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"NEW ADVANCED TECHNOLOGIES FOR SURVEY AND ANALYSIS OF AGROFORESTRY LAND: FROM LAND COVER CHANGES TO RURAL LANDSCAPE QUALITY ASSESSMENT"

Settore Scientifico-Disciplinare

"**Costruzioni Rurali e Territorio Agroforestale - AGR/10**"

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SUMMARY

The general objective of this Ph.D. thesis is to explore the concepts and methodologies for investigating agroforestry land and rural landscape through the integration of historical and remote sensing geodata within a FoSS (Free and Open Source Software) approach; to provide more and more accurate data sets regarding land cover and to improve some mapping and data processing techniques commonly used in this research topic. The first part of thesis describes the different types of geodata used in the course of the studies and, above all, the techniques and methodologies used for their processing are illustrated. Starting from historical cartographies, we will go through aerial surveys and geographical maps up to the new remote sensing using advanced satellite observation technologies. In the second part, more specific issues were dealt in accordance with the general objective of the work have been defined. The issues were approached through case studies within the Basilicata Region where the intensity of the abandonment of the territory and agricultural surface is leading to the loss of many historical rural landscapes and with consequent problems from an ecological point of view due to the disappearance of many agroforestry systems.

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L'obiettivo generale di questa tesi di dottorato è quello di esplorare i concetti e le metodologie per lo studio del territorio agroforestale e del paesaggio rurale attraverso l'integrazione di geodati storici e telerilevamento con un approccio FoSS (Free and Open Source Software); per fornire serie di dati sempre più accurate sulla copertura del suolo e migliorare alcune tecniche di mappatura ed elaborazione comunemente utilizzate in questo ambito di ricerca. La prima parte della tesi descrive i diversi tipi di geodati impiegati nel corso degli studi e, soprattutto, vengono illustrate le tecniche e le metodologie utilizzate per la loro elaborazione. Partendo dalle cartografie storiche, si passerà ai rilievi aerei ed alle cartogrofaie classifche fino al remote sensing basato su immagini satellitari. Nella seconda parte sono state trattate tematiche più specifiche in accordo con l'obiettivo generale del lavoro. Le tematiche sono state affrontate attraverso casi di studio all'interno della Regione Basilicata dove l'intensità dell'abbandono del territorio e della superficie agricola sta portando alla perdita di molti paesaggi rurali storici con conseguenti problemi dal punto di vista ecologico dovuti alla scomparsa di molti sistemi agroforestali.

1. INTRODUCTION

The modern society increasingly utilises the rural land in a great variety of ways and for many purposes, so highly valued landscapes having been developed during centuries, vanish or are completely transformed within a limited number of years (Vos and Meekes, 1999).

In the last decades, human activities, while altering the whole structure of ecosystems (Vitousek et al., 1997; Rescia et al., 2010), have also positively influenced the land transformation and 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 land 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 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 (Reidsmaet 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).

In fact, the importance of the Mediterranean agroforestry land is recognized at scientific level as a sustainable land management practice because it provides different ecosystem services, reduces direct anthropic negative impacts and a sustainable system of food production (Nair 1993; FAO 2013; Lasco et al., 2014; Burges and Rosati, 2018). Moreover, it plays a key role in achieving integrated and connected rural and urban development. In addition to having a high naturalistic value, the agroforestry land also has a huge value in terms of landscape, cultural and historical value as they are representative of many historical rural landscapes of the Mediterranean region (Pardini 2009; Moreno et al., 2018; Santiago-Freijanes et al., 2018; Hillbrand et al., 2018; Paris et al., 2019). Agroforestry land is traditionally a key element of landscape management. Complex systems, based on the integration of crop-livestock-fruit/forestry trees, have provided a wide variety of agricultural products and other ecosystem services (e.g. erosion control, biodiversity conservation and visual quality). Agroforestry systems have been used for centuries and are still managed in marginal and less profitable areas (Tortora et al., 2015), providing diversity in the structure of the territory in terms of composition, conformation and configuration (Udawatta et al., 2019). 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 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 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 land. It also emphasises a lot about the importance of landscape perception by the people.

To prevent these land problematic and loss of rural landscapes in Mediterranean region, it’s necessary to move through a careful and detailed land characterization in order to identify the critical elements for planning, protection, recovery and also valorisation activities. Moreover, it is necessary to obtain a large amount of data to monitor land transformations and develop strategies for a suitable management of natural assets (Pelorosso et al., 2009).

To this end, it seems necessary to implement an integrated operational methodology that takes into account the needs of land and landscape planning. Specifically, a multidisciplinary (Cullotta et al., 2011), multitemporal (Fichera et al., 2017) and spatial (Li et al., 2019) approach is essential in order to consider the landscape in a dynamic way and in its entirety. A multi-disciplinary approach is therefore essential for a complete land planning, in order to take into account, for example, both historical (Del Lungo et al. 2015), ecological (Mimet et al. 2016) and social dimensions (Buijs et al., 2006) over time. Therefore the study and planning of land and landscape requires studies and surveys that make use of different professional skills as many disciplines are extremely different from each other. Multi-temporal landscape analysis, on the other hand, is the process by which information from different periods, concerning the same territory, is compared to determine the location and nature of changes over time. It represents a powerful method of territorial analysis that provides an organic and complete vision of the territory, bringing useful elements for a correct reading of the origins of the current landscape and its vicissitudes. Moreover it could be useful to define potential land use change scenarios (Cervelli et al., 2017). The study of the relationships that man has established over time with the natural productive resources present in a given territory, allows to identify those factors that maintain a significant influence and that constitute the determining elements of a landscape (Blasi et al., 2002).

Finally, defining the spatial dimension is fundamental because, according to the scale of investigation, the interactions and hierarchies between the different systems and level of detail change and therefore require different methodologies and techniques of analysis (Martín-López et al., 2017).

In view of these issues, within the ELC, the actions to be taken by the member states to assess the changes taking place in the landscape and its dynamics have been drawn up (Council of Europe, 2000). But in order to realize them, it is necessary the systematic implementation of monitoring and the adoption of specific methodologies and indicators that can be valid tools for planning purposes. However, even if the topic is of fundamental importance, there are still gaps in the scientific literature and the tools and data commonly used to assess land characterizations often have limitations.

In general, field data are rarely used because they are spatially limited and have temporal limitations and applicability to very large scales (Gillespie et al., 2008). The most used approaches are those that use Geographical Information Systems (GIS) as a catalytic tool for different types of geodata and methodologies (Acutis et al., 2014; Blanco et al., 2018; Nanna et al., 2018), such as, landscape metrics and remote sensing (Scarascia-Mugnozza et al., 2008; Fan et al.; 2016; Amici et al., 2017; Badjana et al., 2017).

Especially when multitemporal land cover geodata are needed, a GIS-based approach is essential. This provides for the integration of several types of data, often very varied and requiring different pre-processing and elaboration techniques. This is possible using historical maps together with other types of cartography and aerial photos, that allows to recover territorial geodata for very long time periods. Even if complex to manipulate and with some errors, they are indeed the only source to process spatialized land cover and land use data, especially when changes are relevant (Amici et al. 2017). In addition, the inclusion of geodata from new generation satellite imagery is essential, since the spatial and temporal resolution ensures a highly detailed land cover mapping (Van Tricht et al., 2018). In addition, they can provide ancillary or predictive information that are essential for the investigation of many spatial and landscape issues, such as biodiversity and the impacts of intensive agriculture (Valerio et al., 2020; Lanorte et al., 2017; Rocchini et al., 2018).

Therefore, the interoperability of GIS tools, represents a fundamental instrument that can simplify the planning activity, both in the initial phase of landscape characterization and in the management and monitoring phase, thanks to the possibility to implement methodologies that can support the decisional activity. Going into even more detail, the current technological evolution allows to approach these issues in a "free and open source" way with both economic and social benefits (Steinger et al., 2009; Steiniger et al., 2011; Muenchow et al., 2019)

1.1 General objective

In this context the general scope of this work is to explore the concepts and methodologies to assess and survey the agroforestry land and rural landscape through the historical and remote sensed geodata integration within a FoSS (Free and open Source Software) approach to provide increasingly accurate datasets regarding land cover.

In the first part of the work, the different types of geodata used in the course of the studies are described and, above all, the techniques and methodologies used for their processing are illustrated. Starting from historical cartographies, we will go through aerial surveys and geographical maps up to the new remote sensing by satellite observation cutting-edge technologies.

The study areas chosen fall within the Basilicata Region (Southern Italy) where the intensity of abandonment of land and agricultural area is leading to the loss of many historical rural landscapes and with consequent problems from an ecological point of view due to the disappearance of many agroforestry systems. From a biogeographical point of view, it has many characteristics common to other areas of the Mediterranean, so the techniques used, in addition to providing methodologies replicable in other territorial contexts, have been useful to provide new datasets useful to understand the dynamics of land transformation.

1.2 Specific objectives

In the second part of this thesis, according to general scope, the following specific objectives have been defined:

- 1° IMPACTS OF HUMAN ACTIVITIES ON THE AGROFORESTRY ENVIRONMENT

Work on case studies on which to apply integrated techniques of diachronic analysis of land cover changes that take into account both historical cartography, aerial photos, orthophotos and satellite images

Case studies:

- “Forenza” municipality (Italy – Basilicata Region)
- “Vulture” Regional Park (Italy – Basilicata Region)

- 2° RELATIONSHIPS BETWEEN RURAL LANDSCAPE AND FARM BUILDINGS

In this section, the interactions between rural buildings (vernacular and new one) and the surrounding land have been examined through two geospatial approaches and as many case studies.

- Geospatial approach to inferring the relationships between historic farm buildings and agroforestry landscape
- Remote-sensed geodata and historical maps to assess interactions between rural buildings and rural land

- 3° RURAL LANDSCAPE QUALITY ASSESMENT

In this part of this Ph.D. thesis, two case studies are illustrated. The first one shows a detailed approach that can be used and implemented on a large scale and on sub-regional portions of land, for example, to monitor and plan at the level of protected areas or areas of landscape interest. The second one, on the other hand, concerns a small-scale approach that is implemented at a regional level and allows for a wider planning:

- Historical landscape visual quality: a case study in Vulture area
- A set of indicators to assess landscape visual quality: a first approach for Basilicata region

Part I

New advanced technologies for survey and analysis of agroforestry land

2. LAND SURVEY AND ANALYSIS USING FoSS APPROACH

The core of any spatial and landscape study is based on land cover and/or land use data.

The terms "land cover" and "land use" are often used erratically as synonyms (Fisher et al., 2005). According to FAO (1998, FAO; UNEP, 1999), the land cover is the globe’s surface section defined in space and recognized in terms of characteristics and properties included by the features of biosphere, which are reasonably unchanging or cyclically predictable. These features include: air, soil, geological substratum, relief, hydrology and the results of interactions with human activity. Land cover is related to the biophysical state of the Earth's surface and its immediate subsurface. It is composed of natural elements, such as vegetation, water, ice, bare rock, sand and similar surfaces. Comber et al. (Comber et al., 2005) point out that the term was expanded to include anthropic structures such as buildings or paved areas. The land use, on the other hand, can be interpreted as the way in which space is occupied by human society - that is, or human activity directly related to the land. Land use refers to the way in which it is used by the local human population (Lambin et al., 2000). It is composed of anthropic activities related to an area of land, with the intention of obtaining products and benefits with resources. In other words, it relates to socio-economic functions - e.g, agriculture, housing, environmental protection areas, among others (Heymann et al., 1994). In brief, land cover is "the observed physical and biological cover of the earth's land, as vegetation or man-made features." In contrast, land use is "the total of arrangements, activities, and inputs that people undertake in a certain land cover type"

Land use (LU) and land cover (LC) information is a powerful advantage for various studies and analyses, such as the measurement of physical and environmental accounts, the determination of indices related to welfare, assessment of human impact, monitoring of habitats and related ecosystem services, landscape changes etc… (Turner et al., 2005). Updated data on land characterization and its distribution are essential for the efficient management of agricultural and forest resources. Land use and land cover mapping contributes to the link between the physical environment and the socioeconomic one. It is essential in environmental studies, decision-making in planning and design of the territory, and the definition of natural resource management policies (Wright, 1982). These land cover data can be used as input for a variety of models (meteorological, ecological, biochemical, economic, hydrological, etc.) to monitor biodiversity, run climate models and assess environmental changes such as deforestation, desertification and urban expansion. Moreover, LC maps are one of the most powerful geospatial products able to measure the indicators for the 17 Sustainable Development Goals (SDGs), defined in the 2030 Agenda for Sustainable Development (United Nations, 2015). The study of spatial and landscape dynamics is mainly based on geodata on land use and land cover from different sources and inventory techniques. In fact, each typology has a usability scale that it is good to know before using them in one's own investigations. Indeed, data are often selected without explicitly considering the suitability of the data for the specific application, the distortions arising from inventory and data aggregation and the effects of data uncertainty on assessment results.

While recognizing differences in data sources and the causes of inconsistencies, several methods have been developed to optimally extract information from the data and document the uncertainties. These methods, as indicated, include data integration, improvement of validation techniques and harmonisation of classification systems. For some types of data, including those used on a global scale, recommendations on use are produced. For example, these include: better documentation using classification systems for land use and coverage data; careful selection of data due to specific application and use of appropriate scaling and aggregation methods. In addition, data availability can be improved by combining different data sources to optimise the information content, while additional data collection should focus on the validation of available data sets and better coverage of regions and land cover types with a high level of uncertainty. Specific attention in data collection should be given to the representation of land management (systems) and mosaic landscapes. In these kind of surveys, appropriate recording of the type of cover/use data should follow a standard classification system, aiming to facilitate photointerpretation and comparative analysis. These guidelines, proposed by Verburg et al., (2011), represent the preliminary actions that should be implemented primarily to any spatial and landscape study, both on a local and global scale.

Furthermore, it must adopt the most compatible scale with the level of detail that you want to get to. But if on a global scale, there are many data available, while on a local scale and for detailed studies it is often necessary to create your own datasets at a larger scale of detail starting from different types of cartography or data plotting. In the case of detailed surveys, such as maps at the local level, the survey is usually based on aerial photographs, orthophotos, satellite images, and sometimes on fieldwork (Veldkamp et al., 2001).

Sources for land use/cover data

The most used ground cover data are remote sensing and in particular those collected from aerial photographs, unmanned aerial vehicles (UAV) and satellites. Remote sensing is based on the reflection of a radiation at a certain wavelength. The reflection is related to the coverage of the Earth's surface which does not always reveal the intended use of the ground. However, the ground cover in combination with spatial structures and additional attributes can, to a certain extent, allow the use of the land to be derived.

But to recover the land cover data that can be used within the several software, it is necessary to interpret these images. For their interpretation and extraction of remote sensing data, there is a wide variety of approaches ranging from completely automated, to semi-automated, to simple visual interpretation (Richards et al., 2006). Completely automated approaches, i.e. the processing of data from images using machine learning algorithms, have the advantage of fast processing allowing high time resolution and replication, which is particularly useful, for example, for monitoring rapid deforestation on a global scale (Asneret al., 2009). Supervised classification techniques and visual interpretation allow the integration of specialist knowledge, training samples, field observations and pattern recognition (Siren et al., 2009), but also introduce an element of subjectivity that makes interpretations dependent on the user (Foody, 2002). This, especially for manual interpretation, can cause replication problems and therefore change the detection, but in some cases, as for historical maps, the classification at a very high level of detail and in the professional and planning field, represents a widely used methodology. Certainly, the integration of the different methodologies makes it possible to compensate for the errors and disadvantages of each technique and allows a more accurate classification.

Besides land cover and land use remote sensed detection, less used but equally important, it's possible to retrieve geodata from topographic maps or map-based on field surveys (Wagle et al., 2020), census data (Aalders et al., 2006) or everything that falls within the field of historical cartography (Tortora et al., 2005).The most used maps are the topographic ones that, during the last two centuries, have been made for military o regional land government purposes by different national military agencies and organizations. These topographic maps show geolocalized plan details and elevation details, i.e. the two-dimensional representation of reliefs using contour lines. These maps represent the detailed relief of the terrain in association with various information related to water bodies (lakes and watercourses and runoff areas), forest cover, administrative areas, road network and buildings, and other artificial features. Also textual information (in particular place names) have a considerable importance in landscape study and reconstruction. These maps are an important primary source of information for any inventory, planning and implementation of land-related development projects as they possess a wide variety of information. In fact, derived/administrative maps can be made from them, thematic maps and maps of terrestrial resources and large-scale maps are necessary for development, administration and statistics at national level.

Census and survey data are other commonly used land cover and use data source. In particular, many countries and international organisations collect statistical information on agricultural land use types as part of an agricultural census. Besides cropping surfaces, sometimes they include management information such as irrigation, fertilizer application rates, crop yields, forestry statistics and economic parameters. Therefore, census information is highly suitable to provide land use information which can never be collected through remote sensing. However, most census data is focused on economic sectors, and ecological information is often not included. In addition, data are often aggregated to the level of administrative units, while the original data are not available as result of privacy legislation.

Of great interest and of which the use is increasing are the participatory maps (Larrain et al., 2019). Finally also cadastral maps (Kain, 2010), with many differences from country to country, can provide useful information for the study of the landscape and territory.

All types of land cover and land use data sources have both positive and negative aspects, so it is important for those involved in land and landscape studies to know all characteristics in order to find ways to integrate the positive one and minimize errors.

Currently, the concession and use of this data has moved from a system of payment or temporary consultation with public bodies, to a system almost exclusively free and/or open, thanks to the evolution of legislation and thanks to the digitization of information that can be easily conveyed by computer systems via web. In particular, the current state confirms that openness has changed the way in which geospatial data are collected, processed, analyzed, and visualized and this has also had a positive impact on spatial and landscape analyses.

Open data issue

The *Open Definition* (2019) describes knowledge as open "if someone is free to access, use, modify and share it - subject, at most, to measures that preserve provenance and penance". This definition, derived from the Open Source Definition (2019), which is specific to software, advances the idea of a common good based on access to information from which everyone can benefit. There is no doubt that the geospatial domain holds the potential to play an important role in achieving this open digital revolution, as more and more geo-referenced data is produced every day - e.g. by sensors, including sensors for citizens (Foody ad al., 2017) - and geospatial technology has become a dominant trend in a multitude of domains.

It’s possible to identify three kind of open data (Coetzee et al., 2020).

Many open datasets emerged from the need to collaboratively collect data. Involving volunteers with local knowledge in geospatial data collection is an effective crowdsourcing mechanism (Fritz et al., 2017). Globalization and modern technologies, such as the Internet, smartphones, the Internet of Things (IoT), and satellite imagery, have led to global initiatives that do not rely on local knowledge only; today, a global community of data collectors contributes to a wide range of open datasets, many with global coverage (Brovelli et al., 2020).

Another kind of open data or knowledge is rooted in the principle that some information should be shared and available to anyone without any restrictions to rights of access or use. Here the focus is not on the collection of data, but on the sharing of data collected by authorities. Generally, transparency and collaboration are well aligned with the principles that democratic governments stand for and with the principles embodied in the Charter of the United Nations (Open Definition, 2019).

Finally, there is open scientific data where research results are shared to encourage verification of research findings and/or integration of research results to produce new findings. There are similarities between collaboratively contributed open data, authoritative open data, open scientific data but there are also differences and sometimes both apply to a particular dataset.

By focusing on the latest type of open data, these allow others to verify, confirm or reject scientific claims. This is ensured when science is understood as an open enterprise, where scientific data is open and freely accessible, universities support and reward open data publication and the community requires open and public access to scientific data and methods. As reported by Wilkinson et al., (2016), the four foundational key concepts aimed at guiding producers and publishers toward improving the sustainable use of digital resources (e.g., data, software, facilities) are: Findable, Accessible, Interoperable, and Reusable (FAIR). Implementing FAIR key concepts in publishing increases the value of digital resources and their reuse by humans as well as machines. In general, FAIR principles apply to digital capitals regardless of their public availability and do not require these resources to be open. However, as specified as best practice in open science, FAIR and open should be considered as complementary by data experts, and resources produced from public funds need to be as open as possible and only as closed as necessary (European Commission, 2018). Several scientific journals promote the paradigm of science as an open enterprise and confirm the new standard of production of open scientific data. For example, in January 2019, the journals *Nature* and *Scientific Data* approved the initiative to enable FAIR data in the earth, space and environmental sciences. This means that publications will be published in these journals only when the related supplementary material is submitted to an open scientific data archive and FAIR. Moreover, government administrations are creating infrastructures for sharing scientific data (Stall et al., 2019; ScienceBase, 2019). In the field of landscape, environment and land study, free and/or open data are essential to carry out multidisciplinary and multitemporal studies.

Free satellite images such as Landsat, MODIS or Sentinel, are increasingly used also because they offer a wide range of options and possible applications. Moreover, the fact that they constantly provide images at the same spatial and temporal resolution guarantees standard elaborations that are highly relevant in territorial and ecological studies (Turner et al., 2015).

