR	CHEST	Tot 1988
BUILT	**61.4**	8	1.9	0	0.1	0.1	7.1	0.3	0.2	**79.1**
ARAB	24.7	**1699.3**	73.6	0	0.3	12.5	41.4	0.8	8.5	**1861.1**
FOR	12.4	60.1	**2669.6**	1.6	16.9	6.4	22.7	16.6	152.3	**2958.5**
LAK	0	0	0.4	**55.2**	0	0	0.3	0	0	**55.9**
RIV	0.1	0.9	11.4	0	**51.3**	0.1	9.8	0	0	**73.6**
GRAS	3.4	189.5	93.1	0	6.4	**72.9**	50.2	1.6	25.2	**442.4**
TRANS	3.3	42.4	106	0	6.4	4.3	**35.2**	4.2	13.7	**215.5**
AFFOR	2	1.4	113.3	1.3	0	0.2	4.6	**108.7**	24.7	**256.3**
CHEST	2.7	3	91.1	0.1	0	0.6	10.5	30.5	**624.9**	**763.5**
TOT 2013	**110.1**	**2004.6**	**3160.4**	**58.2**	**81.4**	**97**	**181.8**	**162.7**	**849.5**	**6705.8**

the territory landform, many areas are actually totally invisible.

On the basis of this operation, the maps showing the index of the quality of the visible landscape have been produced (Supplemental Fig. S2—a), as well as the overlay with the raster of the viewshed analysis (Fig. 7), of the weighed raster on the basis of SHDI and previously fixed land use values (Supplemental Fig. S2—b). The index of the visible landscape value that has been calculated considers above all the quality of the landscape on the basis of the portion of territory that is most visible. From the comparison between the general quality of the landscape of the study area and the quality of the visible landscape it may be noticed, in general, that areas with the highest index scores are, in many cases, amongst the most visible. At the same time, however, there are many areas with a high landscape value score that have a zero visible quality index, since their visual quality is not appreciable from the scenic roads.

In general, over the 138 years, there has not been a radical change in the aesthetic features of the landscape but only minor improvements or mostly worsening, with some of the highest values recorded in the year 1875. To get into the details of the analysis, we have created some maps highlighting the changes in visual quality for each subsequent step. Between 1875 and 1955, Fig. 8 shows a general increase in quality, even if the transformations of the territory around the lakes have determined an important reduction of the quality on a visible portion of the study area. In the subsequent time step (1955–1988) there has been a widespread increase in quality around the most visible area. Finally, in the last period, there have been no substantial changes in quality, only minimal differences in values having been detected: on the one hand, some higher values have been recorded in absolute terms compared to 1955 and 1988, while at the same time there has been a worsening, which appears much less obvious than the previous period.

4. Discussion

The results show that the landscape is almost completely transformed with respect to 1875. In fact, during the 138 years, there has been a critical loss of forests in favour of agricultural areas. From the analysis of the dynamics of conservation, afforestation and deforestation, it is evident that the areas that have been most affected by agricultural transformation are those with the lowest slope, at low elevation and with south-facing slope—likewise similar processes which have been registered in other territorial contexts of the Basilicata region (Statuto et al, 2017b). The period between 1875 and 1955 is one when major transformations occurred. In fact, if most of the forest areas (located in central and western part of the study area) have been replaced by pastures, cereal fields, olive groves and vineyards while, on the contrary, several agricultural areas and pastures which were located on the slopes of the volcano have turned into forest areas (Fig. 9).

The main reasons for this radical transformation of the landscape are to be found in the change in socio-economic conditions. In fact, in this period, there is almost a doubling of the population in the municipalities that fall within the study area (ISTAT, 2018); this has led to an increase in the need for usable agricultural surface, which has been derived from the deforestation of the most fertile and least steep areas of the territory. This process, also supported by public resources, continued until the 1960s years thanks to the land reform for Southern Italy—Law No. 841 of 10/21/1950. The only areas that have not been transformed are those at the valleys with surface runoff water flow.

On the contrary, in the eastern part of the study area, which corresponds to that of the volcano, there has been a process of afforestation that has affected, in particular, the areas with great slopes, which are difficult to exploit for cereal growing or other extensive agricultural activities. Furthermore, the very high naturalistic and touristic importance of the area is beginning to be recognised, so human activities have been reduced starting from the 20th century.

This afforestation process happened both naturally and artificially. In fact, the areas in correspondence of high-level water runoff have been reforested with non-native essences starting from the 1950s years, thanks to the activities expected with the land reform for Southern Italy. Furthermore, these areas were re-naturalised through the chestnut woods, which has been revealed as an important economic source for this area. The increase in the areas of chestnut forest has also led to an important change in the landscape, both in terms of landscape diversity and visual quality. As has been mentioned, the more visible change has occurred on the agricultural areas. After a first rapid growth, between 1955 and 1988, there has been a decrease, which has been widespread in all areas (almost 500 ha) of agricultural activities.

Table 6/b
Cross-tabulation matrix—3rd Period: from 1988 to 2013 [%]. For land use classes acronyms, see Table 1.

1988/2013	BUILT	ARAB	FOR	LAK	RIV	GRAS	TRANS	AFFOR	CHEST
BUILT	**77.7**	10.1	2.4	0	0.2	0.1	9	0.3	0.2
ARAB	1.3	**91.3**	4	0	0	0.7	2.2	0	0.5
FOR	0.4	2	**90.2**	0.1	0.6	0.2	0.8	0.6	5.1
LAK	0	0	0.7	**98.8**	0	0	0.5	0	0
RIV	0.1	1.2	15.5	0	**69.7**	0.1	13.3	0	0
GRAS	0.8	42.8	21	0	1.4	**16.5**	11.3	0.4	5.7
TRANS	1.6	19.7	49.2	0	3	2	**16.3**	2	6.3
AFFOR	0.8	0.6	44.2	0.5	0	0.1	1.8	**42.4**	9.6
CHEST	0.4	0.4	11.9	0	0	0.1	1.4	4	**81.9**

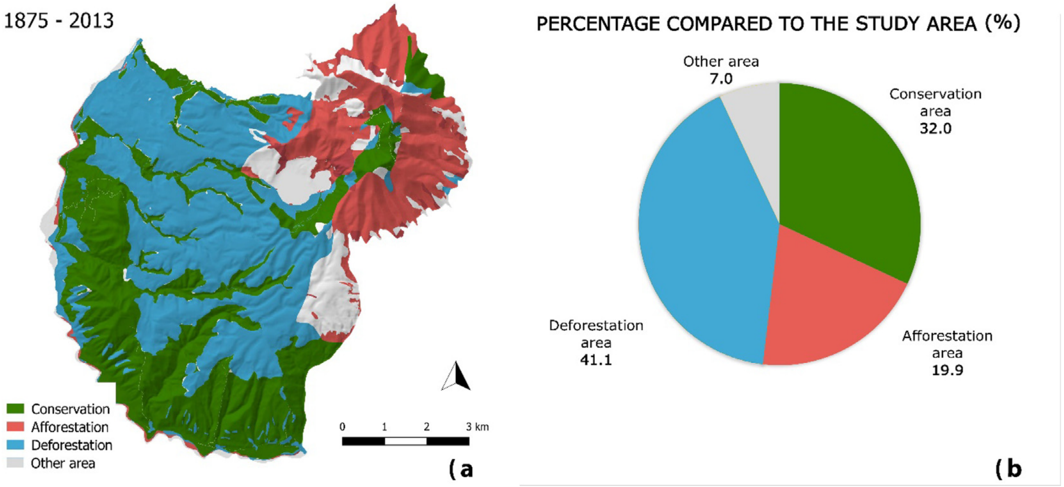

Fig. 4. Naturalness dynamic expressed in form of map (a) and pie chart (b) showing the conservation, afforestation and deforestation areas for the period 1875–2013.