But freely accessible data can also be orthophotos, cartographies, aerial photos or even data in thematic vector format. Their availability and level of "openness" depends on country to country. In Italy, for example, it is possible to use some geodata freely available from the National Geoportal (PCN, 2020) or those provided by individual regions. For the Basilicata Region (RSDI, 2020), one of the most innovative geoportals is available at national level, where a multitude of geodata are provided in a totally open format and with a specific "Italian Open Data License v2.0" (IODL, 2020). This open data license allows (only mentioning the source) users: to reproduce, distribute to the public, lease, show in public, transmit and retransmit in any way, perform, represent, include in collective and/or composite works publish, extract and reuse the Information, create a derivative work and exercise on this the rights referred to in the previous point, for example through combination with other information (mashups).

2.1 Available surveyed geodata for land cover and landscape analysis

Among the several data sources mentioned above, those that are most widely used and that have been the subject of in-depth analysis in this study are: historical cartographies; aerial surveys and geographical maps; remote sensing by satellite observation.

2.1.1. Historical cartographies

The use of satellite images alone would imply a study period limited to about 40 years, so it is necessary to use "old" cartographic or historical aerial photos data referring to different historical periods in order to trace the dynamics of transformation over time of the territory from different points of view (anthropic, agricultural and naturalistic). Moreover, the studies in which the land use dynamics for the Mediterranean area have been reconstructed are limited both in terms of spatial extent (often covering only a part of a given territory) and time. Many studies, based only on aerial photographs and topographic maps, cover a time span of 60 years (for example, some studies are reported: Pelorosso et al., 2009; Geri et al., 2010; Ripa et al., 2013; Statuto et al., 2017; Pindozzi et al., 2016; Statuto et la.,2016; Amici et al., 2017).

If we consider the landscape as a visualization of the cultural and historical-environmental heritage of a given territory in which any sustainable landscape management policy should be the result of a complex construction (Quaini, 2010), historical cartography can contribute as a primary source to an understanding not only "horizontal" of the landscape (configuration and conformation of the structural mosaic), but also "vertical" (processes and dynamics). In fact, historical cartography is one of the representational elements (together with texts, writings, etc...) through which it is possible to reconstruct not only the persistent and/or permanent signs of past territorial settlements, but also the actions of landscape modelling, and therefore imagine both interventions of protection/conservation of geographical objects with identity value, and reactivation of resources through good planning practices of innovative management of the landscapes concerned (Dai Prà, 2013).

It is in the field of applied geography that the geo-historical survey can provide the greatest contribution in terms of sustainable land management and historical-environmental heritage, as proposed by Quaini (2010). The fragility of Italy's rural landscapes has led to the development of a specific demand for "applied historical geography" to develop new documentation practices and promote new management perspectives both locally and nationally; this demand can be read in relation to the exponential emergence of central themes such as land and country in the debate on governance, as well as the refinement of methods and concepts useful for their better understanding, preservation and management. Concepts that historical geography can address by consolidating its theoretical and interpretative paradigms and working side by side with historians, archaeologists and botanists as well as with other disciplines such as urban planning, architecture, agronomy, etc.. (Dai Prà, 2018)

Nowadays, maps and historical photos not only have a scientific role but are now essential for planning and programming purposes. In this sense, it is sufficient to consider Landscape Plans, i.e. the operational tools that regulate the actions of protection, governance and transformation of the territory, defined by Italian Legislative Decree no. 42/2004. The study of historical cartography represents a fundamental phase of landscape analysis and to elaborate the contents of the Plans based on <<… *historical, natural, aesthetic and interrelationship characteristics" necessary to define the landscape values to be protected, recovered, requalified and enhanced.* >>. The use of eighteenth-nineteenth-century maps, or twentieth-century aerial photos, to assess changes in land use and cover and other landmarks of landscape is now an integrated phase in the studies not only of the Regional Landscape Plans, but also of the cognitive frameworks of the Municipal Landscape Plans and even preparatory work for large-scale restoration work on individual historic farms (Guarducci et al., 2016; Gabellieri et al., 2015). Similarly, the initiative aimed at creation of a large Catalogue of Historical Italian Rural Landscapes (Agnoletti, 2010), promoted by the Ministry of Agriculture and Forestry with clear intent to identify the rural heritage, has used aerial photogrammetry and cartography as privileged sources to assess the "significance" of individual landscape data. But, like any historical source, it needs to be properly contextualized and analyzed, in order to be able to critically grasp the limits and potentiality of the information contained.

Before the use of any historical cartography, it is good to make cartometric surveys on them. The term "cartometry" refers to that part of the cartographic sciences that deals with problems related to the geometric-cartesian measurement of maps. In fact, not every historical cartography has been produced with the intention of representing as faithfully as possible the geographical space, distances and geometric proportions; in some cases the distortions have been made intentionally, to graphically emphasize some elements of the territory. Therefore, as far as surveyed and drawn up with accuracy and precision, it can be assumed that each of them contains a certain degree of error, due to the imperfect surveying techniques or the different coordinate system used, and that its overlap with the current maps is not extremely precise. To solve this problem of the map support, the classic georeferencing is not always effective, and in some cases the process may worsen the result, increasing or altering the distance between the various pixels of the raster due to the transformation algorithm. Before identifying and analyzing the metadata inscribed in each map, it is therefore necessary to evaluate its reliability, in terms of both geodetic and planimetric accuracy. The definition of "geodetic accuracy" describes the reliability of a map in the current global coordinate system, in relation to the reference meridian, the projection and the model of the ellipsoid of the Earth. The "planimetric accuracy", instead, identifies the degree of accuracy of the distances, magnitudes and amplitudes of the angles shown on the map in relation to those of the real world. So preliminary cartometry operations are essential to try to estimate the degree of error in the historical map. This is possible through the analysis of its mathematical and geographical characteristics; the process includes the determination of the coordinates (geographical, polar, etc.) of the various points, the measurement of distances, surfaces and angles or the evaluation of orientation (Markoski, 2018). The results of this analysis therefore move in two different directions: on the one hand, they can support historical research in assessing the degree of technical development achieved by the cartographers of a given product; on the other hand, they allow to determine the reliability of a cartographic document and the location of its metadata (Jenny et al., 2011). The method of analysis and digital visualization of the planimetric accuracy of a cartographic source is based on a series of geometric transformation algorithms that are applied to some anchor points that join the ancient map with a current one as a comparison. These algorithms produce as a visual result the distortion of the map at the mismatched anchor points, and statistical and geodetic measurements of the map characteristics, such as scale, rotation angle and projection system. A software that allows you to do this is MapAnalyst; this open-source application in Java is equipped with interactive tools both to compute distortion grids, error vectors, and to calculate the scale, rotation angle and centroid of the historical map image (Jenny et al., 2007).

Considering the characteristics of each historical cartography, a different approach is needed for each one in order to assess its usability and to reduce the errors that can result from manual or semi-automatic digitisation. In fact, for a correct land use analysis with this methodology, several aspects have to be taken into account, such as: definition of the minimum mapping unit (Burnett et al., 2003), the impossibility to verify the thematic attribution to the different cartographic elements (Bailey et al., 2007) and the different resolutions to which the elaborations are made (Turner et al., 1989). But, on the other hand, the use of maps obtained from the manual digitization of historical cartography represents the only possibility to retrieve information about the spatial configuration of the territory in the past (Geri et al., 2010, Statuto et al., 2017/a).

However, the key point of the research on the historical cartographies is primarily to collect them. The skills to find such materials, which are scattered across numerous libraries or archives around the world, is essential, and it determines whether it will be possible to undertake the planned research at all. To find an object in a digital library or archive successfully, appropriate metadata should be provided. Metadata are the key to resource discovery and the use of any collected document. Despite much experience in this field, most institutions do not register map-specific data in the metadata, which is required to support map searches, although scientists emphasize that consistency is an essential aspect of the quality of metadata, including maps and atlases. Moscicka et al. (2020), metadata profiling of archival maps have proposed, which is based on the ISO 19115-1 standard and contains map-specific information, which should be saved as metadata to provide the proper characteristics of the old maps. This tool can be useful both in research and cataloguing historical maps, but it could also be a way to describe and present the historical maps used in international scientific work.

2.1.2. Aerial surveys and geographical maps

One of the first forms of remote sensing data is represented by historical aerial photos, which allow to retrieve an enormous variety of information related to land cover. They also provide a set of basic data for qualitative and quantitative analyses of the landscape over time more complex and accurate than the use of classic historical or topographic maps (Morgan et al., 2010). While other types of sources containing spatial information are rarely generated in series with the same characteristics, aerial photos produced continuously and frequently since the 1930s can provide information on land management for almost a century. For this reason they are a unique source to map the directions of landscape change and assess its evolution over the medium term at various scales, from the topographic scale (e.g., to identify individual trees) to the regional scale to identify the landscape schedule and its changes over time.

Their production, which varies from country to country, began during the Second World War period for military purposes and, until the 1970s when satellite images began to be produced, it was the only product that could be used for territorial and landscape analysis. Due to some technical limitations, processing difficulties and partly also their accessibility, the use of historical aerial photographs is still limited and often relegated only to scientific fields, but it represents a very valid methodology for landscape and territorial reconstruction activities for the period before satellite images (Tomscha et al., 2016). But, this resource has been used in a number of scientific fields, and its importance has increased in recent years to address questions involving long-term changes in socioecological systems. As presented by Pinto el al., (2019), almost 260 scientific papers, between 1990-2018, discuss historical aerial photographs and most of them in environmental/ecology applications were carried out (50% in USA and 29% in European studies). Certainly the limited use of historical aerial photos is given by the technical difficulties of processing. In particular, the greatest limitation is given by the effort required for the accurate orthorectification and georeferencing of the photos, so that they can be compared and integrated into GIS.

In addition, orthorectification is a complex process that involves a number of errors, since historical ground control information, calibration certificates and precise or even basic knowledge of the camera parameters are often not available. Moreover, aerial images present the same problem as topographic maps: the process of embedding Earth surface into a plan introduces distortions, because we are forcing a rugged and curved surface to fit on a two dimension flat plan; furthermore, photographs are sensible to the atmospheric conditions and light exposure. Geometric errors alter the perceived position and size of some feature: tilt displacement is due to inclination of the focal plan with respect to the ground and relief displacement is due to a change in elevation.

In general, these processes, which fall within the scope of photogrammetry, until a few years ago were difficult to access for GIS users, who needed to use other types of software that were often not interoperable.

Finally, the digitization of aerial photo information presents further challenges in territories undergoing transformation processes, due to the dramatic changes in land cover that can occur over time, which makes it difficult to find adequate ground control features that can be used for classical georeferencing through comparison with modern digital orthoimagery. Moreover, being almost exclusively in black and white, photointerpretation is not immediate and needs to conform with other types of cartography of the same period. Because of these technical issues, there is not yet a standard and fully automatic methodology for the digitization of historical aerial photographs.

From the literature analysis provided by Pinto el al., 2019, several different approaches to extract information from historical aerial photos were implemented.

Some works have used a simple approach concerning only relative orientation of the aerial photos rather than geographic placement and orthorectification, which provides a quick solution when limited spatial resolution is enough to identify changes. These studies have generally dealt with stable areas over time, usually urban or man-made landscapes, with change analyzes usually performed on small spatial expanses or at low resolution. Other studies from the literature search used previously orthorectified images or only georeferenced images, but provided little information on image processing. In other cases, the camera information (metadata) was complete and available, but often there was no reference to the orthorectification process itself. More details are usually provided in technical studies dealing specifically with remote sensing, with several authors describing feature-based recording methodologies for historical aerial image orientation and orthorectification, such as the use of TIL (Time-Invariant Lines) or OBIA (Object-Based Image Analysis) processes. An interesting approach based on the use of a single FOSS GIS environment for both orterectification, georeferencing and land cover classification is the one proposed by Gobbi et al., 2019.

Through specific GRASS modules, it is possible to realize the internal and external orientation and the final orthorectification with limited errors (about 10 meters) even of those aerial photos that do not have calibration certificates.

In addition, with different GRASS modules, it is possible to perform a semi-automatic classification of ground cover through OBIA algorithms, implemented on the basis of the characteristics of each individual aerial photo. Every single operation that leads to the final ground cover map, besides being modular and therefore calibratable according to technical requirements, it is possible to incorporate it into a single workflow in order to digitize a large number of aerial photos in less time (FIGURE TO DO). However, sometimes the manual classification of historical aerial photos represents a more immediate and accurate solution. This depends both on the objectives of the study and the characteristics of the individual frames. This approach (Gobbi et al., 2019) certainly represents a facilitation for GIS users as it allows the use of different photogrammetric and geospatial techniques in a single working environment. Regardless of the classification methodology chosen, a fundamental step is the photo-interpretation of the elements of the territory. Photo-interpretation requires various stages of work and reading; initially normalized for manual and analogic reading, this approach has remained similar with the introduction of new technologies and GIS tools (Morgan et al., 2010). The first step is the delimitation of polygons, to create a gradient on the image to delineate homogeneous areas with the same characteristics: for example arable land, buildings, wooded areas. The second step is the classification: the characteristics of each polygon must be interpreted and classified according to predetermined categories. In this phase, the reading of the photo can be facilitated by the knowledge of the area and observations of the terrain. These operations can be complicated by a series of problems that can compromise the interpretation and analysis, such as geometric or displacement errors (position inaccuracy, high incidence of oblique angle of shooting or magnification/resizing effects due to the lens used by the camera, radiometric errors or incorrect representations of the image color). The use of a single GIS software to manage the different phases of aerial photo processing, also allows to integrate ancillary data useful both in the georeferencing phase and for the classification of the land cover. In fact, it is also possible to combine aerial photos with topographic maps that have been created from aerial photogrammetry operations on the same aerial photos. In fact, as in the works subsequently illustrated, in order to improve the quality of the data obtained, for example from the GAI (Italian Aeronautic Group) flights of 1954/1955 made in Italy, it is possible to use the IGMI (Italian Military Geographic Institute) cartography of the same years which also provides information on the land use and cover.

Currently, even in this case, the use of geographical and topographic maps is not very present in studies in which landscapes of the last 30/40 years are reconstructed due to the constant and extensive use of satellite remote sensing data. But thanks to their geographical precision, in level of detail and accuracy given by the ground surveys, they represent a baseline of fundamental data for the study and characterization of the landscape. Moreover, thanks to the presence of textual elements such as toponyms, they provide countless useful information for the study of social, historical and cultural aspects of the territory. Moreover, since there is the altitudinal component thanks to the presence of contour lines, it is possible to relate the land cover with the topographic and morphological aspects both for qualitative surveys but also for the three-dimensional reconstruction of landscape, useful both for the simple production of 3D maps and for analysis related to visual and aesthetic aspects.

2.1.3. Remote sensing by satellite observation

The interest in knowing more about the Earth's coverage and how it has changed over time motivated the mission and the design of the sensors of the first remote sensing systems. The rapid developments in computer hardware and software over the last forty years have significantly increased the ability to acquire satellite data, downlink, transmission and applications for the end user. The repetitive coverage of satellite images and the improvement of image quality can provide valuable assistance in the identification of land cover changes. Temporal and spatial resolutions allow scientists to monitor and detect changes over a broad scale and help planners to obtain or maintain information on various phenomena, such as shifting agricultural patterns, crop stress, disaster monitoring, land use and landscape changes.

Since the launch of the satellite Landsat-1 MSS in 1972, a variety of remote sensing platforms (e.g. satellite, aerial) have collected data in the form of image observations. Each sensor gathers imagery at a pre-defined spatial resolution, which denotes the ground measurement that each pixel represents in an image. Spectral resolutions vary based on the wavelength intervals that the sensors are collecting reflectance of the sun on the earth's surface. The temporal resolution of a given remote sensing platform is derived from its orbital path and speed, which determines the satellite's revisit rate for collecting a new image in the same location. Sensors currently in operation include optical sensors from NASA's Landsat program, optical and synthetic aperture radar (SAR) sensors from the European Space Agency Copernicus constellation, and many other public and privately owned airborne and space borne systems. Researchers are able to choose their remote sensing sources based on their research questions, whether they use sources such as unmanned aerial vehicles (UAVs), active sensors like light detection and ranging (LIDAR), field-based spectroscopy, cross-boundary satellites.

In the review work of Crowley et al., 2020, the use of remote sensing for landscape analysis purposes were reported. A primary focus of remote sensing research is to develop methods for converting remotely sensed data into a meaningful description or picture of what is actually on the ground. This is referred to as "classification" of the remotely sensed data. Several recent advances have greatly improved algorithms used in classification. For example, object-based image classifications group neighbouring pixels into objects and classify the objects based on their shape, size, color, texture (spatial variation), and context (neighbouring or ancillary information). Machine/deep learning approaches (e.g., convolutional neural networks, random forests) are automated classification algorithms that rely on minimal user interference when classifying imagery. Additionally, time-series analyses have been used to map land cover changes by stacking images from multiple sources and identifying disturbance patterns and deviations from expected values. This allows the rapid detection of landscape change and disturbances like forest loss and fires. Time-series analyses have created reliable global-scale landscape change datasets that are freely available for subsequent analyses. For example, a regularly updated forest cover dataset including landscape changes and drivers of changes is available annually for the entire globe. Additionally, the World Resources Institute's Global Forest Watch initiative detects forest changes globally in near real time. Other recent studies have used time-series analyses, machine learning, and object-based image analyses to analyze land surface temperatures and identify urban heat islands, to provide increased data to support forest inventory efforts, to map landscape changes related to climate change, to inform precision agriculture, to monitor air pollution, to quantify colored dissolved organic matter in lakes, to quantify aboveground bio-mass, and to track urbanization.

The major general characteristics of remotely sensed images that drive for a large part their application in landscape study are (Groom et al., 2006): spatial and temporal coverage, subjectivity-free data and standardization.

A key feature of the relationship between remote sensing and landscape analysis is the spatial extent of information collection that remote sensing makes possible. This is most notably associated with satellite images, with many examples of individual image scenes that cover areas extending over tens and hundreds of kilometres. Much satellite imaging operates globally, irrespective of borders, so given the large number of nation states within Europe, each with its own history in surveying and mapping, the relevance of satellite images for harmonisation of Europe-wide landscape work is also significant.

Compared to other major sources of spatially extensive information for landscape ecology, such as field data collection or map products, remote sensing provides significant possibilities for frequent data capture. Spatial-temporal analysis of landscapes often can only be done through the use of remotely sensed data, and archive images represent a major opportunity to re-visit the landscape of the past. Aerial photographs, which are stored in many national archives from at least the early 1930s, represent image contributions in the temporal domain with a long history, while imaging from Space plays a significant role from the 1970s. Furthermore, within the temporal domain provided by many satellite sensors, with repeat periods of between 15 min and a few weeks, it is also possible to undertake ecological work concerning the monthly, seasonal and yearly dynamics of landscapes.

Two important data collection methods are field survey and use of topographic maps. Notwithstanding their significance, both these methods have limitations. Field data collection is time consuming, often difficult to undertake and expensive. Potentially more problematic, existing map data may be readily available but represent a highly abstracted and filtered representation of the landscape. For example, a topographic map is a cartographic product and is the result of applying a specific set of rules of what features within the landscape should be mapped and how they are represented. This means in general a strong simplification of reality. Working with remote sensing images is therefore seen as a means that has the potential for capturing landscape information through the use of a data source that is effectively free of human abstractive processes. The visual impact of remote sensing images as pictures of how the landscape actually is operates highly effectively. This is particularly so with photographic image data (such as aerial photography) in which the general level of detail seen is close to that which might be noted in a live viewing. Moreover, in many types of field surveys, the synoptic information provided by remote sensing images can help in preparations for efficient fieldwork.

As with any technique for making physical measurements, it is important for their use that the individual data are comparable. Moreover, this is a fundamental requirement for a technique such as remote sensing, that is largely based around visualisation. Thus, most remotely sensed datasets are characterised by high levels of internal data standardisation. Image data standardisation is also normally based upon fundamental physical principles, enabling the calculation or estimation of many land surface properties such as moisture content and biomass. Data standardisation is particularly the case for satellite remote sensing, with control possible over parameters, such as illumination and viewing angles, that can otherwise result in aberrant data values. Standardisation is also present with respect to the principle way by which remote sensing data are provided, i.e. as rasterised data in widely usable computer file types.

Nowadays, the increase in the availability of open and free data of several space platforms has led to an increase in the use of satellite images in landscape and land studies. Freely available remote sensing data from satellite sensors with large spatial coverage has become available in the last 10 years. For example, in 2008, the free and open Landsat data policy was implemented, and in 2014, the first sensor from the European Space Agency’s open-access Copernicus mission was launched. With increasing data availability for large-area coverage and medium spatial resolution sensors like Landsat and Sentinel, there has been a dramatic increase in research using satellite data in the last 5 years (Zhu et al., 2019).