This process of reducing primary agricultural activities and increasing natural and semi-natural areas has, indeed, been observed in many other mountainous areas of the Mediterranean region (McDonald et al., 2000; Lasanta-Martínez et al., 2005; Tortora et al, 2015; Pindozzi et al., 2016; Amici et al., 2017). Yet, unlike what happened in other areas, this process has not been progressive, because in the last analysis period (1988–2013), there has been a consistent stabilisation of the agricultural areas that have been abandoned in lower percentages compared to other similar land of Mediterranean region. This has been probably due to the strong agricultural vocation of this territory due to its high soil fertility gained by volcanic activity of the past, which allowed the establishment of highly profitable crops. A further confirmation of this process of permanence of agricultural land comes from the analysis of land use classes in 2013 in which secondary ecological successions (natural grasslands and transitional woodlands) occurred, which are quantitatively very small compared to the previous years. Even the persistence of arable land in some areas could have caused environmental problems. In fact, as summarised by Lasanta et al. (2017), the expansion and persistence of the agriculture in marginal slopes constitutes a case of environmental land use conflict (soil erosion, loss fertility, increasing in nitrate, etc.), which may have considerable impact on the total environment of this territory. Therefore, integrating techniques that correlate changes in land use with topographic variables (similar to those presented in this work) would highlight areas in which these problems could appear.

From the analysis of the landscape structure, it is possible to deduce that, after the radical changes between 1875 and 1988, the landscape has not diversified as much. Even from the analysis of the SHDI, it is possible to conclude that in the last period (1988–2013), the landscape has been stabilizing in terms of diversity. The areas with the highest values are those that have been most affected by transformation processes, i.e. areas where an important urban and industrial expansion has occurred, as well as areas around the lakes which have been affected by an increase in tourism activities and by a dynamic evolution of their naturalness. Therefore, thanks to this methodology, it has been possible to identify areas where the landscape is more fragmented and heterogeneous, as a result of the implementation of simple techniques of calculating the values of landscape metrics (McGarigal and Cushman,