3. LAND COVER AND RURAL LANDSCAPE ANALYSES

3.1 The free and open GIS environment for integrating geodata

Geographic Information Systems (GIS) are increasingly used as the main "tool" for the digital exploration of landscape variations, as they provide the necessary functions for the collection, management, analysis and representation of spatial data. As landscape deals with the interaction between landscape structure and function, landscape dynamics and ecological processes over a wide range of spatial, temporal and thematic scales, it involves gigantic amounts of spatial data to represent diversity, complexity, heterogeneity and hierarchy of the ecological systems. GIS not only has the advantage in collecting, processing, storing and managing spatial data, but also provides a very effective platform for anchoring comprehensive multi-level spatial analyses and various mathematical models. GIS provides an effective means of understanding the landscape spatial structure and dynamics, especially the complex relationships between physical, biological, and anthropogenic processes (Yu et al., 2019).

As in other working area, also in the geospatial field, several organizations are considerably increasing the adoption of open source software, and the last decades have seen significant progress in this direction (Coetzee et al., 2020).

The use of proprietary GIS is still adopted, because it can meet the requirements of functionality, customization and extensibility, and can also have a low price. However, they typically do not meet the research requirements in terms of implementation (of algorithms) and distribution/application of newly developed models, as the original software is needed to make the model work. The reason for not meeting these requirements is to be found in the software licenses that are applied by companies that offer proprietary software. Therefore, we argue that GIS software that could meet the proposed requirements should be distributed with licenses that guarantee greater freedom of use and support openness, such as the licenses used by FoSS GIS projects (Steiniger et al., 2009).

Over the last years the paradigm of FoSS development has taken root in the GIS community, resulting in the creation of several very sophisticated GIS software projects, whose aim is to develop free software for numerous purposes, ranging from Internet map server applications (e.g. the MapServer project), and spatial database management systems to store geographic data (e.g. PostGIS), to desktop GIS for data editing and analysis (e.g.; QGIS, SAGA, etc.). Here, the term 'free software' is not used in the sense of 'free-of-cost software'. Rather it addresses the freedoms of the user to freely use, study, modify, and distribute. The history of open-source software in GIS domain started in 1980s with the first version of GRASS GIS the first versions of GRASS GIS which was released by the US Army Construction Engineering Research Laboratories. Moreover, another important project that definitively sanctioned the success of the geospatial open source field was MapServer (https://mapserver.org/) developed by the University of Minnesota for web mapping.

Today, there is at least one mature, sophisticated open-source software product for every geo-technology area and geospatial application—from data collection in the field, crowdsourcing, data processing, analysis, modelling and simulations, spatial extensions to database management systems, visualization, web mapping, that can be integrated within a software stacks (see examples in Figure 2, Figure 3 and Figure 4). Together, they can be used to create sophisticated free and open Web and cloud-based systems. Based on a not recent, but still valid, survey by Steinger et al. (2009), the most important free and open desktop GIS software that are suitable for GIS tasks in landscape analysis and have reached a mature stage of development to provide sufficient GIS functionality for the creation, modification, analysis and integration of different geodata are: GRASS GIS, QGIS, SAGA GIS, gvSIG.

The choice of a software based upon Free and Open Source philosophy (such as GRASS) allows the final user to access the source code behind every module (Neteler and Mitasova, 2008). It is worth noting that full access to the program code represents a major advantage with respect to a proprietary solution: the possibility of checking every step of an algorithm is useful to guarantee the appropriate robustness of the output (Rocchini et al., 2012). Futhermore, it is possibile to modify the procedures and the algorithm according to the user requirements, provided that personnel with sufficient programming skills is available (Ciolli et al., 2017).

However, in addition to a typical GIS (Desktop) that can serve all these purposes simultaneously, there is a wider range of geographic information tools (GI tools) that serve only one or a subset of these tasks. In fact, thanks to these new tools, it is possible to create a complex GIS structure in a free and open environment that could provide enormous advantages to those who deal with large-scale landscape and land planning (Yu et al., 2019).

Moreover, considering that geospatial data and tools are becoming ubiquitous in all scientific disciplines, industries, governments, and communities, GIS tools are becoming more and more widespread thanks to the association with open-source data science languages, modelling and simulation platforms, virtual reality engines, machine learning, and web applications. For example, R (https://www.r-project.org/) has recently established itself as one of the main open source data science languages in the field of remote sensing and geospatial science, relying on its well-established support for geo-referenced data processing and a wide range of spatial analysis tools. As far as programming languages are concerned, Python is the leading scripting and programming language for both proprietary and open source geospatial software (Coetzee et al., 2020).

This ecosystem of GIS software communicating with each other and therefore interoperable, is allowing a better, simple and efficient integration of spatial data, i.e. the process in which different geospatial datasets, which may or may not have different spatial coverages, are made compatible with one another. In land and landscape studies, integration procedures are fundamental because the data that are generally used are generated by various sources and different stakeholders, and they correspond to different locations and times. Sometimes, in consideration of the different types and origin of spatial data, we are faced with different formats that until some time ago needed different software for management and transformation and often implied a loss of accuracy or quality. Now, thanks mainly to open and free tools, many types of spatial data can be processed within a single software.

3.2 Historical and remote sensed geodata in an open-source GIS for rural land studies: a brief review

The study and analysis of the land deals with a more general and vast field, but when one enters into the details of landscape studies, the research field becomes more detailed and specific. To this concept, a wide range of meanings and interpretations formulated by the most varied disciplines is attributed, from human sciences to physical sciences, with a semantic ambiguity not only lexical but also cultural, that makes it difficult to identify a single and exhaustive definition. This also affects the methods of study and representation through modern geographical technologies. This presupposes that, before defining the tools and techniques, it is necessary to define the scope within which to define the rural landscape (Gambi, 1961).

For those who deal with geography, in fact, the landscape is a historical construction, with its own stratigraphy and dynamics, and only a fully interdisciplinary and diachronic method can therefore lead to its full understanding.

In the works and studies carried out in this thesis, it was preferred to use the broader term "rural landscape", meaning the visible and material expression of the complex agro-sylvo-pastoral systems that have developed for centuries in various forms.

The landscape elements of the rural contexts that can be implemented thanks to a historical GIS are therefore summarized in the use of land and plant cover, in the particle mosaic, in the road and road network, in the settlement, in the agricultural artefacts and arrangements and in the hydro-morphological elements; elements that in turn are the expression of certain historical processes linked to the use of the territory by the local communities.

A diachronic GIS on rural landscapes integrating historical and remote sensed geodata can provide a more detailed information base than a traditional qualitative reading based on topographic maps, allowing to superimpose different raster or vector layers related to sources of different periods, as well as integrating for each vector element different information such as land use, owner, soil quality, cadastral value. As a result, it can be used for quantitative analysis of landscape changes in the long term and to read the dynamics of transformation; to help interpreting the changes occurred by anthropic or natural dynamics; to support the decision-making process in landscape and rural heritage management and planning. The fundamental question for a historical geographic information system dedicated to the rural landscape is how it can be elaborated in order to assign a value to the diachronic process. If we consider the landscape as a topological variation of land cover, it is possible to identify certain units based on the various ways of anthropic use. In this case, GIS allows to build a land use map, to compare it with similar documents produced by different periods and sources, to integrate this information with those derived from a Digital Elevation Model

(DEM) such as altitude, and to calculate the percentage of each type of land use (Grava et al., 2020).

The old maps sometimes are dated back several centuries and are valuable for studying long-term land-use history and vegetation dynamics. Their utility is growingly recognized and in the scientific literature there are already several works that make a combined and integrated use of historical cartography and remote sensing data. As examples, Cousins (2001) combined non-geometric historical maps with aerial photos to analyze land use/land cover change in south-east Sweden. Haase et al. (2007) analyzed multiple old topographic maps for Saxony, (Germany) to track landscape changes and tackle contemporary environmental issues. Fuchs (2015) incorporated historic statistics and old topographic maps into reconstructions of land cover/land use for Central Europe back to 1900. Liu et al., (2018) showed that the lack of reliable and explicit historical data on land use and land cover could be partially filled by using historical maps.

The use of old maps to fill data gaps not just brings prospects to land change research but also presents some practical challenges. Foremost, old maps are diverse in nature and are incompatible with modern digital maps in terms of map projection, survey methods, spatial details and scales, and thematic representation (Loran et al., 2017; Schaffer et al., 2016). Map distortion is difficult to quantify and rectify, even with many ground control points. The geometric correction may be invalid for local features, which is of no concern for coarse-level analyses but problematic for fine-scale analyses. Further, unlike remote sensing imagery that records true physical signals, old maps are secondary—sometimes, subjective—representations of spatial objects. Their interpretation needs expertise, caution, and even educated guesses. This is particularly true if metadata are lacking or information desired is rendered only implicitly in the old maps. Currently, old maps are predominantly analyzed manually (Pavelková et al., 2016). Uncertainties exist regarding how modern image analysis techniques can facilitate the information extraction from old maps. Overall, large gaps still remain in research on the integrated use of old paper maps and modern digital imagery for land change analysis, urging for more cases studies, especially those focusing on fine-scale landscape characterization.

Part II

From land cover changes to rural landscape quality assessment

In order to present the wide variety of documents that can be used, singularly or preferably crossed with each other, for the diachronic analysis of rural landscape and land contexts, the following chapters are sructured in such a way as to show the different potential applicatons related to the digital processing of different sources, such as historical maps, topographic maps, thematic maps, orthophotos, aerial photos and satellite images.

The idea, starting from some study areas in the Basilicata region, has been to implement a standard methodology for processing the different images present at different levels, through a free and open system, so as to make these resuls available first of all to the scientific community, then secondly to the decision-makers of public bodies that deal with monitoring and protection of the landscape and rural territory as well.

4. IMPACTS OF HUMAN ACTIVITIES ON THE AGROFORESTRY ENVIRONMENT

The new advanced geographical technologies, the increasing availability of satellite data, the open data made available at different levels by public authorities and the European community and the need to provide large-scale analysis, mean that in the scientific literature most of the work concerns studies and analysis at regional or national level. This involves the use of data at such a scale as to provide preliminary and general investigations and an evaluation of global phenomena and processes. The concept of "scale" in land and landscape studies is fundamental. In fact, the representation of land properties and ecological processes is closely linked to the scale of analysis. These scale dependencies suggest the need to integrate scale effects into landscape research (Moody et al., 1995; Cullinan et al., 1992). This is mainly due to the scale of the datasets used, which, at the level of global or subnational studies, can not have a scale too large due to the processing time. On the other hand, the local scale implies a more detailed analysis, and therefore, leads to a much greater knowledge of the land.

For this reason, which deals in particular with landscape and territory, the question arises: what is the appropriate landscape scale to study that given process or phenomenon? Minang et al. (2015) addressed the problem by reasoning on two practical levels: the choice of scale on the basis of the phenomenon or what scale considerations are necessary to facilitate decision-making and multi-stakeholder actions in landscapes. The authors themselves, in order to solve this issue, proposed three dimensions of scale that can be considered; but the best approach seems to be the one where no single scale is sufficient for comprehensive analysis and for facilitating processes and planning. It should be recognized that cross-scale procedures and relations are just as important and perhaps more significant than the scale itself.

Assuming these concepts, for this reason in the thesis are presented both at a regional and a local scale in order to evaluate the processes and phenomena of transformation and territorial and landscape characterization at different levels.

To assess the different types of impacts of human activity on the rural environment, two case studies at local scale were analysed. Clearly, many small scale methodologies can be translated for large scale ones using datasets at a greater level of detail.

It was decided to carry out the study on two case studies, for different reasons: even if they are part of the same administrative region, they are located in different territorial and landscape units; they all present the problem of the process of abandonment of the territory, but with different characteristics and speed; to explore different techniques based on the basic datasets that can be used.

For each of the different case studies, in addition to common methodologies and preliminary operations, it has been evaluated how the different impacts of human activity have affected the rural environment using different approaches and types of investigation.

The case studies can be summarized as follows:

- "**Forenza" Case Study**: a methodology for analyzing the evolution of the rural landscape is proposed, exploiting a multitude of different types of data, starting from historical cartography to remote sensing images. The objectives of this study were to understand the driving forces (anthropic and natural) of landscape changes, as well as to analyze rural landscape dynamics in terms of land cover changes and landscape metrics. The starting point has been the historical cartography, which allowed this possibility. Furthermore, modern technologies can also evaluate the current state of the rural landscape; in particular, aerial phothos, orthophotos and satellite images can deliver ecologically relevant, long-term datasets suitable for analysis of changes in ecosystem area, structure and function at temporal and spatial scales with the aim to monitor both the natural and artificial dynamics of the rural landscape.

- "**Vulture" Case Study**: in this part of work, some land cover 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. 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.

4.1 “Forenza” case study

4.1.1 Study areas

The study area (Figure 1) is located in the Basilicata region (Southern Italy). It spans about 18 km^2, covering one part of the Forenza municipality (40°47′57” N 15°51′39.4” E, datum WGS84). It is about 5 km away from the urban centre, a hilly area often characterized by high slopes, forests and other semi-natural areas. The study area is part of the hydrographic basin of the Bradano River, which crosses the area from the northwest to the southeast for 6.5 km; after 2 km it flows into the Acerenza’s dam, then continuing its course towards the Ionian Sea. The altitude of the area ranges from 450 to 920 m above sea level (a.s.l.). The soil composition has, in turn, determined the topography of this area, which has influenced the socio-economic context through relevant agricultural activities. Considering the thermo-pluviometric data of the weather station located in Forenza, the annual rainfall is 660 mm in average (Hydrological Annals of Ministry), distributed into 86 rainy days with higher values during autumn and winter. The mean annual temperature is 12.8°C, the average monthly temperature is lowest during January with 3.4°C, whilst the hottest month is August with a monthly average of 22.8°C.The territory offers employment mainly in agricultural activities, many farms present in this area have livestock and cereal crops. The largest profit comes from cattle breeding and in particular the production and sale of dairy products. Moreover, fodder, olive groves, orchards and vineyards cover the hilly territory. The wooded area is located in the San Giuliano area. The forest communities encountered are typical of the phytoclimatic area

Castanetum and *Quercus-Tilia-Acer*-mixed deciduous forest belt of Schmid. At lower altitudes, the vegetation characteristics are similar to those of the Mediterranean basin, while those at higher altitudes of the mountain are typical of the sub-mountain belt. With nearly 4000 ha of wood, Forenza is one of the municipalities with the largest wooded area in the whole Basilicata region.

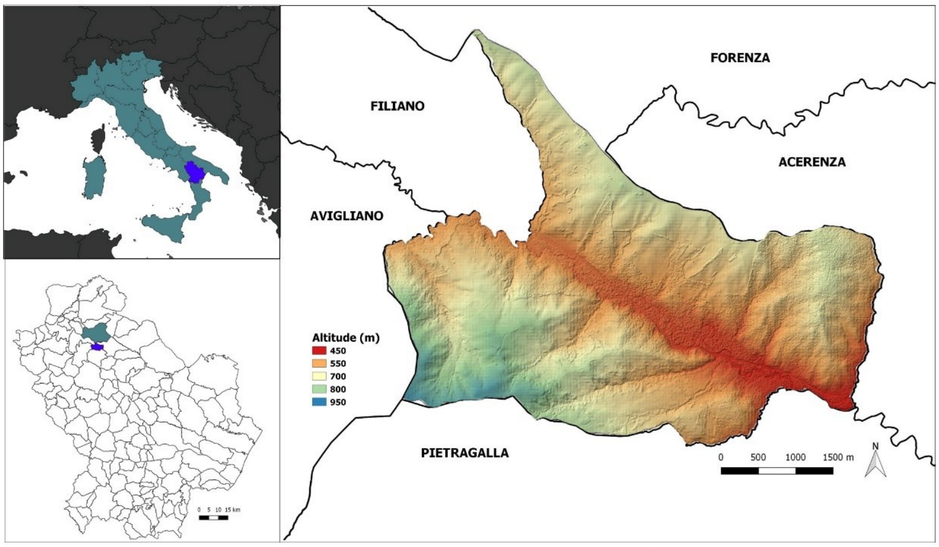

Figure 1: Location of study area (right) within Basilicata region (left).

4.1.2 Materials and data processing

A preliminary collection phase of archive documents, historical and digital cartography, remote sensing images and realization of specific thematic maps has been performed. All preliminary cartographic processing, land cover classification of satellite imagery and spatial analyses have been conducted using free and open-source GIS software (Statuto et al., 2015). The analyses were carried out by integrating archive documents, historical cartography, topographic maps, thematic maps, management plans, aerial photographs, orthophotographs, open data and Sentinel-2A remote sensing imagery, covering a period of 188 years (from 1829 to 2017).

Several land cover maps were produced, through post classification comparison technique, providing complete matrices of change directions. Finally, to identify areas where the landscape has evolved naturally, a map of areas has been manually realized through spatial analysis tools, and compared in different times during the 188-year period. For this study, the development of specific GIS techniques, which integrate historical and digital cartography, are fundamental and allows the analysis of land use changes and to understand the factors able to drive the transformation processes of rural landscape and then to plan possible recovery intervention (Tortora et al., 2015; Statuto et al., 2017).

The land cover classification was carried out in six different time steps: years 1829, 1875, 1955, 1988, 2008 and 2017. Given the different kinds of data, various techniques have been used to process the specific cartography for each period and to elaborate land cover maps that are standardized and comparable. This approach is followed due to the availability of high diversity of professional open-source software packages and the importance of open access and data sharing in general to earth observation (Petras et al., 2015). The first part of the study concerned data collection and processing of different cartography in order to produce land-use maps for the years of analyses. All operations were carried out with QGIS software (QGIS Development Team, 2020) and some of its plugins. For each type of data, a different analytical approach was followed.

1829 historical map

The historical map was produced after border disputes in year 1829 by legal experts to solve division of domains (Statuto el al., 2016). Similar maps were realised in the whole Southern Italy, as a result of the abolition of feudalism. These maps were drawn using legal documents and diplomatic sources, which showed the land use rights, and surveying on the ground (Figure2).

This historical map was manually drawn and represents part of Forenza municipality (San Giuliano’s Wood). It constitutes a complete cartographic support, integrated with thematic information about the land use at that time. In particular, the area was divided into two parts, assigned to the municipalities of Forenza and Acerenza, the division was realised according to land surveying techniques of the period. The author used ink on paper and watercolours to report cartographic toponyms, boundaries and other information about rural landscape elements at that time; the interpretation of the written text and different symbols is the only way to detect the land use because there is no legend. Units of measurement are expressed according to the system in force into the Kingdom of Naples, and the scale corresponds to about 1:12,000. An artistic representation of compass rose displayed the map orientation.

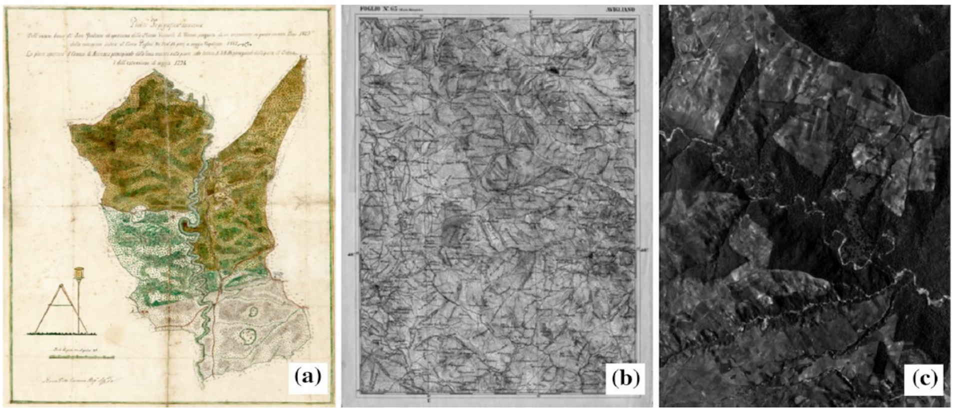

Figure 2: Three different kinds of historical data used: (a) map of 1829, (b) cartography of 1875 and (c) aerial photograph of 1955

The analysis of land use is based on the next described operations: i) chromatic differences between the territory of Forenza and Acerenza municipalities (Black and white range); ii) hydrography is coloured in light blue. The contour lines of river course are jagged and marked by a green colour; they symbolise riparian vegetation (*Salix caprea, Salix fragilis, Salix purpurea, Populus alba*) and also watersheds; iii) forest is represented as some tree-like symbols irregularly distributed. Different density of pattern is correlated to the type of forest management. In fact, areas with a lower density of symbols represent woods exploited for human activities (pasture and firewood). Moreover, these are not covered by green colour, typical of other forest covers of map: i) the orography is not included in the map because there are not contour lines expressing elevation; ii) road network is pictured into two different ways: main streets are larger, well defined and characterised by specific marks, whilst the small road network is marked by a green colour which symbolises margin vegetation; iii) farms and other rural buildings have been reproduced considering their real aspect; various building types (farms of different sizes, a church, a butcher shop, caves and corrals) can be distinguished indeed.

This map reports, around the farms, the presence of agricultural land, coloured in a yellow colour, and the name of some farm districts. The evaluation through chromatic differences was possible thanks to the comparison of other similar historical maps (same period and surrounding areas), which had a more detailed description. In addition, from historical documents, some useful information were obtained, linked to the realisation of the map. They can be considered as ancillary data, able to better describe the historical situation.

The paper map has been digitized in .tiff format at 300 dpi resolution. The digital version has been imported into QGIS for the next georeferencing phase. After an accurate evaluation of the topographic defects and the limits of the map, points common to an already georeferenced cartography were used (Regional Technical Map of Basilicata Region, 2013). Through an iterative process, the best ground control points (GCP) and the best coordinate transformation algorithm (GCP) were chosen, to guarantee a root mean square (RMS) of less than 100 meters. Thanks to a second order polynomial transformation, it was possible to reach an RMS value around 20 m (Brovelli et al., 2012) and also allowed a visual accuracy assessment, thus validating the georeferencing. Visual accuracy of the historical maps of 1829 has been assessed with the help of MapAnalyst, an open source Java application (Jenny et al., 2011). MapAnalyst calculates the mean position error (MPE) and the standard deviation (SD), that is, the mean deviation error, for all the control points on the historical maps. The lower the MPE and the SD are, the more accurate the old map is. The map has been reported to a datum UTM/WGS84 33N-EPSG: 32633.

The georeferenced raster images were converted into vector maps through a manual procedure finalised to digitise the polygons relative to the land cover classes. The characteristics of the historical map did not allow the realization of semi-automatic classification procedures. Considering the characteristics of the map, a manual classification of the map was carried out.

1875 historical topographic map

The historical map of 1875 —also stored in the same State Archive of Potenza (Figure 2)— is a topographic map created by the Italian Military Topographical Institute (currently converted into the Italian Military Geographical Institute) to create a complete mapping of the Italian territory after its national unification. Geodetic surveying and topographic evaluation were highly accurate, and the ITM decided to immediately print some drafts using a photolithography technique. This cartography consists of 174 sheets, the study area being located into Sheet no. 65—Avigliano, eastern part. The scale of the map is 1:50,000 and the altitude was represented with contour lines having an equidistance of 10 m, and elevation of the highest areas. 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 (Bonne projection) was identified. In particular, it had been assumed as the origin of the coordinate system, the intersection of the meridian passing through the Astronomical Observatory of Capodimonte (Naples) and the 40th parallel; 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, differently from other works that have used this cartography (Tortora et al., 2013; Pindozzi et al., 2016), it has been possible to speed up the geo-referencing of entire sheets, improving their accuracy as well. This improvement in ITM's topographic map elaboration technique certainly represents an important advancement in the state of the art and could allow a better and more accurate mosaic operation of all the sheets and therefore create a fundamental and geographically accurate document for the reconstruction of what the territory looked like in that period. Moreover, thanks to the availability of numerous toponyms and an accurate representation of the road network, this cartography allows the realization of historical surveys of considerable importance. Finally, the presence of contour lines also allows the three-dimensional land reconstruction, useful both for qualitative surveys through virtual landscape representation (Statuto et al., 2016) and for quantitative surveys on, for example, topographical profiles (Tortora et al., 2015).

The georeferenced raster images were converted into vector maps through a manual procedure finalised to digitise the polygons relative to the land cover classes. The characteristics of the historical map did not allow the realization of semi-automatic classification procedures. Considering the characteristics of the map, a manual classification of the map was carried out. Both historical maps (1829 and 1875) can be freely consulted and used for study and research purposes.

<u>1955 Historical aerial photos</u>

For the classification of the 1955 ground cover, two black and white aerial photographs were used (Figure 2). These are areas taken after the World War II by IGMI with the collaboration of the USA Army Map Service and Italian Aeronautics Group. Each one of these photos was shot in May with focal length of 152 mm (Fairchild camera), the size of the photo is 230×230 mm, the flight altitude is around 6000 m, its approximate scale is 1:33,000. The quality of the survey allows an accurate assessment of land cover. Currently IGMI still holds the rights for original data, but every Region of Italy acquired the digital version of these frames and it is possible for everyone interested to access the data.

After digitizing at 800 dpi, an orthorectification and georeferencing was performed. Orthorectification is the process of modifying the geometry of an image to make it compatible with a carthographic projection. This procedure is performed in three steps: internal orientation to evaluate the position of the image with respect to the camera; external orientation to evaluate the position of the camera with respect to the external reference system; orthorectification to re-project the image. To perform the first step it is necessary to measure and identify the position of 4 or more fiducial markers on the original photograph. To perform the second step is necessary to set a consistent number of Ground Control Points, or points whose coordinates are known in both the reference systems of the original image and the target reference system. Finally the re-projection is performed using a set of equations, called collinearity equations, which rectify the original image by shifting, rotating and scaling each one of its pixel (Novak, 1992). A DEM (Digital Elevation Model) which describes the geometry of the ground surface must be available.

Due to the small size of the study area, the small number of photo areas and the ease of identifying known points and landmarks, the operations were performed directly in QGIS with the specific plugin with errors (RMS) around 15 meters. Also in this case, due to the small surface area of the study area, a manual vectorisation of land cover was carried out.

1988 and 2008 digital orthophotos

For the years 1988 and 2008, data were remote sensed from two similar types of data (Figure 3). In fact, two digital orthophotos already geo-referenced and made available through a Warehouse Management System (WMS) service were processed. Specifically, the mosaic of the black and white 1:10,000 scale orthophotos of 1988 provided by the Italian national geoportal (2018) was used.

For 2008, the colour orthophotos supplied by AGEA (consulted through WMS layer provided by the Basilicata region Data Catalog) were used. Both were vectorized manually in consideration of the reduced extension of the study area.

2017 Satellite images

To assess the land use of 2017, satellite images of the Sentinel-2 MSI (Figure 3) mission were used. Sentinel-2 mission is a land monitoring constellation of two identical satellites (Sentinel-2A and Sentinel-2B) that deliver high-resolution optical imagery (ESA, 2017). The Sentinel-2A was successfully launched on 23 June 2015 and offers new perspectives for studying land and vegetation (Drusch et al., 2012). This is possible through the combination of high-resolution (up to 10 m), novel spectral capabilities (e.g., three bands in the red-edge plus two bands in the SWIR), wide coverage (swath width of 290 km) and minimum 5-day global revisit time (Malenovsky´ et al., 2012; Gascon et al., 2017). The classification of Sentinel-2A images was elaborated with Semi-Automatic Classification Plugin (SCP). The SCP is a free open-source plugin for QGIS that allows for semi-automatic classification of remote sensing images. It provides several tools for downloading of free images, pre-processing, post-processing, and raster calculation. The overall objective of SCP is to provide a set of intertwined tools for raster processing in order to make an automatic workflow and ease land cover classification, which could be performed also by people whose main field is not remote sensing (Congedo, 2016).

A supervised classification was used to produce the land cover map. In supervised classification, the image processing software is guided by the user to specify the land cover classes of interest. The user defines “training sites” – areas in the map that are known to be representative of a particular land cover type – for each land cover type of interest. The software determines the spectral signature of the pixels within each training area, and uses this information to define the mean and variance of the classes in relation to all of the input bands or layers. Each pixel in the image is then assigned, based on its spectral signature, to the class it most closely matches. It is important to choose training areas that cover the full range of variability within each land cover type to allow the software to accurately classify the rest of the image. The common classification algorithms used for supervised classification is Gaussian Maximum Likelihood Classifier. Supervised classification can be very effective and accurate in classifying satellite images and can be applied at the individual pixel level or to image objects (groups of adjacent, similar pixels). However, for the process to work effectively, the person processing the image needs to have *a priori* knowledge (field data, aerial photographs, or other knowledge) of where the classes of interest (e.g., land cover types) are located, or be able to identify them directly from the imagery. This method is often used with unsupervised classification in a process called hybrid classification. Unsupervised classification can be used first to determine the spectral class composition of the image and to see how well the intended land cover classes can be defined from the image. After this initial step, supervised classification can be used to classify the image into the land cover types of interest (Creutzburg, 2018).

To evaluate classification accuracy, fieldwork was carried out to verify the types of land use and locate them using GPS.

Figure 3: Digital data used: (left) b/w orthophotos of 1988. (middle) color orthophotos of 2008 and (right) satellites image of 2017

<u>- Land cover dynamic analysis</u>

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. From this phase the classification of the 2017 satellite images is excluded as a raster is automatically produced. Conversion from vector to raster errors were calculated for each land cover 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. The pixel resolution of 1 metre has been chosen because, since the area is small, it does not imply problems of file size for the following spatial operations

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. (2010). This is however the only possible methodology to retrieve dated information, describing the structure and dynamics of the landscape.

Land cover classes used in this study are:

Built-up areas: Include new and old farms, buildings and artificial surfaces, and infrastructure to regulate water flow and road network. In particular, only roads with a significant surface and an important traffic flow and paved roads were considered. Provincial and municipal roads were included, while all typologies of minor rural roads were excluded;

Arable lands: Land under temporary agricultural crops (i.e., in this study: cereals, legumes and fodder crops);

Vineyards Areas: planted with vines;

Olive groves: Areas planted with olive trees;

Forest area: In according to FAO definition (FAO 1998);

Afforested area: Area with conifers and allochthonous species planted by men;

Transitional woodland: Bushy or herbaceous vegetation with scattered trees. Can represent either woodland degradation or forest regeneration/colonization;

Natural grassland: Low productivity grassland. Often situated in areas of rough, uneven ground. Frequently it includes rocky areas, briars, heathland and occasional grazing;

River zone: Area corresponding to the bed of the Bradano river and the riparian vegetation present along the river;

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). Then plugin automatically produces the transitions change maps shown in Figure 4.

- Landscape structure assessment

Quantitative analysis of the structure of a landscape, as well as how it has changed over time, could be performed through the use of landscape metrics. There are many variants of the ''landscape'' definition depending on the research or management context. Scientists who study landscape ecology have used different terms to talk about the elementary elements that define a landscape (Forman et al., 1986). In the scientific literature, the term that occurs most often is patches. In fact, when we talk about the landscape metrics, the landscape is often defined as a composition of a mosaic of patches (Urban et al., 1987) and, by quantifying their specific spatial characteristics, it is possible to describe the landscape metrics and therefore the landscape structure. The main application fields are, for example, biodiversity and habitat quality analysis, estimation of water quality, urban landscape pattern, landscape aesthetics, management, planning, and monitoring (Uuemaa et al., 2013;

Cervelli et al., 2020). A series of landscape metrics minimally redundant and easily interpretable were calculated using the Fragstats 4.2 free program (McGarigal et al., 2012), to assess the multi-temporal patterns of landscape structure changes (Cushman et al., 2008). The basis of the spatial metric calculation was land use map of different years realized previously. Moreover, for some metrics, the LecoS QGIS plugin was used to speed up operations and display the results graphically on the map. LecoS (Jung, 2016) is based on metrics taken from Fragstats and its functions include the calculation of metrics on raster and vector layers. A polygon overlay tool is also available to ease up computation. LecoS provides some functionalities to manipulate classified raster images. In particular, metrics at class level and landscape level described by McGarigal et al. (2012) were used, namely: number of patches (NP), patch density (PD), edge density (ED), landscape shape index (LSI), contagion index (CONTAG), interspersion and juxtaposition index (IJI), Shannons diversity index (SHDI), Simpson’s diversity index (SIDI), and aggregation index (AI). Some of these (Inkoom et al., 2018) are landscape metrics popularly used in assessing ecosystem services (e.g., ecological functioning and aesthetic value) and applied to spatial planning.

4.1.3 Results and discussion

<u>- Temporal land cover dynamics</u>

The total surface in hectares (ha) and the percentage accounted for was calculated for each land use class and in different years of analysis (Table 1). Figure 4 reports these data on relevant land cover maps corresponding to different chronological layers.

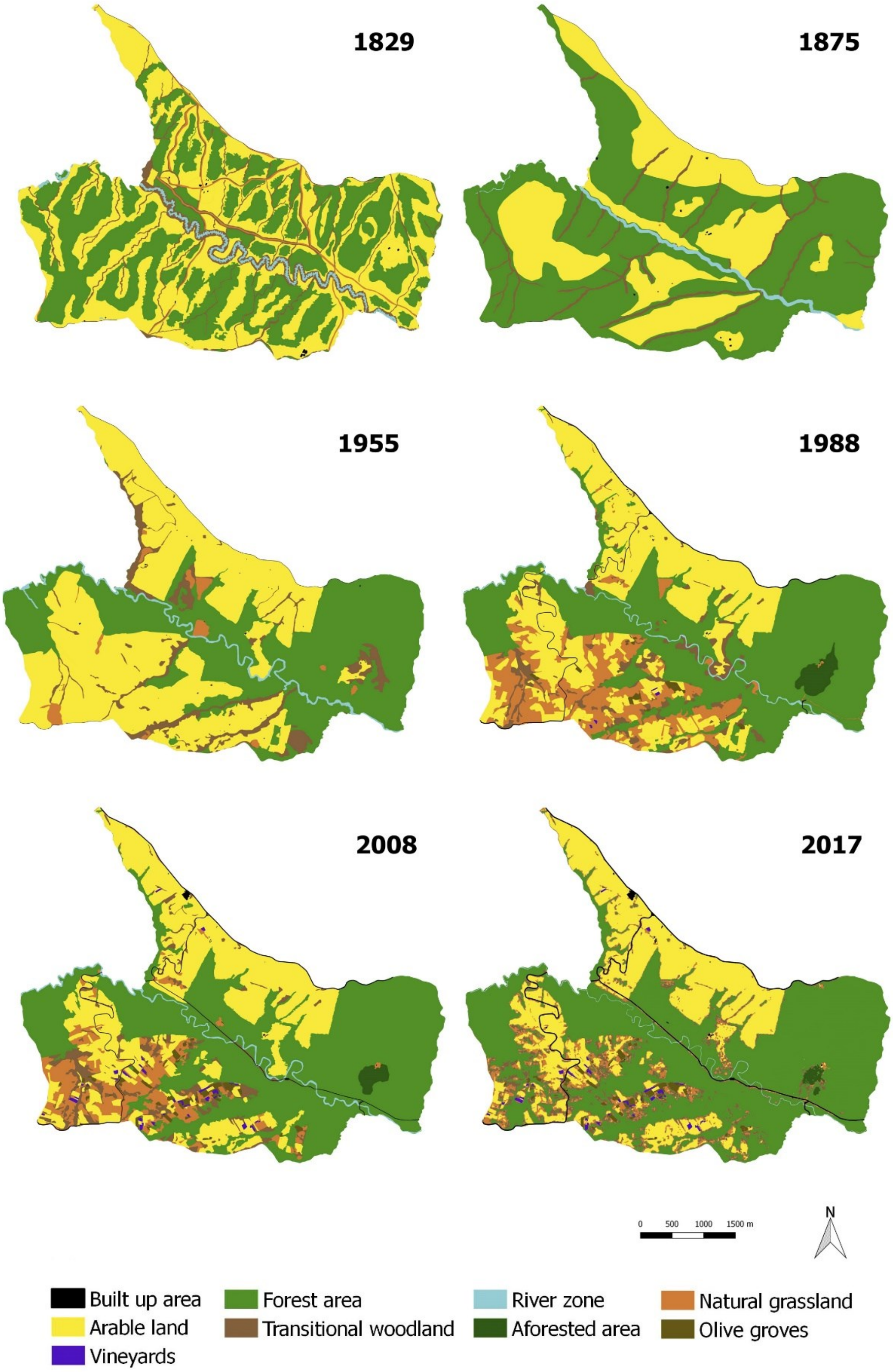

Figure 4: Land cover maps for different years of analyses.

Table 1: Total area expressed in hectares (ha) and the percentage accounted for by each land cover class for respective years of analysis.

Land Cover	**1829**		**1875**		**1955**		**1988**		**2008**		**2017**	
Classes	**ha**	**%**	**ha**	**%**	**ha**	**%**	**Ha**	**%**	**ha**	**%**	**ha**	**%**
Built up area	1.10	0.06	0.82	0.05	0.66	0.04	14.41	0.79	19.40	1.06	19.49	1.07
Arable land	570.28	31.25	600.04	32.88	878.91	48.16	596.19	32.67	553.30	30.31	492.07	26.96
Forest area	1068.23	58.53	1106.73	60.64	761.03	41.70	843.28	46.20	957.09	52.43	1029.18	56.39
Transitional woodland	122.15	6.69	74.46	4.08	126.28	6.92	91.70	5.02	91.14	4.99	128.22	7.03
River zone	31.23	1.71	28.02	1.53	29.63	1.62	17.25	0.95	17.23	0.94	7.62	0.42
Afforested area	0	0.00	0	0.00	0	0.00	26.44	1.45	14.46	0.79	7.89	0.43
Natural grassland	32.16	1.76	15.09	0.83	28.51	1.56	226.86	12.43	141.26	7.74	109.46	6.00
Olive groves	0.00	0.00	0	0.00	0.09	0.00	8.17	0.45	23.05	1.26	23.03	1.26
Vineyards	0.00	0.00	0	0.00	0.05	0.00	0.86	0.05	8.23	0.45	8.20	0.45
Total	**1825.16**	**100.00**	**1825.16**	**100.00**	**1825.16**	**100.00**	**1825.16**	**100.00**	**1825.16**	**100**	**1825.16**	**100.00**

To highlight the dynamics and summarize the most important trajectories of land use changes, a cross-tabulation matrix across the years of analysis was constructed. The transitions for the time intervals from 1955 to 2017 are reported in Table 2, which display the land use categories of 1955 and 2017 in rows and columns, respectively. While the row vectors show the evolution of a land use type in the period 1955–2017, the column vectors show the land use type in 1955, from which another land use type was transformed in 2017 (e.g., 13.92 ha of arable land in 1955 have transformed into built-up area in 2017). The values in the diagonal represent the areas of land use type that did not undergo any change (Modica et al., 2012). The matrix was prepared using MOLUSCE tool, which is based on QGIS that allows to perform quick and convenient analysis of land cover changes. The plugin automatically produces the transitions change maps shown in Figure 5. During the period of 188 years that was studied, the landscape has undergone important transformations caused mainly by economic issues that have affected the study area, and which were similar in all the internal areas of the Basilicata region. Oak woods with low forest density canopy mainly characterized the landscape in 1829. Livestock - i.e., the main agricultural activity of the Forenza municipality in the last century - caused this situation. On the 1825 hectares analyzed, the landscape was mainly composed of forest (60%) and instead arable land covered about 570 ha of the study area. Another important class is transitional woodland (7%) that covered water flow areas. After 46 years, during year 1875, the hectares of arable land did not change, but the geographical location and the type of agricultural activity have been changed. In fact, many pastures were replaced by cereal crops. This intensification was due to higher food requirements of the Forenza municipality population, which was gradually increasing.

Table 2: Cross-tabulation matrix between land use of 1955 and 2017.
The values are expressed in hectares.

2017 **1955**	**Built up area**	**Arable land**	**Forest area**	**Transitional woodland**	**River zone**	**Afforested area**	**Natural grassland**	**Olive groves**	**Vineyards**	**TOT 1955**
Built up area	**0.04**	0.28	0.13	0.05	0	0	0.11	0.04	0.01	0.66
Arable land	13.92	**472.69**	163.25	97.35	0.07	3.98	97.17	22.46	8.02	878.91
Forest area	4.18	8.32	**721.88**	18	1.26	0.27	6.97	0.14	0.01	761.03
Transitional woodland	0.54	8.19	103.12	**7.82**	0.06	2.66	3.51	0.23	0.15	126.28
River zone	0.35	0.03	21.74	1.09	**6.17**	0	0.25	0	0	29.63
Afforested area	0	0	0	0	0	**0**	0	0	0	0
Natural grassland	0.46	2.56	19.06	3.91	0.06	0.98	**1.45**	0.02	0.01	28.51
Olive groves	0	0	0	0	0	0	0	**0.09**	0	0.09
Vineyards	0	0	0	0	0	0	0	0.05	**0**	0.05
TOT 2017	19.49	492.07	1029.18	128.22	7.62	7.89	109.46	23.03	8.2	**1825.16**

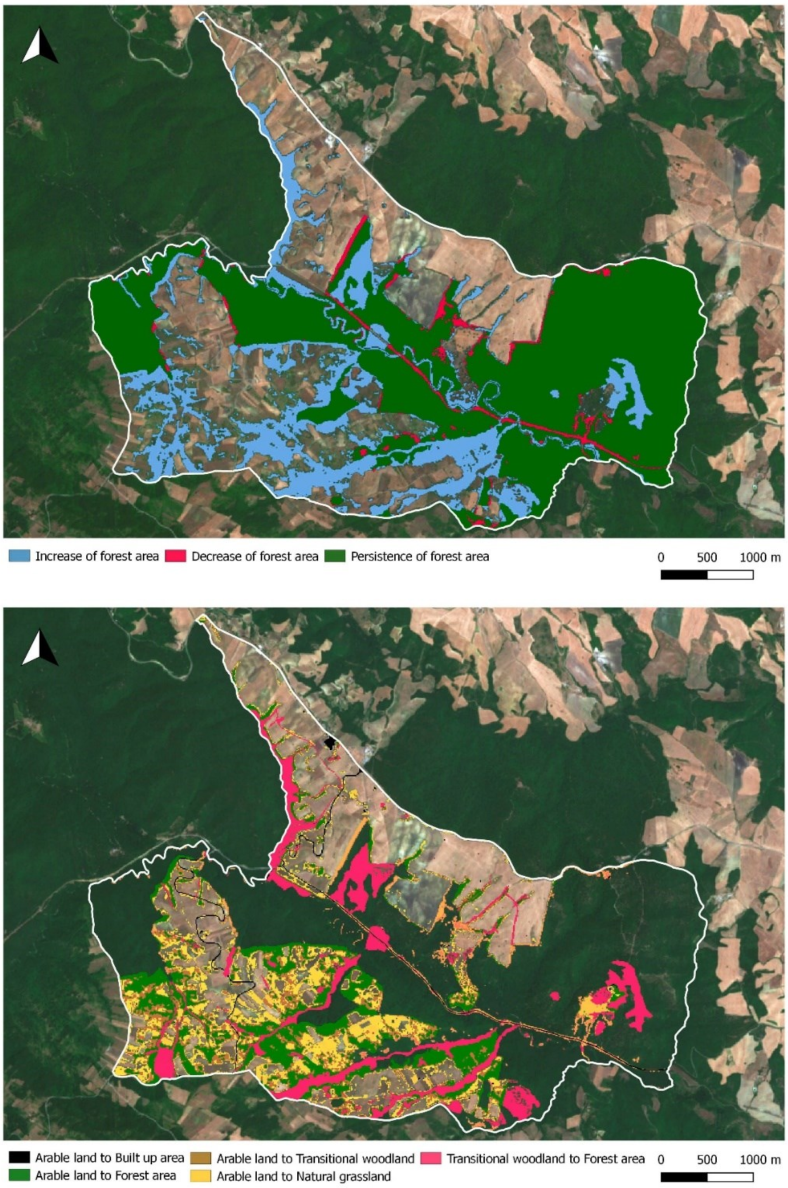

Figure 5: Map of the main land cover changes between 1955 and 2017 (top) and map showing the forest area variation for the same period (bottom). Base image is Sentinel-2A image RGB (bands 4–3–2).