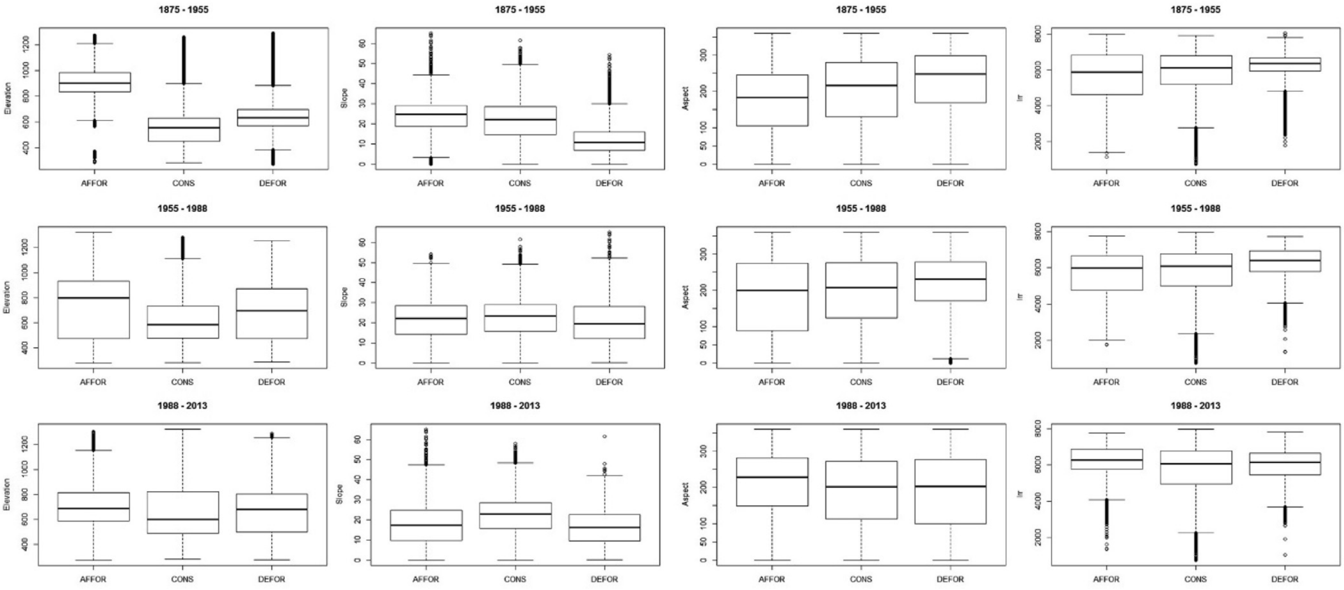

Fig. 5. Box plots of the relationships between topographical variables (elevation, slope, aspect and global irradiance) and conservation (CONS), afforestation (AFFOR) and deforestation areas (DEFOR) for different periods (1875–1955, 1955–1988, 1988–2017). Circles indicate outliers, horizontal lines inside the box indicate median value of variables, the bottom of the box is at the first quartile (25-percent of distribution), and the top is at the third quartile (75-percent of distribution) value and whiskers indicate variability outside the upper and lower quartiles.

Table 7

Average and standard deviation of topographical variables (elevation, slope, aspect and global irradiance) and conservation, afforestation and deforestation areas for different periods (1875–1955, 1955–1988, 1988–2017).

	1875–1955			
	Altitude (m)	Slope (°)	Aspect (°)	Global irradiance (Wh*m-2*day-1)
Afforestation	910 ± 131	23.6 ± 7.44	177.75 ± 91.82	5681.36 ± 1298.13
Conservation	571 ± 180	21.66 ± 9.13	201.35 ± 97.62	5854.18 ± 1224.1656
Deforestation	618 ± 135	12.10 ± 7.25	223.22 ± 97.44	6233.281 ± 694.35
	1955–1988			
	Altitude (m)	Slope (°)	Aspect (°)	Global irradiance (Wh*m-2*day-1)
Afforestation	743 ± 266	20.96 ± 9.31	184.66 ± 105.09	5662.39 ± 1292.20
Conservation	633 ± 220	22.37 ± 8.82	196.09 ± 97.47	5793.35 ± 1257.57
Deforestation	698 ± 245	20.06 ± 10.19	215.74 ± 88.91	6250.113 ± 914.78
	1988–2013			
	Altitude (m)	Slope (°)	Aspect (°)	Global irradiance (Wh*m-2*day-1)
Afforestation	703 ± 216	17.46 ± 10.24	210.54 ± 93.24	6166.03 ± 942.40
Conservation	652 ± 222	22.06 ± 8.75	191.75 ± 97.95	5769.87 ± 1255.74
Deforestation	668 ± 230	16.31 ± 8.38	192.17 ± 100.48	5940.29 ± 979.66

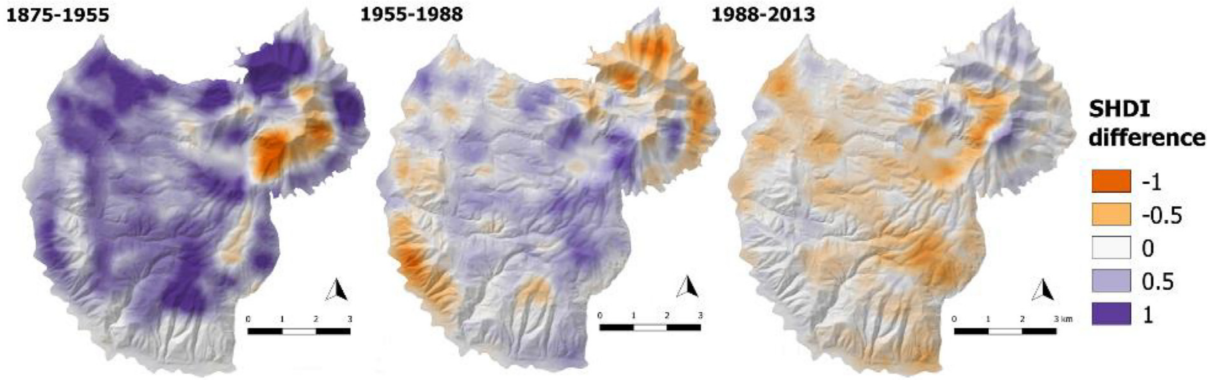

Fig. 6. Difference between Shannon's Diversity index (SHDI) values for the three periods analysed.