The landscape has undergone significant transformations after World War II (Statuto el al., 2016). Indeed, land management has been completely revolutionized through a general economic recovery and specific reforms. This transformation took place mainly in Southern Italy after a land law (10/21/1950—no.841), which had among its objectives the improvement in the conditions of farmers and better exploitation of the territory. One of the first consequences of the law was the increase in the area dedicated to cereal crops, which replaced pastures because they became less profitable. In fact, a large part of the land, during 1955, was mainly covered by arable land (48%) and the forests reached a minimum peak (41.7%). The current trend, as demonstrated by the analysis of land use in the period 1988–2008–2017 (Table 3), shows progressive increase in spontaneous vegetation at the expense of agricultural areas. Of the 400 hectares of arable land that have been lost in the last 62 years, 89% have been abandoned but subsequently re-naturalized, whereas 260 hectares were not temporarily abandoned (rotation crops) but subjected to secondary forest succession (forest area and transitional woodlands). The cause of abandonment was mismanagement of the forest that has led to a loss of quality (too frequent and intense cuts) and the use of fossil fuel instead of wood fuel. With the development of the set-aside scheme (EEC Regulation 1272/88), the abandonment process has strongly increased. Indeed, with this regulation, farmers were encouraged to abandon the cultivation of cereals and other crops in order to control overproduction and reduce prices (Statuto et al., 2016). The process has accelerated over the last 10 years (an annual decrease of 6%) due to two factors:

1. The depopulation of small villages, which also led to the abandonment of cultivated areas. This process was accentuated in the Basilicata region, where agricultural property was fragmented and farms were at a family level (ISTAT, 2010). In Forenza municipality, the population changed from 5837 inhabitants in 1951 to 2122 in 2015;

2. The economic crisis, and in particular that of the agricultural sector in Italy, which has led to the abandonment of less productive areas and above all to areas where mechanization was more economically disadvantageous. Through spatial analysis between abandoned agricultural areas and the slope raster, 39% of abandoned areas were in class III (soils with considerable limitations) and 38% in class 4 (soils with very strong restrictions) of the land capability classification (Costantini, 2006). The inverse transformation, from another class of land use to arable land, concerned only a very small part of the territory; in particular, 16 hectares of forest area and transitional woodlands have been converted to arable land.

Table 3: Land cover analysis over the years and % of annual change

	Surface of land use (ha)				Annual change (%)		
	1955	**1988**	**2008**	**2017**	**1955-1988**	**1988-2008**	**2008-2017**
Built up area	0.66	14.41	19.40	19.49	+0.42	+0.25	+0.01
Arable land	878.91	596.19	553.30	492.07	-8.57	-2.14	-6.80
Forest area	761.03	843.28	957.09	1029.18	+2.49	+5.69	+8.01
Transitional woodland	126.28	91.70	91.14	128.22	-1.05	-0.03	4.12
River zone	29.63	17.25	17.23	7.62	-+0.38	+0.00	-1.07
Afforested area	0	26.44	14.46	7.89	+0.80	-0.60	-0.73
Natural grassland	28.51	226.86	141.26	109.46	+6.01	-4.28	-3.53
Olive groves	0.09	8.17	23.05	23.03	+0.24	+0.74	+0.00
Vineyards	0.05	0.86	8.23	8.20	+0.02	+0.37	+0.00

- Rural landscape structure assessment

The evolution in the structure of the rural landscape in the study area—even connected to the above described abandonment processes—has been assessed through the use of landscape metrics. This analysis was performed at the level of land use classes first, followed by those relating to the entire landscape. The NP is a simple measure of the extent of subdivision or fragmentation of the land use classes. In particular, NP illustrates the diffuse sprawling development and the fragmentation of rural areas. An increase in both PD and NP reveals landscape fragmentation when used to compare the same landscape in different time periods (Leita˜o et al., 2006). In the study area, the NP and PD increase in all classes starting from 1875, demonstrating an increase in the fragmentation of the entire landscape. In detail, in 2017, the classes of transitional woodlands and natural grasslands show a greater increase because the abandonment and renaturalization were accelerating (Table 4). In 1829, the fragmentation was a little more accentuated than in 1876. The PD can be applied to ecosystem services (Franklin et al., 1987; Leita˜o et al., 2006) to evaluate which patches should be increased or maintained for spatial differentiation of the landscape by public decision makers.

Table 4: Landscape metrics quantification at class level

	NP						**PD (number per 100 hectares)**						**ED (meters per hectares)**					
	1829	**1875**	**1955**	**1988**	**2008**	**2017**	**1829**	**1875**	**1955**	**1988**	**2008**	**2017**	**1829**	**1875**	**1955**	**1988**	**2008**	**2017**
Built up area	16	12	30	53	80	80	0.89	0.66	1.64	2.9	4.38	4.38	1.06	0.77	1.04	15.6	22.4	22.39
Arable land	61	11	29	44	52	65	3.38	0.6	1.59	2.41	2.85	3.56	141.7	29.4	47.7	68.6	69.3	82.03
Forest area	59	31	32	46	51	67	3.27	1.7	1.75	2.52	2.79	3.67	96.65	64.3	39.9	50	57.7	99.38
Transitional woodland	94	23	74	125	167	206	5.21	1.26	4.05	6.85	9.15	11.3	102.6	36.9	40.5	37.2	43.5	144.1
River zone	17	16	10	11	11	19	0.94	0.88	0.55	0.6	0.6	1.04	15.39	8.5	13.7	13	13.1	11.67
Afforested area	-	-	-	1	1	2	-	-	-	0.05	0.05	0.11	-	-	-	2.01	1.21	1.82
Natural grassland	22	1	14	79	87	99	1.22	0.05	0.77	4.33	4.77	5.42	23.22	0.05	5.71	49.8	40.9	123.2
Olive groves	-	-	1	13	53	59	-	-	0.05	0.71	2.9	3.23	-	-	0.07	2.98	10.8	11.13
Vineyards	-	-	1	4	30	33	-	-	0.05	0.22	1.64	1.81	-	-	0.05	0.58	4.93	5.02

Similar information regarding landscape fragmentation is conveyed by ED as well, since low values associated with a lower number of interfaces between different types of patches were detected, with consequent less variation in patch shape. It is an expression of the form and complexity of classe patches, as well as of the heterogeneity of the mosaic that constitutes the whole scenario. The ED can assume any value greater than or equal to zero. If in 1829 there was a higher value in arable land due to the more heterogeneous distribution of cultivated fields, the ED assumed the highest value in 1875 when the arable lands were bound to specific, more compact portions of the territory. In the following trend, the value increased until 2017. To demonstrate the processes of abandonment and re-naturalization spread over the entire surface that was previously cultivated, an increased ED was observed in 2017 for the classes: transitional woodland; natural grassland; and forest area. Monitoring the disruption of spatial and critical habitat can be performed by evaluating the ED (Syrbe et al., 2012). The values of the other landscape level metrics are reported in Table 6. The LSI is equal to 1 when the landscape consists of a square (or almost square) polygon; it increases up to infinite values when the shape of the landscape becomes more irregular. In the study area, there was an increase in LSI from 1875 until 2017, when the value was slightly more than in 1829. In contrast, the CONTAG approaches zero when the classes are disaggregated to the maximum (i.e., each cell belongs to a different class) and interspersed. The CONTAG is equal to 100 when all the classes are aggregated at most, i.e., when the landscape consists of individual patches.

Therefore, the period when the landscape was most aggregated was between 1875 and 1955, which is when it was possible to notice the most consistent increase in arable land in the same portion of territory. In this period, the lowest value of LSI was reached. The arrangement of patches and land use classes in the landscape (landscape configuration or composition) was assessed via IJI. Its increase between 1875 and 2008 indicates a more uniform configuration of the landscape; the patches and patch types were more regularly distributed across the study area, indicating a more uniform spatial distribution of the land use classes. The subsequent decrease in IJI in 2017 was partly due to a slight increase in the number of land use classes. This index approaches zero when adjacencies are unevenly distributed; IJI = 100 if all patch types are equally adjacent to all other patch types. High values of IJI were observed for those areas which form the landscape matrix (arable land and forest) and which, as a consequence, were adjacent to other land use classes. The maximum disruption (lower AI index) occurred in 2017, but all values were close to 100% so there is a strong cohesion between the different classes of land use. The AI is equal to zero when the classes are mostly disaggregated (i.e., when there are no adjacencies); it increases when the landscape is increasingly aggregated and assumes a value of 100 when the landscape consists of a single patch. Applicable to planning, AI has been used for defining functional land use classes (Lafortezza et al., 2005). Regarding the diversity of the landscape (Table 5), two different metrics were calculated: SHDI and SID. These two diversity indices have been applied in many studies in which landscape diversity has been evaluated over time (Liu et al., 2013). The SHDI measures the ecological diversity in a population but can also be applied to the landscape. There is not diversity when a landscape contains a single patch (its value is zero); as the different patches and their spatial distribution increase, diversity also grows. In contrast, another popular index that measures the landscape diversity, similar to the SHDI but with a more intuitive interpretation, is the SIDI. Precisely, the SIDI is given by the probability that two randomly selected landscape points are different types of patches. The numerical value of SIDI varies from 0 to 1 (landscape with high complexity). SIDI is a dominance index, which is weighted toward the abundance of the most common land use category (Magurran, 1988). It should therefore be less dependent on the number of land use classes than the SHDI

(Herzog et al., 2001). A little reduction in the values of SIDI and SHDI is observed after 1988. This means that the level of diversity in terms of different cover types and the equal distribution of patch types were decreasing due to the progressive expansion forests to the disadvantage of other land use classes. However, SHDI and SIDI should be used with caution when landscape diversity is assessed (Nagendra, 2002). Before 1900, it is noted that the lowest values of SIDI and SHDI were present in 1875 because there is less uniformity in the distribution of land use classes. Subsequently, the SIDI and SHDI values increased from 1875 to 1988 due to the more even abundance of land use types, balancing the dominance of forest area. Currently SIDI and SHDI values are slightly decreasing, so the landscape is becoming dominated by large patches of a few land use types due to the abandonment of the arable land and consequent re-naturalization. Diversity indices are also used to evaluate the landscape aesthetics and in particular Dramstad et al. (2006) have found a positive correlation of SHDI with visual landscape preferences.

Table 5: Landscape metrics at landscape level

	LSI	**CONTAG**	**IJI**	**SHDI**	**SIDI**	**AI**
	adimensional	%	%	adimensional	adimensional	%
	1 - ∞	0 -100	0 -100	0 - ∞	0 - 1	0 -100
1829	22.11	60.29	58.58	1.03	0.57	90.41
1875	9.35	76.47	35.47	0.87	0.51	96.43
1955	9.81	72.3	47.03	1.04	0.59	96.25
1988	14.66	63.87	65.93	1.3	0.66	94.03
2008	15.93	64.09	72.98	1.27	0.62	93.43
2017	28.6	62.78	59.87	1.2	0.6	87.44

4.2 “Vulture” case study

4.2.1 Study area

The study area, located in the north of the Basilicata Region - Italy (Figure 6), 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.

The landmark of this area is the Mount "Vulture" (1,326m), an extinct volcano which has had a notable influence on the geographic, botanical, zoological, 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 centers 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 to the border with the Campania region, in the municipalities of "Rionero" and "Atella", it is located the SAC "Grotticelle of Monticchio" (Code IT9210140): 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 gray color, 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 respect to all other Italian Quaternary volcanoes both from a geological-geographic point of view and considering a geochemical-geodynamic aspect (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 meters while the average depth is about 8.9 meters. The smallest lake is 38 meters deep; it has an average depth of 17.9 meters.

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 et al., 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 the 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 in 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.

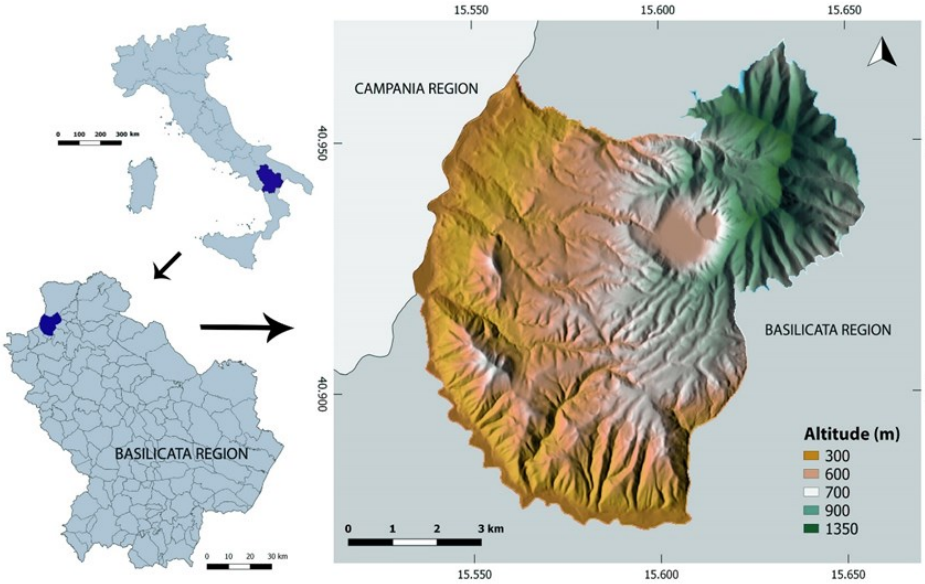

Figure 6: Location of the study area (centroid: 40°55'18.8"N 15°35'22.6"E, Datum: WGS84)

4.2.2 Materials and data processing

The first operation carried out has been the preparation of the land cover 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 (Figure 7). 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, but considering the need for better spatial accuracy than the data, it was preferred to *ex-novo* build the datasets. Preliminary steps and all the subsequent operations were performed with an open-source GIS tool together with some other open-source tools able to guarantee an effective analysis of landscape dynamics. The statistical analysis has been performed through the R software.

Figure 7: Extract of a part of the study area in the 4 main maps and position with respect to a secondary historical cartography used (Topographic Map of "Bosco Monticchio").

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 the City of Potenza. 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 cover 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

The techniques of georeferencing, accuracy verification and digitisation of land cover classes are those used in the Forenza case study given the similar characteristics of the maps and the fact that topographic maps created by the Italian Military Topographical Institute are the same. More attention has been paid to the maps "Topographic Map of the Bosco Monticchio" and "Topographic map of Vulture mountain" as they present typical characteristics of iconographic maps. Through different techniques and software, it has been possible to reach an RMS value around 20 m.

Year 1955

To cover the whole study area, a set of 5 black and white aerial photos was used, which are part of the same series and type of the previous work (Forenza Case Study). After the 1200 dpi scan, the images were orthorectified using the methodology proposed by Gobbi et al., (2018) in view of the considerable size of the study area. This allowed faster processing of a different number of images without losing accuracy. All the operations were performed within GRASS GIS 7.4, which has several modules that can be called singularly or in series. The used modules are:

i.ortho.target: This module sets a target location for the image to be rectified. The target location is a subset of maps in GRASS containing the maps used during the procedure (DTM and maps for GCPs) and implicitly defines the output orthoimage reference systems and projection.

i.ortho.elev: This module allows the user to select a DTM for the ortho-rectification process. In this study a DTM with 5m resolution was used.

i.ortho.camera: This module sets the parameters used for the internal orientation of the image. The focal length of the camera and the coordinates of the fiducial marks on the image must be provided. Since the calibration certificate of the camera is not available for the current dataset, the coordinates have been determined measuring the distance between the marks on the physical copy of the photographs. These measures revealed a distance of 231 mm between east-west markers and 232 mm between north-south markers. The internal orientation has been performed using a 6 parameters affine transformation, therefore the coordinates of at least 3 points must be provided.

i.ortho.init: This module can be used to provide initial values (and their RMS) for the unknowns in the iterative least square adjustment for the evaluation of the external orientation parameters. The need to provide initial values of the 7 unknown parameters, representing 3 translations, 3 rotations and a scale factor, is due to the non linearity of the equations. Initial approximate values are automatically calculated, If no value is provided.

g.gui.photo2image: This module provides a graphical interface to indicate the position of the fiducial markers on the digital image.

g.gui.image2target: This module provides a graphical interface to locate GCPs on the image and provide their coordinates. It is possible to either manually enter the coordinates or locate the same point on a (geo-referenced) map. The height is provided by the DTM.

i.ortho.rectify: This module performs the actual rectification of the image.

Thanks to this operation it was possible to have very small errors in all 5 aerial photos with an RMS ranging from 10 to 12 meters. This approach is certainly a very useful method for orthorectification of a large dataset of photo areas, and as reported by Gobbi et al. (2018), GRASS GIS has proven to be a suitable solution for orthorectification because:

1. it is a free and open software, for many researchers it allows collaboration and research reproducibility;

2. it represents a way to save costs and still work with a powerful GIS tool capable of orthorectifiyng;

3. its code could be edited to give better performances in orthorectification;

4. it is user-friendly and troubleshooting is made easier by an active community of developers.

Considering the size of the area, in addition to the manual digitization of land cover categories, a semi-automatic classification methodology proposed by Gobbi et al

(2018) was also tested. The test was carried out on a plot of study area, in order to assess the degree of reliability and accuracy of this methodology.

The semi-automatic classification tested is based on the Object-based Image Analysis (OBIA) algorithm. This process generates a map where each ”pixel” or ”object” is grouped in a finite number of set, each one representing a type of land cover. OBIA algorithm does not classifies each single pixel as, for example, maximum likelihood algorithms, but it creates groups of pixels, called segments, which are classified as single objects using machine learning. The parameters (Clewley et al., 2014) used by the machine learning are the statistical distribution of the pixels radiometric response inside the single object and the geometry of the same object (perimeter, area, compact circle, compact square, fractal index). Each segment of pixels is called ”object” and it is characterized by pixels with a similar spectral response. The choice between the two algorithm should be driven by the resolution of the input image. If the objects (houses, trees, roads, water bodies) depicted in the image are larger than the pixel resolution, an OBIA approach is more likely to give a cleaner land cover output map. The procedure was tested using the Orfeo ToolBoox suite through the specific interface within QGIS (De Luca et al., 2019). The same test area has been digitized and classified manually in order to compare the two approaches. Then, through these two procedures, two ground cover maps were produced, which were visually compared by random points to evaluate the results. The analysis showed that the manual classification, although more expensive in terms of time, was more accurate. This can be explained both by the fact that the OBIA procedure can be further improved, and by the characteristics of the study area, which is extremely heterogeneous. In addition, the photo areas in this area have a very pronounced white and black contrast.

An accuracy of about 85% has been recorded with OBIA procedure, which is generally accepted in the literature, but for detailed planning and monitoring in heterogeneous areas, this is not sufficient. So, considering the need for a high level of detail for this case study, a manual classification of the land cover was chosen.

<u>Year 1988</u>

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. In this case, too, in view of the remarkable etorogeneity of the study area, a manual vectorization was chosen, which allowed for a more detailed land characterization.