2005). The identification of these hotspots of landscape diversity can be the starting point for further deep analysis of the biological diversity and visual quality, including their relationship with landscape diversity. Indeed, the relationship between landscape diversity and biodiversity is a concept that is currently widely discussed in scientific literature (Wilson et al., 2016), as well as the relationship between fragmentation and aesthetic preference (Di Giulio et al., 2009). Moreover, from the analysis of the diversity of the landscape, it emerges that the less dynamic areas from the point of view of the transformation are those in which management and safeguard policies have been suitably implemented, i.e. that are zones in which protected areas have been established (e.g. Nature 2000 sites and natural reserves). These are the only lands where the processes of abandonment of mountain agricultural and pastoral activities typical of many Italian mountain regions were registered (Geri et al., 2010b). This led to a process of homogenisation of the landscape due to the loss of semi-natural classes (natural grassland and transitional woodland). The phenomenon of homogenisation of mountain areas can lead to the disappearance of habitats and species of conservation interest (Jongman, 2002). A good part of the protected areas are also those in which a certain degree of naturalness has been maintained in terms of persistent forest cover. Specifically, the areas in which the forest has been preserved for all the 138 years, as shown by the spatial and statistical survey, are above all the less accessible ones at higher altitudes, with a higher slope and with unfavourable exposure—all factors that prevented the development of agricultural activities or the increase in urbanisation (Statuto et al., 2019a). Considering the geo-location of the conservation area, it is noted that the entire extinct volcanic cone of Mount Vulture is currently covered by forests—a situation almost completely opposed to that which emerged from the study of historical cartography (1875) and which was confirmed by archival documents and artistic representations of the time.

Concerning the landscape visual quality, it is important to highlight that most of the area with the highest degree of naturalness, even if it has a high landscape value score (Supplemental Fig. S2—b), is not included in the map in Supplemental Fig. S2(a) because it is not visible from the scenic roads. This shows, as in other studies (La Rosa, 2011; Franch-Pardo et al., 2017), that landscape preservation and visual quality are two elements which are not necessarily connected, and that a similar approach to this work is finalised to better define and contextualise the rural landscape management as much as possible. The analysis showed that the area with the highest visual quality is located around the lakes. However, as emerged from the previous elaborations, it is also the area in which there were major anthropic transformations and diversification and which contains a part of the area with the greatest degree of naturalness. So, it is an area that needs a particular consideration, both from a nature conservation point of view and that of its valorisation. This last example demonstrates how the spatial analysis between different types of information can be useful to identify critical areas for landscape planning. Moreover, the decrease in the dynamics of landscape transformation, has also led to a minor change in the visible landscape value from 1988 to 2013. Finally, it is noted that