Year 2013

For the year 2013, the ortho-photos in GeoTIFF (.tif) format from the Geographic Database of the Basilicata Region (under Italian Open Data License 2.0) were used. For the same reasons expressed above, they have been vectorized manually.

Land cover classification

Thanks to georefenging and vectorization processess, the raster images were converted into vector maps through a manual procedure finalized to digitize the polygons relative to the land cover classes and subsequently re-transformed into raster maps. Conversion from vector to raster errors were calculated for each land use classes as the ratio of the difference between the area of classes in vector format before rasterization and the area of classes in the raster dataset after rasterization to vector map. After several tests starting from pixel resolution of 1 meter, the value used - which provided a lower rasterization error value between the different land use classes (less than 1%) without the file being too large for post processing operations - has been 5 meters. Furthermore, the choice of this resolution guaranteed the possibility of comparing with terrain data used subsequently. Land cover temporal transition analysis and assessment ware performed using MOLUSCE.

Land cover classes are shown in Table 6.

Table 6: Land cover class, acronym and description

Land use class	Acronym	Description
Built up areas	BUILT	Artificial surfaces realized 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/colonization. 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 semi-natural habitat; in fact they are part of the habitat 9260 of the Natura2000 network.

Naturalness assessment

Basing on the definition given by Tveit et al. (2006) that generally use 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 the present 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, then expanding the survey to the entire study period and not to a specific year, as proposed by some other authors (Martin 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 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-naturalization processes are being carried out (afforestation area) and areas where naturalness is disappeared due to deforestation processes (deforestation area) have been compared.

In according to the methodology presented by Geri et al. (2010) and by Amici et al. (2017), the cross-classification map has been superimposed on the 5m 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 ($Wh \cdot m^{-2} \cdot day^{-1}$). The variables were calculated with the QGIS Raster Based Terrain Analysis Plugin and module of GRASS GIS r.sun. 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.

This approach can be useful both to identify 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 it can also be useful to understand the areas in which a certain degree of naturalness is being recreated.

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 to evaluate the multi-temporal patterns changes of the landscape structure. 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 (Liu et at., 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 et al., 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 (Burton et al., 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 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.

4.2.3 Results and discussion

Land cover dynamics

The land cover maps produced for the 4 different time steps, in which the surfaces relevant to each land use class were summarized (expressed in ha and in %), are shown in Figure 8. These data are also reported in Table 7, 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).

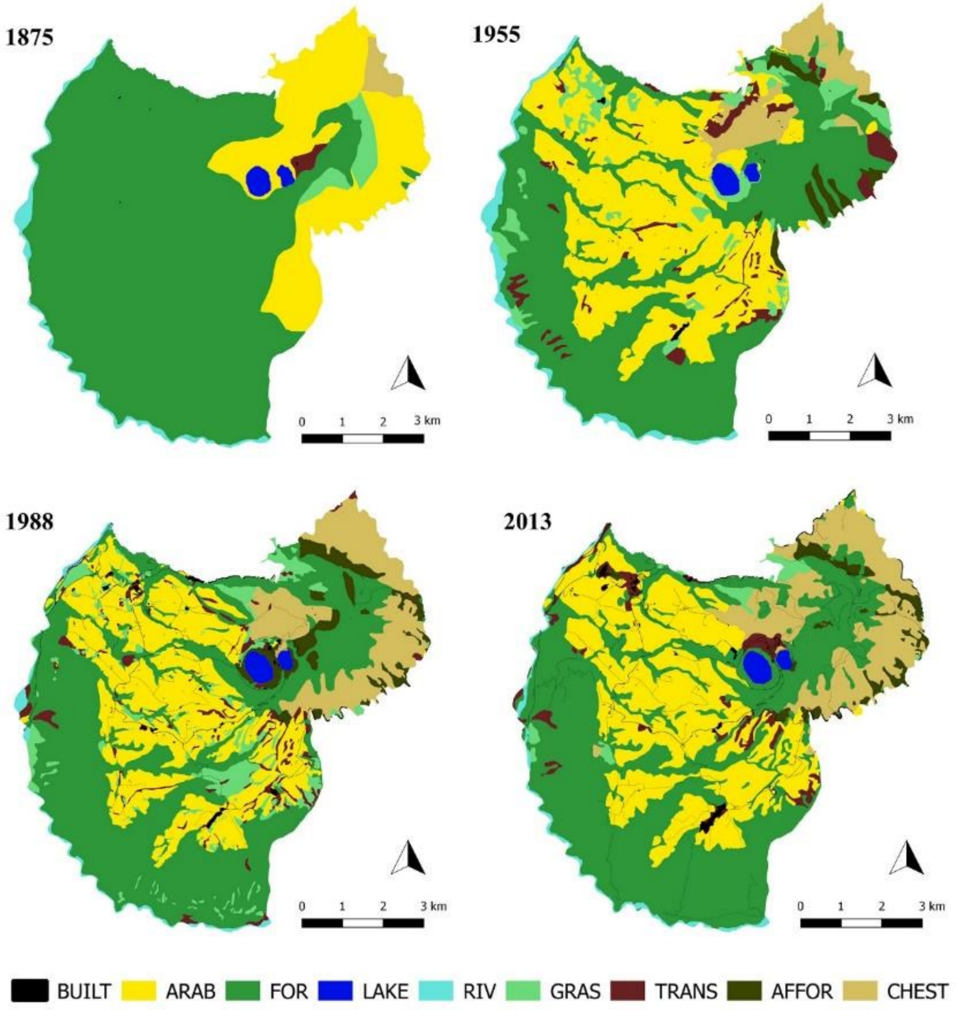

Figure 8: Land cover maps derived from the classification of the different cartographies for the 4 years which have been analyzed.

With the aim to enable a more detailed analysis, a contingency 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 to calculate the total surface extent of land use change occurred at different times. The operations were carried out by 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 analyzed period, 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 8/a shows that Arable land for 420.20 hectares in 1875 has changed into Forest land in 1955, while, on the contrary, other 2009.09 hectares of Forest land in 1875 has changed into Arable land in 1955.

In this way, Table (8/a, in hectares; and 8/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. Those ones which showed most dynamism are, on the opposite, the natural grassland (8.5%), which have been replaced mostly by forest area (about 120ha). From the comparison with the other tables, it is clear that the period 1875-1955 is that 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 9 (9/a in hectares; 9/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 the territory has been replaced (in terms of their size) from forests, arable land, as well as also by about 88 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 10) (10/a in hectares; 10/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 1955-1988, then by a further increase (+ 7ha).

Table 7: Total surface for each land use class (in ha and %) and net change (ha) over the years

	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 8/a: Cross-tabulation matrix - 1st Period: from 1875 to 1955 [Ha]. The AFFOR row is missing because this land cover class is absent for the year 1875

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 8/b: Cross-tabulation matrix - 1st Period: from 1875 to 1955 [%]. *The AFFOR row is missing because this land cover class is absent for the year 1875*

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**

Table 9/a: Cross-tabulation matrix - 2nd Period: from 1955 to 1988 [Ha]

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**

Table 9/b: Cross-tabulation matrix - 2nd Period: from 1955 to 1988 [%]

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 10/a: Cross-tabulation matrix - 3rd Period: from 1988 to 2013 [Ha]

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**

Table 10/b: Cross-tabulation matrix - 3rd Period: from 1988 to 2013 [%]

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**

Naturalness assessment

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 (Figure 9 - Left). This approach overgeneralizes 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 (Figure 9 - Right), it emerges that this conservation areas with greater naturalness, cover only 31.96 % of the total study area. In general, even if this area has an high naturalistic vocation, the prevailing socio-economic dynamics have led to the deforestation of the territory (43.26 % of the study area). The main naturalization 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, some box plots have been created for the time periods 1875-1955, 1955-1988 and 1988-2013 (Figure 11), through a statistical analysis (Table 11) relating these three areas (conservation, afforestation and deforestation), according to some topographic variables (elevation, slope, aspect and global irradiance).

In the first analysis period (1875-1955), the forest persisted in zones (conservation area) with elevation on average less than 600 meters and with quite high slopes. Comparing to global irradiance, the areas that were most preserved have been those with an 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 an higher elevation than the conservation area and especially at lower slopes. At higher elevation and slopes, areas with naturalization processes are especially concentrated.

Between 1955-1988, 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-naturalized, 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 in particular for afforestation and deforestation processes, the areas concerned are those with an exposure from South-East to South-West (range between 150 to 200 degrees to the North).

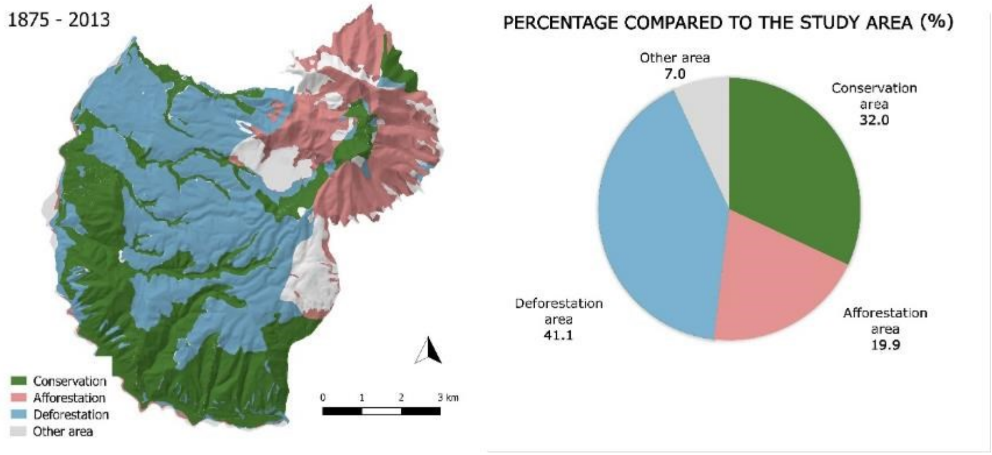

Figure 9: Naturalness dynamic expressed in form of map (left) and pie chart (right) showing the conservation, afforestation and deforestation areas for the period 1875-2013.

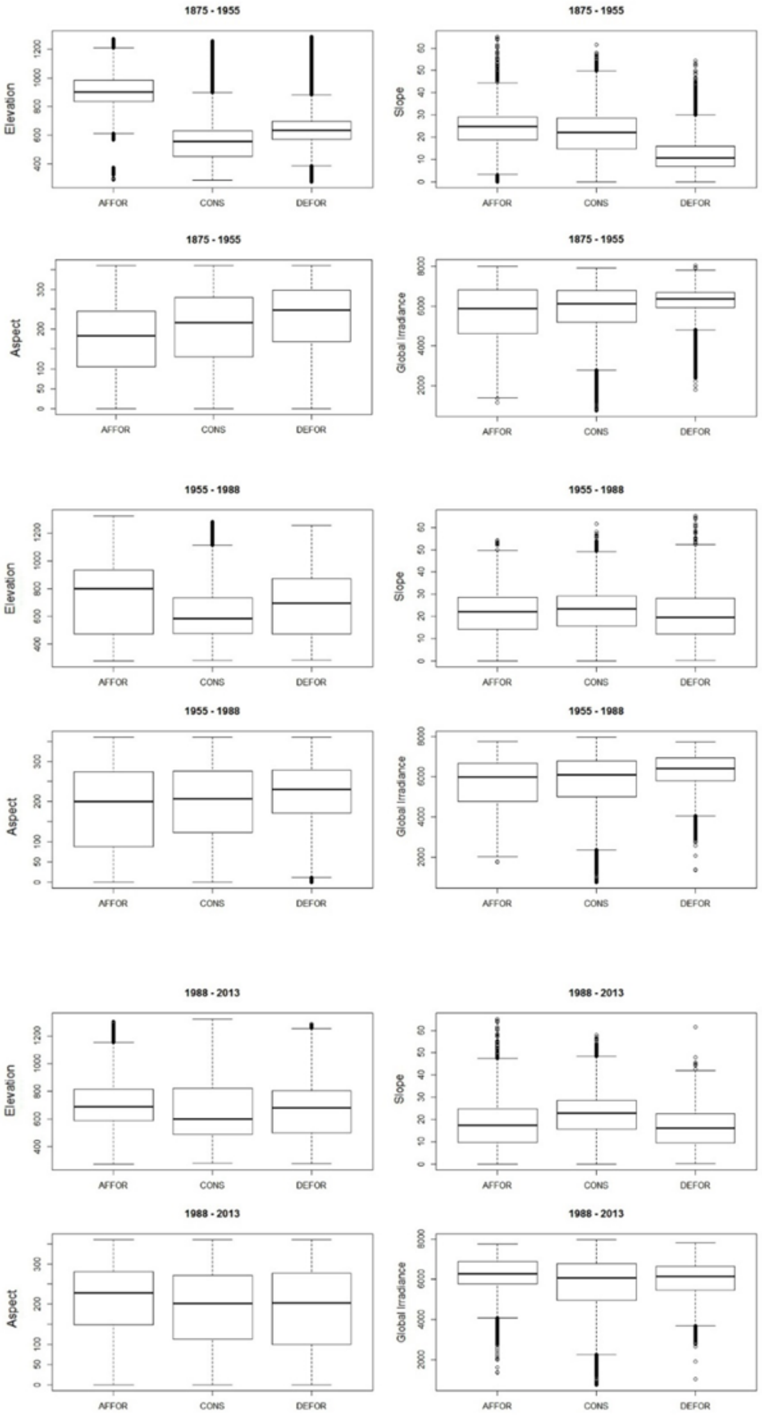

Figure 10: Box plots of the relationships between topographical variables (elevation, slope, aspect and global irradiance) and conservation, afforestation and deforestation areas for different periods (1875-1955, 1955-1988, 1988-2017)

Table 11: 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

Landscape diversity

The variation in the diversity of the landscape during the 138 years of analysis was assessed through the mapping of the SHDI (Figure 11). 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 certainly was 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 realization of the maps highlighting the differences in values of the SHDI (Figure 12), it has been possible to investigate some of these dynamics. The period in which there were major changes within the landscape structure has been 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 has been indeed an increase in heterogeneity in land use, especially in the northern side of the volcanic cone. Instead, along the southern side of this volcanic cone, there has been 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 to highlight 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 have been recorded around the lake area. Finally, analyzing 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.

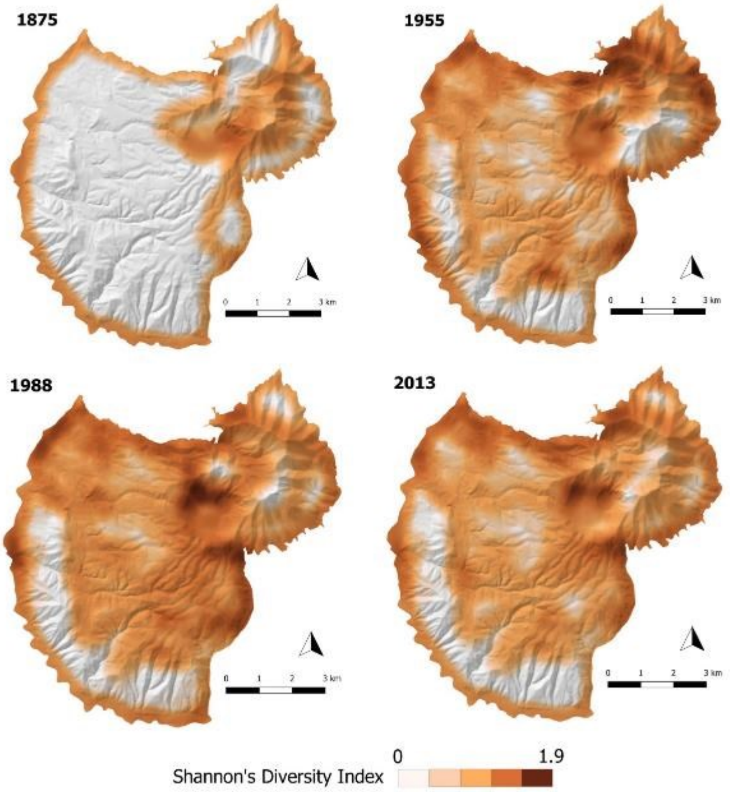

Figure 11: SHDI maps elaborated for the 4 years of analysis derived with Fragstats 4.2 software.

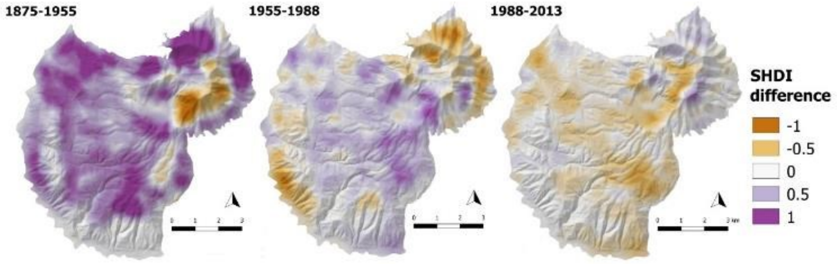

Figure 12: Difference between SHDI index values for the three periods analyzed.

The results of land cover dynamics, naturalness and landscape diversity assessments 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., 2017). The period between 1875 and 1955 is that one when major transformations have occurred. In fact, 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 located on the slopes of the volcano have turned into forest areas.

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 1960th 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 recognized, 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 1950th years, thanks to the activities expected with the land reform for Southern Italy. Furthermore, these areas were re-naturalized through the chestnut woods, which has 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 it 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 widespread in all areas (almost 500 ha), of agricultural activities. This process of reducing primary agricultural activities and increasing natural and semi-natural areas has been indeed observed in many other mountainous areas of the Mediterranean region (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 stabilization 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 summarized 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 1875-1988, 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 going stabilizing in terms of diversity. The areas with an 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 its naturalness. Therefore, thanks to this methodology, it has been possible to identify areas where the landscape is more fragmented and heterogeneous, as resulted by the implementation of simple techniques of calculating the values of landscape metrics. The identification of these hotspots of landscape diversity can be the starting point for further more deep analysis of the biological diversity and visual quality, including their relationship with landscape diversity as well. Indeed, the relationship between landscape diversity and biodiversity is a concept that is currently widely discussed in the 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., 2010). This led to a process of homogenization of the landscape due to the loss of semi-natural classes (natural grassland and transitional woodland). The phenomenon of homogenization of mountain areas can lead to the disappearance of habitats and species of conservation interest. 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 urbanization. Considering the geo-location of the conservation area, it is noted that the entire extinct volcanic cone of the Vulture mount 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.

5. RELATIONSHIPS BETWEEN RURAL LANDSCAPE AND FARM BUILDINGS

In its effort to convert the uncultivated land to agricultural activities, humanity has built constructions conceived to host farmers and biological productions, so contributing to increase the level of agricultural productivity and meet the food demand. Now, this built heritage constitutes a unique example, due to architectural and technical issues different from other building sectors, which plays a central role in the formation of the rural landscape, as well as on relevant ecosystem services.

In some European countries in particular, these rural structures have been built based on traditional agricultural needs and typical land characteristics. Considering the land abandonment that has occurred over the last five decades, with farmers moving to more comfortable residences in neighbouring urban settlements, historical farm buildings have often been abandoned, thus causing a leakage of the historical-cultural heritage of the rural landscape.

In the past, the process of wilderness and re-naturalization of the mountain territory was preferred from both an aesthetic and a planning point of view when compared to the concept of rural landscape (Agnoletti, 2014). Starting from the year 1990, the vision has changed due to the implementation of the ELC (2000) and the EU Habitats Directive. In fact, there has been an increase in appreciation for traditional rural landscapes, rewilding them from both cultural and ecological points of view. Traditional rural landscapes have acquired ever greater value due to the demonstration of their uniqueness from cultural and historical points of view. Their importance for the conservation of biodiversity has indeed become increasingly recognized due to several studies that have linked certain types of agricultural activities with the conservation of relevant animal and plant species.

Nowadays, open data and geographic technologies together with advanced technological tools allow us to gather multidisciplinary information about the specific characteristics of each farm building, thus improving our knowledge. This information can greatly support the protection of those buildings and landscapes that have high cultural and naturalistic value.

In particular, a strong connection between biodiversity and conservation/restoration of grassland is currently emerging . This connection necessarily includes our rural heritage through conserving rural buildings. This is especially true for some Natura2000 priority habitats, such as the semi-natural dry grasslands. Moreover, if we also consider the increase in tourist flows in rural areas, it is necessary to analyse the relationship between rural landscape and farm buildings, assessing the impacts they have had or could have within the ecological sustainability of landscape. For this reason, the monitoring of the rural buildings and of the surrounding landscape, considering multidisciplinary and strong spatial components of the information (Ledda et al., 2020), requires a suitable approach, which is now possible when based on new geographic technologies (Calaciura et al., 2008; McKenzie et al., 2011; Haller et al., 2018)

In this section, the interactions between rural buildings and the surrounding land have been examined through two geospatial approaches and as many case studies.

- **A geospatial approach to interpreting the relationships between historical farm buildings and rural land**: This first approach is based on some key-aspects for an integrated management of vernacular farm buildings in the context of the surrounding rural landscape. The first of these aspects — which may change in relation to territorial realities, but that is common to many other territorial contexts — refers to the consistency of the geodatabases. Generally, the realization of heritage geodatabases through Geographic Information Systems (GIS) mapping is a common operation, but for rural heritage, often different types of data are used. Indeed, georeferenced information is often incomplete or only partially usable; thus, in many cases, preliminary research, cataloguing, intersection of data, and verification are necessary. The studies of vernacular rural buildings, in most cases, have made use of cadastral documentation, archival data, and surveys of the territory, thus the method presented in this work — the use of open data and a geospatial approach to identification — differentiates them from the point of view of structural integrity and relates them to the surrounding rural landscape. This is certainly a new approach that can be useful for future developments of this theme, in particular for areas (such as the chosen study area) where there is a need to improve and expand knowledge about the built heritage and the rural landscape. Considering these assumptions, the objective of the case study is to propose a geospatial method for the evaluation of the relationships between farm buildings and rural landscape, in order to provide public decision-makers with a useful tool for an integrated approach.

- **Remote-sensed geodata and historical maps to assess the interactions between rural buildings and agroforestry land**: In this case study, in addition to the assessments based on land cover and geomorphological aspects, a further fundamental element for the characterization and analysis of the agroforestry land has been considered: the built rural heritage. The study of land transformations has been put in relation to a buffer area around the rural buildings in order to carry out a first preliminary study on the relations between territory and rural buildings. The relationships between rural buildings heritage and the surrounding land have been surveyed through a comprehensive geodatabase that incorporates several geodata from topographical maps, aerial photos, orthophotos and satellite images which has been implemented into a GIS. This approach has made it possible to evaluate the dynamics of the land around rural buildings, in order to prepare models for the determination of land cover dynamics, both in qualitative and quantitative terms, with specific focus on the most relevant classes of the agroforestry territory, since it represents an important part of semi-natural habitats with a high naturalistic value. In consideration of the impacts of human activities on the rural environment, in this preliminary case study, attention has also started to be paid to buildings trying to answer the question: is there a relationship between land transformations and dynamics related to rural buildings?

5.1 A GEOSPATIAL APPROACH TO INFERRING THE RELATIONSHIPS BETWEEN HISTORIC FARM BUILDINGS AND RURAL LAND

5.1.1 Study area

The study area covers the entire territory of the Basilicata region. The study area covers the entire territory of the Basilicata region (Southern Italy—see Figure 13), which is characterized by a traditional agricultural vocation and where the process of abandonment, rewilding, and fragmentation of rural areas is extremely topical. Two main territorial compartments have been identified, corresponding with the administrative division of the two provinces: the province of Potenza, the regional capital, has mountainous and hilly terrain, including the Apennine Ridge and some of the most significant mountain ranges in southern Italy; the province of Matera is orographically constituted by the clay terraces of the Fossa Bradanica, which slope with hilly undulations towards the Apulian Region to the east and towards the coastal plain that hosts the mouths of the main Basilicata rivers to the south-east. This orographic conformation, corresponding to completely different landscape characteristics, has meant that, in the mountainous area, agricultural systems linked to small properties, to closed fields, and to a scattered and poor rural architecture have remained almost unchanged over time. The exception is the volcanic area of Mount Vulture, where the fertility of the soils and deforestation have allowed the establishment of important farms, with the consequent creation of more complex rural types. The area belonging to the province of Matera, on the other hand, is both hilly and flat and has been subject to considerable effort to improve it, as this territory has played a leading role in the agricultural economy of the whole Basilicata region.

From a landscape point of view, Basilicata is characterized by different protected areas of particular interest from a naturalistic and historical-cultural point of view. Many areas require continuous monitoring and planning actions, due to the fragility of the natural heritage and the increase in tourist pressure. The Basilicata’s landscape presents varied morphological aspects thanks to the geological differences, that determines an important vegetational and faunistic richness.

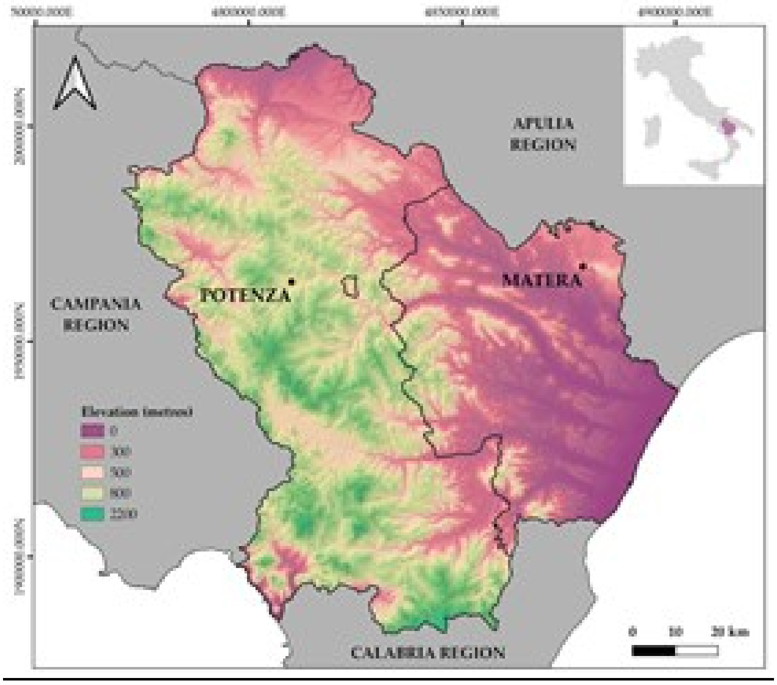

Figure 13: Basilicata Region localization

Over the last century, the agricultural landscape of Basilicata has undergone significant transformations. Although a "poor" rural economy has persisted, especially in the mountainous areas of the province of Potenza, considerable efforts have been made to improve economic and social conditions of the rural populations trying to support the agricultural sector. Rural typologies represent the most obvious indicators of the changes — not only economic, but also cultural — that have taken place in agricultural systems. This is particularly evident in the case of Basilicata, where large areas not "contaminated" by processes of agricultural mechanization remain alongside regions involved in modernization (Picuno, 2012; Picuno, 2016). Moreover, there are vast areas where agricultural systems have evolved slowly, leaving visible traces of pre-existing settlements and production conditions. Another significant phenomenon is the abandonment of areas that, until a few decades ago, were used for grazing. Sheep farming, a family livelihood linked to the territory and residual in a few internal areas, has been replaced almost everywhere by stable farming. This has led, on the one hand, to the proliferation of building structures with morphological characteristics almost everywhere flattened by a typological homologation. On the other hand, the abandonment of pastures, which were long maintained through pastoral activity, has occurred with the consequent loss of such architectural heritage, as sheepfolds and mountain shelters.

In an attempt to stimulate the tourism sector in the face of a widespread crisis in the agricultural sector, a proliferation of accommodation facilities located in buildings that were once rural or ex-novo built, is currently occurring. The consequent introduction of new landscape elements has compatibility with the structural features of the landscape, in ways that are complex and often questionable. Typical elements are the "*masserie*", the oldest evidence of the vernacular settlement scattered in Basilicata (the first traces of which, date back to Greek colonization). Over time, the term has extended its meaning to cover all forms of rural settlement in the area, even if not managed by a farmer, and any independent rural farm connected to agriculture and livestock (Grano et al., 2019). More than other buildings, the *masserie* determined and conditioned economic and social life of the region, until the mid-1900s representing the concretization of the history of the farmer, who almost always lived under the control of the large landowners (Basilicata region, 2007). As reported by Franciosa Franciosa, 1942), height variations play a fundamental role in the characterization of different architectural types. The buildings in mountainous areas and high hills are characterized by a simple shape, often on a single floor. On the other hand, in areas at lower altitudes or located near the coast, rural dwellings expand, and very often the buildings include settlers' residences and structures used for production or processing of agricultural products that are located next to the main house of the farmer. In this case, we find forms that are more refined and rarer, offering more complex architectural solutions. Many of these rural buildings have assumed high cultural value due to their inclusion in Italy's cultural heritage list (Statuto et al., 2017b).

5.1.2 Materials and data processing

5.1.2.1 Traditional Rural Buildings Geodatabase

The census of rural buildings identified as masserie was the basic preliminary operation. It constituted the central geodatabase that will form the basis for implementing the system and the subsequent analysis. At present, there is no geo-referenced and official database of all the farms in Italy, except for those with high architectural value and those protected through a specific cultural heritage code. The approaches are different and, in the past, mainly statistical/archival data have been used or direct surveys of the territory in some cases. However, given the increase in complete and updated open source datasets, it was possible to carry out an effective census of all the rural buildings that were identified in the past with the toponym "masseria" (Figure 14). Crossing the national database of the Italian Geographical Military Institute (IGMI) toponyms (Geoportale Nazionale, 2019) with the vectoral data created by the Basilicata Region in 2013 (RSDI, 2020), it was possible to create a geodatabase consisting of all the buildings identified as "masserie", further dividing them into abandoned and not abandoned using the information contained within the regional dataset. This distinction considers, among those abandoned, only farms that are definitively abandoned, since they have been pulled down or ruined.

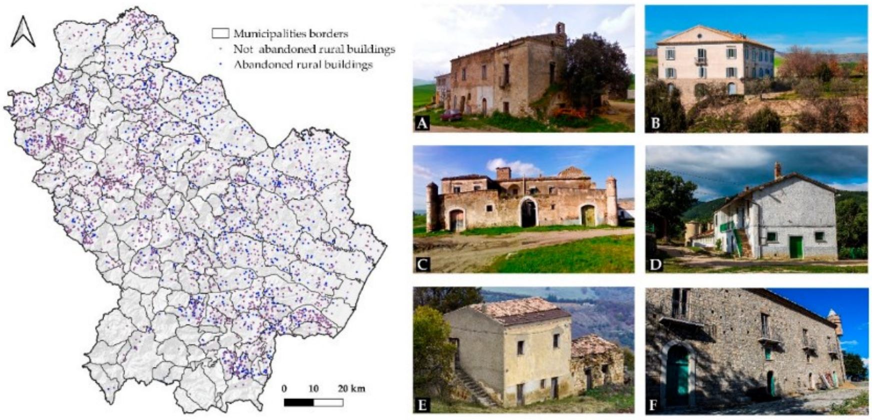

Figure 14: Map with distribution of abandoned and not-abandoned rural buildings in Basilicata Region. In the pictures, some of the rural buildings included in the database: abandoned (left) and not abandoned (right). (A) Masseria Di Pierro; (B) Masseria San Germano; (C) Masseria Parasacco; (D) Masseria Marsino Nicola; (E) Masseria Cillis; (F) Masseria San Zaccaria.

5.1.2.2 Geospatial Analysis

All operations of geospatial analysis were carried out with the open-source software QGIS 3.8 while, for the statistical analysis, the R Project for Statistical Computing was used.

5.1.2.3 Rural Buildings: Distribution and Density

The first geospatial analysis concerned the quantification and the distribution of traditional rural buildings located in the territory. This operation proved useful at the planning level to identify the compartments and the areas that need to be taken into account more in the local actions of management and restoration of the rural landscape. In addition to the classic building distribution at the level of municipality or other administrative limits, at the landscape level, it may be useful to use a concentration map to identify specific units of the landscape on which attention should be focused. Through the QGIS Heatmap plugin, it was possible to perform a kernel density estimation to create a density (so-called heatmap) raster of an input point vector layer. Therefore, the vector files of the points of interest were constituted by the centroids of the polygons that represented the abandoned and the not-abandoned rural buildings. The density was calculated considering the number of points in a given position, where a greater number of points generated greater values. Maps allow for easy identification of hotspots and grouping of rural buildings (Figure 15). By specifying the heatmap search radius, it was possible to map the density per 10 km^2 of abandoned and not-abandoned rural buildings.

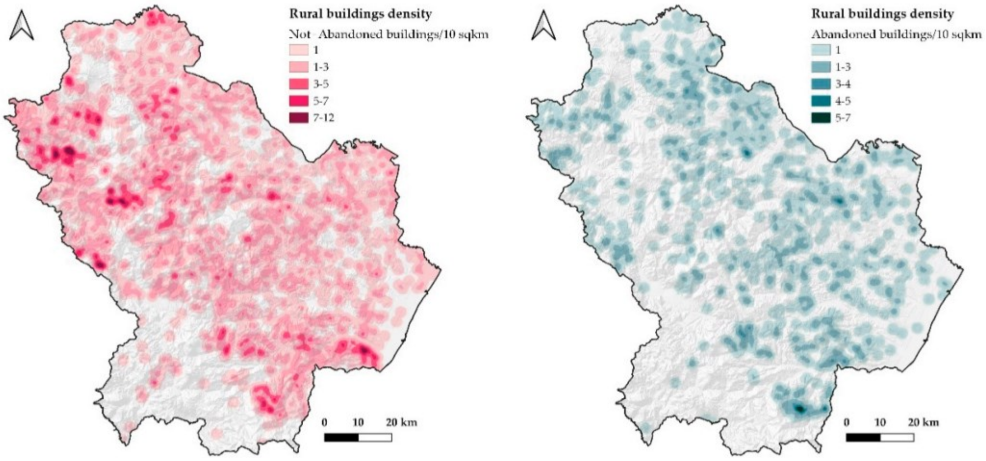

Figure 15: Map of rural buildings density calculated with Heatmap plugins expressed in number per 10 sq. km. Abandoned (left) and not-abandoned (right).

5.1.2.4 Relationship with Farm Buildings Currently in Use for Agricultural Activities

In order to assess the distribution of vernacular farm buildings over the regional territory as well as their relationship with the surrounding landscape, it was necessary to compare the connection that exists between the abandoned and the not-abandoned rural buildings with the other modern agricultural buildings currently in use. With this aim, we queried the regional geodatabase of buildings, to extrapolate the position of buildings classified as “agricultural” and recently built. Through use of the plugin NNJoin, we were able to obtain a result layer as a vector file that contained all the attributes plus new information, including the distance between the joined nearest features. By setting the input layer as the one with abandoned and not-abandoned farms and the joined layer as one of the farm buildings currently in use for agricultural activities, it was possible to have a graduated map of each vernacular farm in relation to the orthogonal distance from the nearest agricultural building. In this way, we could characterize each farm in relation to this distance and hence identify the degree of isolation of individual buildings from the agricultural agglomerations currently active.

5.1.2.5 Relationship with Road Network

Similar to the previous operation, we carried out a spatial analysis of vernacular farm buildings and the road network. As far as the latter is concerned, a vector layer of the regional geodatabase was used. It included only the most important roads (motorways, main, secondary, and municipal roads), excluding minor roads such as paths, forest roads, and rural roads. This exclusion is because these types of roads, especially in some territorial contexts, are little exploited and managed as they are often privately owned and built to reach cultivated fields or land properties in general. Therefore, the main road network has a greater value in terms of usability and fruition. Using again the NNJoin plugin, it was possible to relate each rural building to the nearest road, by associating the distance in meters. This operation allowed us to create a basic vector that can be used for static surveys and other, more complex spatial operations.

5.1.2.6 Relationship with Topographical Parameters

In order to understand the relationships between the abandoned and the not-abandoned vernacular farm buildings on the one hand and some important topographical variables that characterize the landscape on the other, a one-hectare-square buffer zone was created around each building. For each one of these square buffer zones, we calculated the average values of the following parameters:

- Altitude: height above sea level;

- Slope: based on first-order derivation estimation, it expresses the maximum gradient angle for each pixel in degrees.

In addition to these parameters, two more indices that are widely used for landform classification were also implemented (De Reu et al., 2013; Amatulli et al., 2018):

- Topographic Position Index (TPI): this index measures the topographic position of a central point as the difference between the elevation at this point and the average elevation within a certain established area. Negative TPI values represent the valleys and thus a lower position than the areas. Positive TPI values represent the ridges and therefore positions above the average refer to the surrounding environment. TPI values close to zero represent flat areas or areas with a constant slope (where the slope of the point is greater than zero). The topographic position is a phenomenon that depends on the scale (Weiss, 2019).

- Terrain Ruggedness Index (TRI): to express the difference in elevation between adjacent cells of a digital elevation grid, the process automatically calculates the difference in elevation values between a cell in the central position and the eight cells that surround it. The higher the value is, the rougher the land is (Riley et al., 1999).

To calculate these indices, we used the DEM of the Basilicata Region (cell size 5 m) and calculated with the QGIS Raster Based Terrain Analysis Plugin. Subsequently, the statistics and the box-plot of altitude, slope, TPI, and TRI versus abandoned/not-abandoned rural buildings were elaborated to assess the separateness of buildings. This approach proved very useful for identifying whether abandonment could also be influenced by landscape landform and especially for identifying areas where rural buildings could be susceptible to abandonment.

5.1.2.7 Visual Impact of Rural Buildings

Viewshed analysis is a typical tool used to assess the visual impact of a rural building. Visibility strongly depends on the morphology of the terrain, but other parameters can influence the calculation of the viewpoint, such as the height of the observer as well as that of the observed object, vertical and horizontal viewing angles, the presence of different physical obstacles (e.g., vegetation, buildings, characteristics of the landform), the curvature of the Earth, and the weather conditions. The viewshed calculations involve the use of a Digital Surface Model (DSM) with a horizontal resolution of 5 m, which includes vegetation, buildings, and other heights of vertical structures in order to partially mitigate the problem of alteration of visibility conditions from these elements. To perform this calculation, we used the QGIS plug-in Viewshed Analysis. It allows the facilitation of operations when it is necessary to set multiple different parameters and work with large amounts of data. The calculation allowed us to extrapolate the areas in which each rural building considered a valuable asset of the landscape — which improves cultural and aesthetic qualities — is visible within a pre-imposed radius of 1 km. The result was an integer raster grid, in which each cell stored the number of visible rural buildings. The sum of the areas with a radius of 1 km around each rural building provided the potential visible area. This potential visible area was compared with the real visible area, i.e., the area from which each rural building may be observed without being obscured by any obstacle, that came out from the raster grid. In this way, it was possible to identify the area in which each rural building had a greater visual impact in order to discriminate, at the level of large-scale planning, the areas that need more attention and monitor the aesthetic quality of the landscape.

5.1.3 Results

The creation of this geodatabase provided several kinds of information that can be employed as a source for an integrated spatial analysis of the rural landscape as well as a relevant planning and management tool for public decision-makers. In fact, due to the possibility of consulting and integrating different types of data, it was possible here to expand studies on the consistency of the rural heritage information that was gathered in the past, including rural buildings of considerable historical and architectural interest.

5.1.3.1 Rural Buildings: Distribution and Density

We identified a total of 3242 rural buildings associated with the toponym masseria. Among these, we classified just over 25% (n. 816) as ruined/abandoned. From the location of both types, it emerged that the farms are distributed throughout the region except for the south-west part. This needs further investigation to assess whether this lack is due to the actual inconsistency of rural buildings being defined as “farms” or another classification. From the clustering of the different typologies, it emerged that abandoned rural buildings, except for some areas, do not form important agglomerations; on the contrary, the not-abandoned rural buildings form large clusters in different areas of the region (Figure 16).

5.1.3.2 Relationship with Farm Buildings Currently in Use for Agricultural Activities

Concerning the analysis of the relationship between vernacular rural buildings — abandoned and not abandoned — with the linear distance with respect to new farm buildings currently in use for agricultural activities (Table 12), it can be seen that abandoned rural buildings are, on average, 532.76 m away from new rural buildings (Figure 16), more than twice as much as not-abandoned buildings (256.95 m). This shows a certain tendency for vernacular farm buildings to be far from the most important agricultural centres. There is a certain variability in the distribution of data in the different distance classes (Figure 17) compared to the not-abandoned ones, which are instead almost totally distributed in the first distance class. The distance from the new rural centers for agricultural activities is certainly an important parameter to be considered. This method allowed us to quantify it and to include it in spatial operations in a fairly effective and accurate way for the evaluation of the potential impacts of traditional buildings on the landscape.

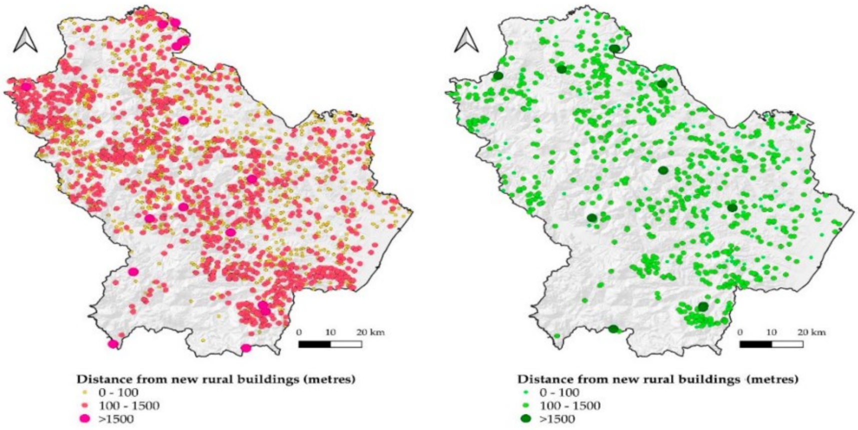

Figure 16. Map of the distance of the abandoned (left) and the not-abandoned (right) vernacular rural building from the new farm buildings currently in use for agricultural activities.