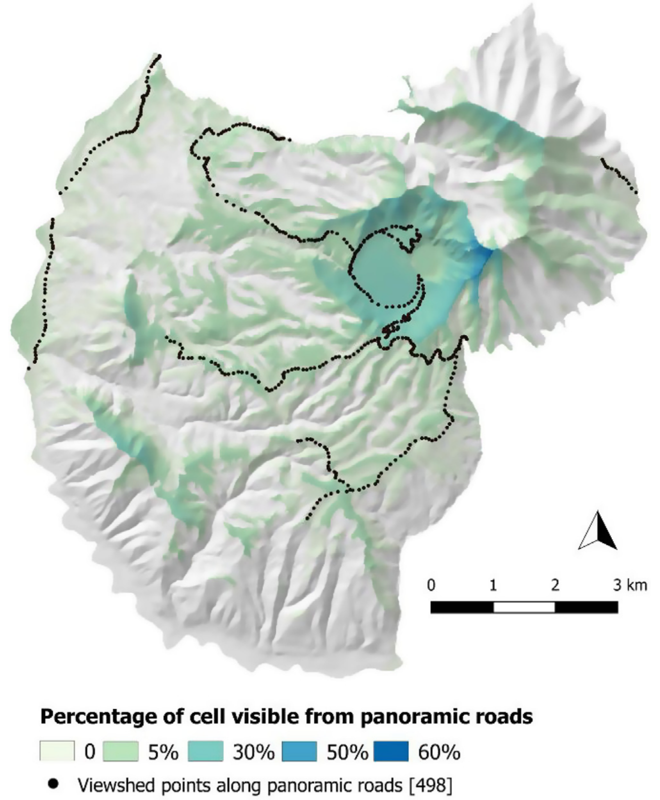

Fig. 7. Performed viewshed analysis starting from the Digital Surface Model (DSM) and points along panoramic roads. The result is expressed as a percentage of cell visible from these points.

most of the area of study is not visible (less than 5% of observation points) from the panoramic road, but this portion is also that one which has a lower landscape value due to the almost exclusive presence of arable land, anthropised area and low diversification in SHDI.

5. Conclusion

The study of the state of the components of the environment of a territory requires a holistic multidisciplinary approach since all of them may contribute to the analysis of the typical elements of the landscape. But if the "time" factor is included in this approach, this methodology can be suitable to understand how environmental modifications have influenced the landscape dynamics. The comparison of diachronic land use dynamics represents a direct, replicable and modifiable methodology based on survey parameters to quantify and spatialise the correlations between different systems and ecosystems (forest, agricultural and anthropogenic), especially in regions and territorial contexts where the interface between the natural environment and the rural land is very complex.

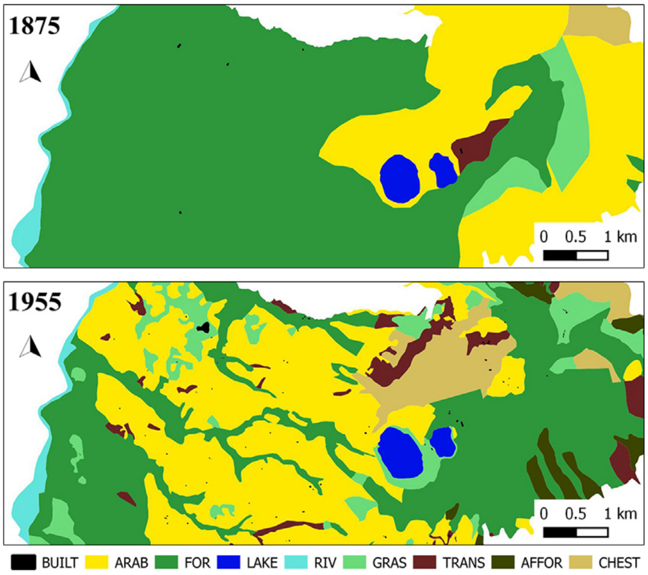

Fig. 9. Detail of the areas that have undergone major transformations in the period 1875–1955: the western and central areas with intensive deforestations for agricultural purposes and areas (eastern part), with simultaneous afforestation due to the abandonment of agricultural activities for naturalistic protection purposes, are clearly visible.

In particular, the analysis of the evolutionary dynamics of the rural landscape on space and time through the land use patterns is fundamental in the study of the naturalness, of the landscape diversity and on the visual quality. Indeed, the methodology here presented can be used in rural landscape planning, to monitor habitats of particular interest, or to design further improvements to the ecosystem services which they provide, taking into account the combination of natural and human environment, which are fundamental aspects for experts, practitioners, planners and managers involved in planning, constructing or restoring in a sustainable way the environmental systems. These arguments are complex, and the literature shows that there are different techniques

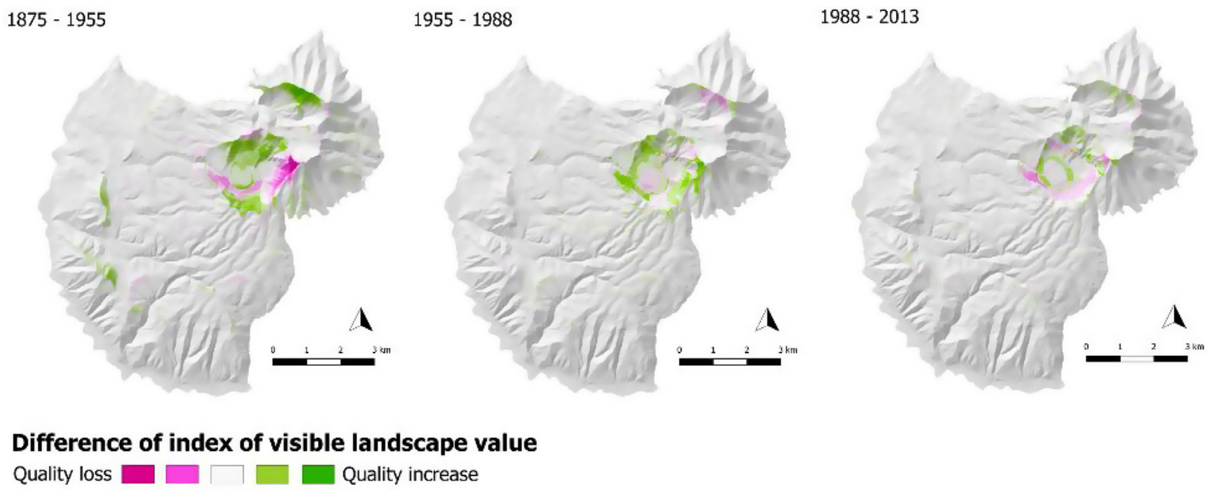

Fig. 8. Difference maps that highlight the increase or loss of index of visible landscape values.

and approaches to these issues, but what is clear is that the interactions between all physical, biological and human elements must be synergistically taken into account. The implementation of GIS tools is a suitable and efficient methodology, because it allows to include, both in space and time, different types of information, producing standardised procedures that can be modified according to needs as well. At the same time, the temporal comparison is often limited by the availability and quality of historical maps and the information contained there.

This study aimed to be an improvement to what has been analysed in previous works, proposing a multidisciplinary approach of a large area that includes some of the fundamental parameters for rural landscape analysis, so as to provide a useful methodology for landscape planning, able to mainstream all the components of the environment. This first attempt was based on the combination of direct and indirect landscape evaluation techniques because both the natural components of the environment and the perceptive and aesthetic ones have been considered and mapped in a GIS. Moreover, historical cartography has allowed the inclusion of the "time" factor in the methodology, which makes it possible to establish both the "how" and the "why" a rural landscape has been transformed so as to become as it appears in its present structure. The information levels that can be used in the future would be increased so as to further improve the proposed methodology. This GIS procedure can be of fundamental importance in areas, such as the one which has been analysed here, where the pattern is very complex, since a quality agriculture coexists with areas characterised by a high naturalistic value, in which there is a growing increase in tourist flow, as well as with extensive industrial areas. Thus, the proposed approach, joining information coming from the past with new cutting-edge tools, constitutes a method streamlining the use of both ecological (landscape diversity; naturalness; etc.) and engineering aspects (spatial/temporal planning; aesthetic characteristics; etc.) to design, monitor or restoring traditional rural ecosystems. This option appears to be of special interest for Mediterranean regions, in which a strong correlation between agriculture, nature and anthropological actions is a leading component of its millenary tradition, and where the need to better integrate the human society with its natural environment is urgently pressing, so as to contribute to the sustainability of the socio-economic management of its rural land.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoleng.2019.08.010.

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