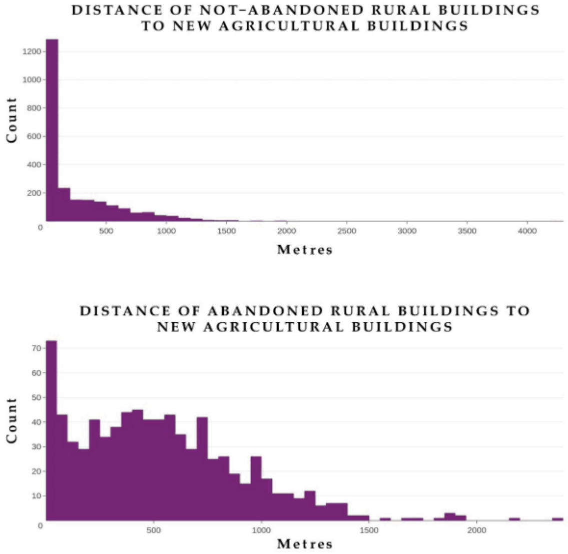

Figure 17: Distribution of not-abandoned vernacular rural buildings (above) and abandoned vernacular rural buildings (below) with respect to the distance from new farm buildings currently in use for agricultural activities.

Table 11: Average, minimum, maximum, and standard deviation of the distance (expressed in meters) of each typology of vernacular rural buildings from new farm buildings currently in use for agricultural activities.

Rural Buildings	**Mean**	**Min**	**Max**	**Std. Deviation**
Abandoned	532.76	19.15	2355.63	382.48
Not Abandoned	256.95	16.25	4210.21	355.76

5.1.3.3 Relationship with Road Network

The analysis carried out for the distance to the main road network showed that the more isolated the farms were, i.e., more distant from the main roads, the more their abandonment relentlessly continued (Table 12). The average distance from the main road network is 46.68 m for not-abandoned buildings with almost all of the farms being distributed within 100 m (Figure 18 and 19). Also, many of the abandoned farms fall within the first class, but they are more distributed in the other classes with a much higher (about 135 m) average value.

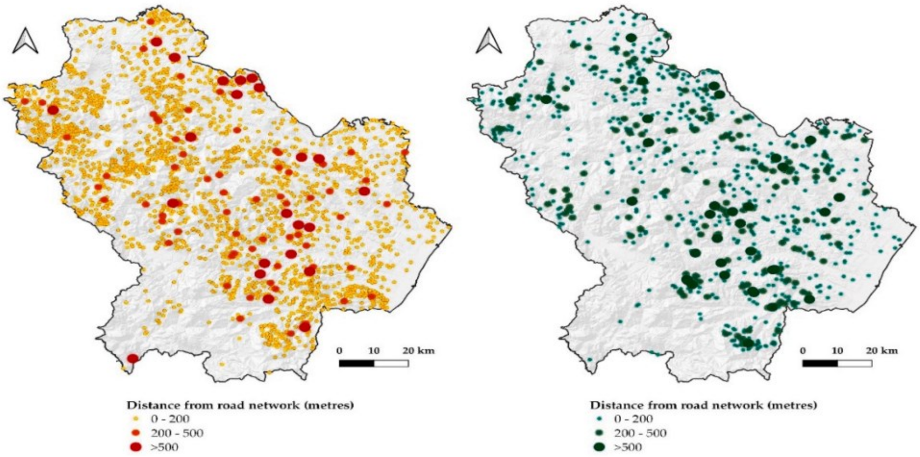

Figure 18. Map of the distance of the abandoned (left) and not-abandoned (right) vernacular rural buildings from the main road network.

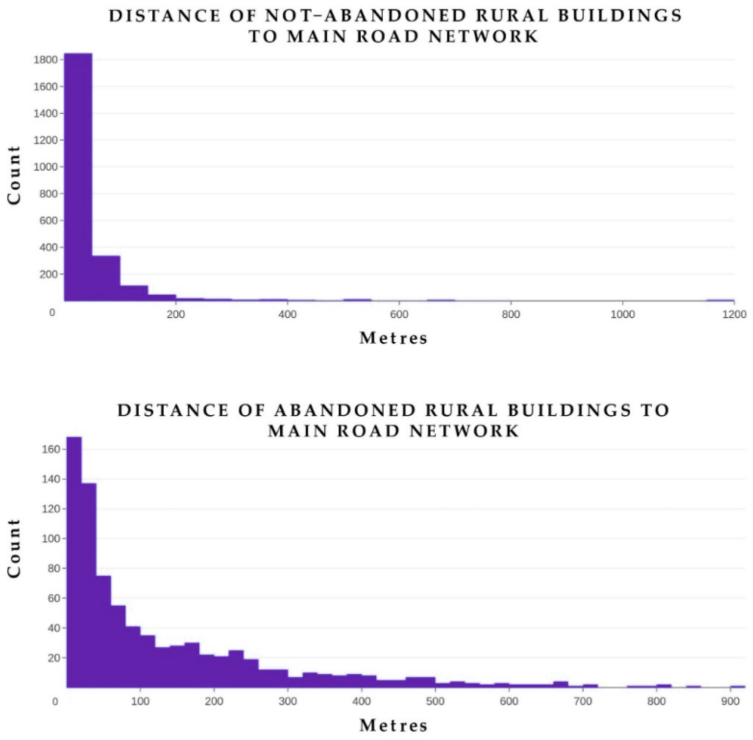

Figure 19: Distribution of not-abandoned vernacular rural buildings (above) and abandoned vernacular rural buildings (below) with respect to the distance from the main road network.

Table 12: Average, minimum, maximum, and standard deviation of the distance in meters of the two typologies of vernacular farm buildings from the main road network.

Rural Buildings	Mean	Min	Max	Std. Deviation
Abandoned	135.01	4.54	918.01	158.23
Not Abandoned	48.68	2.92	1152.65	79.97

5.1.3.4 Relationship with Topographical Parameters

As far as the relationship between topographical parameters and rural buildings is concerned, what emerged in general is that there is no parameter showing a clear influence on the abandonment of rural buildings (Figure 20). Analyzing their average values in detail (Table 3), we note that, in general, the rural buildings (abandoned and not) are located in areas of the region with an average altitude 500 m above sea level in mid-slope areas (with slope value around 10–11° and TPI with positive values tending toward hilltops). From the differentiated analysis, it emerged that the abandonment is more distributed along all the values for the four topographical parameters when compared to the values of the not-abandoned farms (Figure 21).

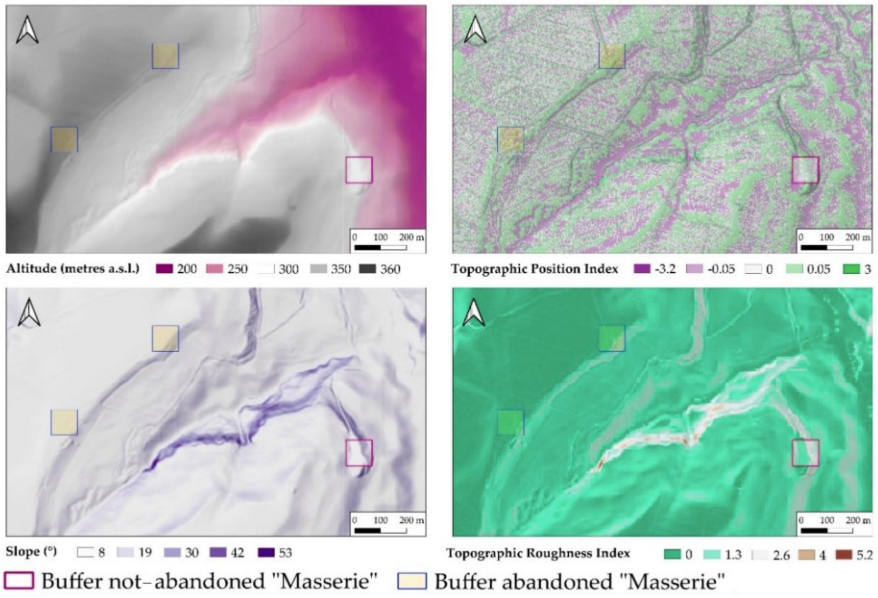

Figure 20: Extract of a part of the study area representing the four different topographical parameters. As an example, the square buffers of some types of farms in the area are also reported.

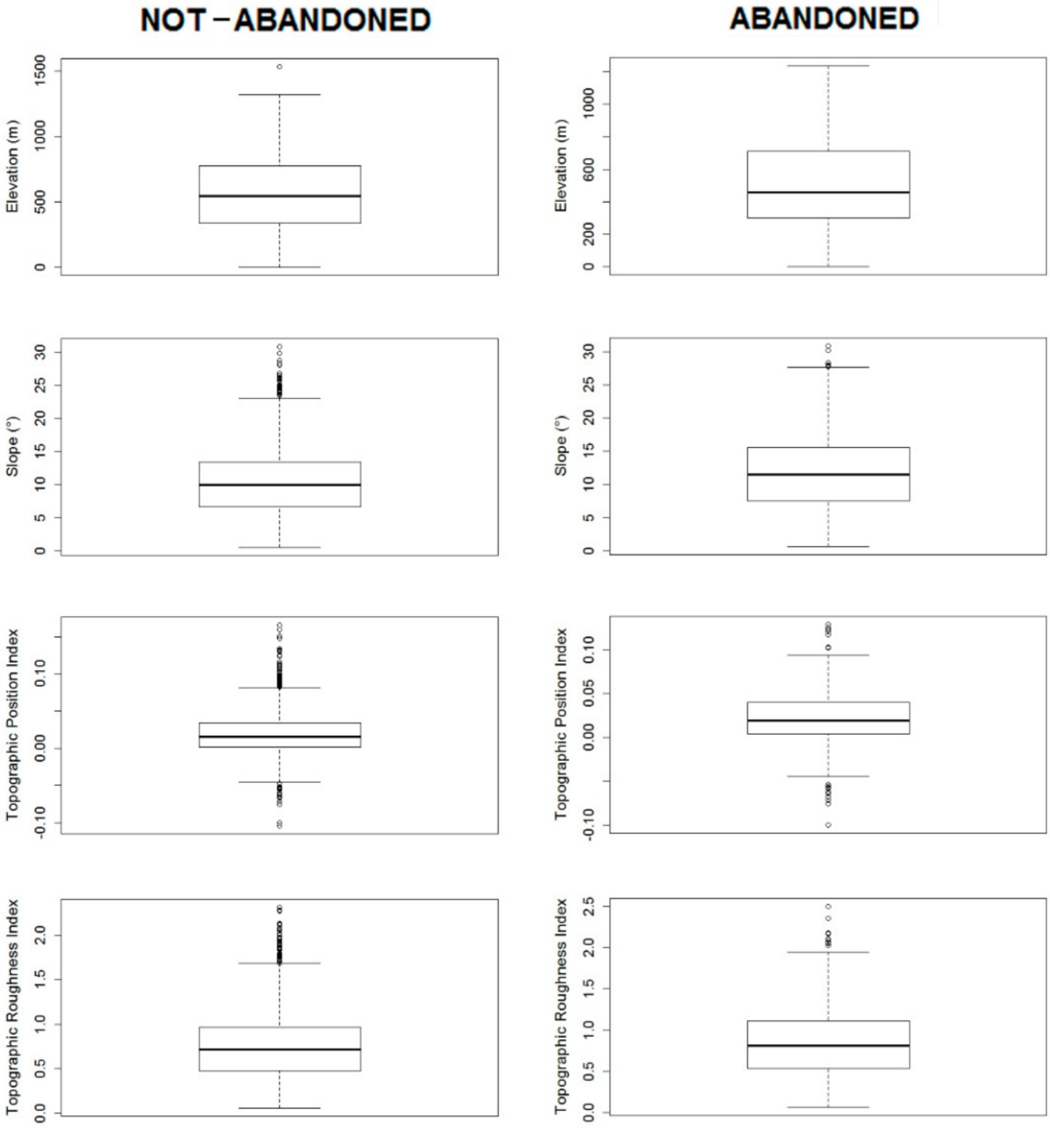

Figure 21. Box plots of the relationships between topographical parameters (altitude, slope, TPI, and TRI) for abandoned and not-abandoned vernacular rural buildings. Circles indicate outliers; horizontal lines inside the box indicate the median value of each parameter. The bottom of the box is at the first quartile (25% of distribution), and the top is at the third quartile (75% of distribution) value, while whiskers indicate variability outside the upper and the lower quartiles.

Table 13: Average and standard deviation of the four topographical parameters [altitude, slope, Topographic Position Index (TPI), Terrain Ruggedness Index (TRI)] considered for analyzing abandoned and not-abandoned rural buildings.

	Altitude (m)	**Slope (°)**	**TPI**	**TRI**
Abandoned	506.27 ± 276.15	11.67 ± 5.87	0.022 ± 0.029	0.845 ± 0.436
Not Abandoned	551.33 ± 277.89	10.24 ± 5.12	0.019 ± 0.028	0.744 ± 0.377

5.1.3.5 Visual Impact of Rural Buildings

The analysis of the inter-visibility between landscape and rural buildings enabled us to estimate, on the basis of the parameters set in the plugin, the total surface area of the potentially visible area with 1 km radius, which is visible from the rural buildings. This total potential visible area is equal to 256,224 ha for abandoned rural buildings and 761,764 ha for not-abandoned rural buildings. The total real visible areas, which were obtained after excluding the area inside the 1 km radius from which each rural building may not be observed (since they are hidden by some obstacles), were respectively 20.1% and 26.9% of the whole potential visible area (Table 14). Therefore, generally, we can conclude that the rural buildings considered have a relatively limited visible impact area. Moreover, the visible area for both types of buildings (abandoned and not abandoned) and the greatest visual impact is limited to some individual buildings (Figure 22). In Table 14, it is possible to notice that just over 85% and almost 93% of the visible area include only one building. It should also be noted that, with regard to the abundant buildings that have a greater interest in the impact they can have on the landscape, the visible area is almost exclusively linked to isolated farms (almost 100% if we also consider class 2). For buildings that are not abandoned, the situation is similar, but there are also values for the upper classes. Highlighting these areas through this methodology may reveal an important issue for planning purposes because, in order to have an impact on the surrounding landscape, these are the areas that are most visible. Therefore, they need more accurate monitoring in order to avoid radical transformations of their rural landscape identity.

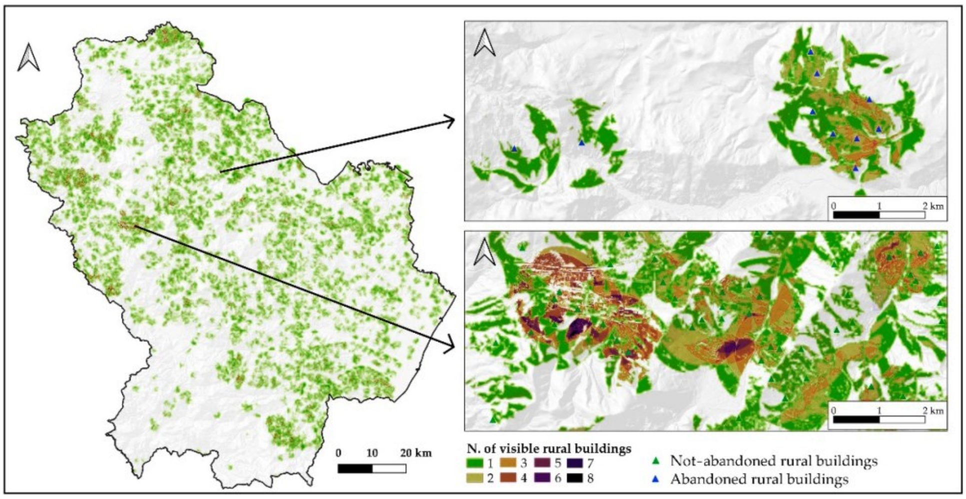

Figure 22: Result of the cumulative viewshed analysis for the whole study area. On the right are details of two parts of the study area in which the result is expressed as the number of visible abandoned and not-abandoned vernacular rural buildings

Table 14: Surface in hectares and percentage of number of visible buildings (abandoned and not).

	Not Abandoned		**Abandoned**	
N. of visible buildings	**ha**	**%**	**ha**	**%**
1	174669.12	85.187	47811.12	92.705
2	24256.21	11.830	3390.22	6.574
3	4619.56	2.253	298.76	0.579
4	1176.97	0.574	59.97	0.116
5	271.12	0.132	13.07	0.025
6	48.96	0.024	0.03	0.001
7	4.81	0.002		
8	1.98	0.001		
9	0.03	0.001		
TOT	**205041.93**	**100**	**51573.17**	**100**

5.1.4 Discussion

The continuous increase in both descriptive and geographical open data at all levels leads to increasingly easier retrieval of useful information for issues related to sustainable management territory and landscape. In parallel with this considerable increase in data, there has been a continuous improvement in software and geographical information techniques. These tools allow, in addition to better verification of the accuracy of the data, a diversification of analysis and possible studies. Regarding the elaboration of the geodatabase with different typologies of rural buildings, much depends on the data available from the relevant local authorities. For regions of Southern Italy, the combined approach between regional vector cartography and the toponyms database provided by the Italian Geographic Military Institute can be the first accurate investigation, as demonstrated in other studies (Martínez-Graña et al., 2017). In addition, this approach can be useful in identifying other types of traditional rural structures of considerable interest. Obviously, for a complete realization of a geodatabase that is useful for management, recovery, and enhancement of these rural buildings, it is necessary to make a detailed survey of each one of them that reports the name masseria. The differentiation between abandoned and not-abandoned buildings also depends on the consistency of the database. Alternatively, manual approaches can be used to identify them. The potential of semi-automatic procedures for classifying very high-resolution images or orthophotos to assess the consistency of individual buildings should be investigated as well.

Finally, the creation of concentration maps proved a valid tool for identifying areas of investigation released from the physical location of the building. The abandonment of old rural buildings and their farmlands in general, in addition to causing the loss of an irreversible cultural and ethno-anthropological heritage, is the phenomenon that has the greatest impact on landscape sustainability. This issue requires predictive methods that are able to take into account some new techniques such as machine learning (Xu et al.,2019). Indeed, the main aim of this work is to provide a reliable method to better evaluate the implementation of suitable management practices that aim to examine the integrity, the resilience, and the sustainability of some typical historical rural landscapes. The density of abandoned farms is especially important because it allows us to identify areas where the phenomenon is more concentrated and then go into more detail to understand relevant drivers and causes.

With regard to evaluating the spatial relationships between the two categories of rural buildings (i.e., abandoned and not-abandoned) and some aspects of the landscape, the method proposed here takes into account some aspects that have an influence on abandonment (Lasanta et al., 2015). At the same time, it also gives information about how the different types of buildings have impacted in the past as well as how they could do so in the future, so as to identify the areas that may be most susceptible to abandonment and to reduce the possible impacts with a view to a more sustainable management of the landscape.

The distance from roads is one of the factors that has most determined the phenomenon of abandonment. Considering the importance of this variable, it is necessary to go into even more detail about this parameter by more thoroughly differentiating the different types of roads. At the level of landscape planning, rural buildings not yet abandoned that are close, for example, to areas of high natural value and that are furthest from the main roads are those which more attention must be given, due to the ecological impact that could lead to their abandonment. What mainly arises from the analysis of the relationships between rural buildings and topographical variables is that they have an importance in the dynamics of abandonment and transformation of the rural landscape. In this case study, however, it did not clearly emerge.

Finally, the analysis of the inter-visibility between landscape and farms has proven very useful for evaluating, in spatial terms, the area of visual influence that each type has. This method can be very useful in terms of landscape planning for identifying the areas of visual influence of each farm and for monitoring and possibly directing the actions of conservation and/or restoration of activities related to rural buildings. For example, the areas with the highest visibility and linked to a greater number of abandoned rural buildings are certainly the areas that need more attention from the point of view of sustainable landscape planning. This is in order to prevent this abandonment from leading to radical transformations from the point of view of land use and cover and therefore to a loss of the identity typical of that specific rural landscape. Moreover, starting from this first type of analysis, it would be possible to address the actions of tourism enhancement due to the integration within this geospatial analysis of the network of scenic roads, by assessing the quality of the landscape as well.

With this method, it was possible to identify some parameters that, for the study area, have most influenced abandonment. In order to consider the visual aspect of the area around each farm, the proposed technique provided a fundamental overview to identify, for example, the most visible rural buildings from a stretch of scenic road, which would need more attention in case of abandonment or change of land use. This integrated method proposed here can also be modified and calibrated in relation to the setting of a Visual Impact Assessment (Palmer, 2019). Since it takes into account some parameters, it would prove a useful tool for planners to assess the relationship between landscape and rural buildings. In addition, the parameters can be expanded to take into account geological, socio-economic, and cultural variables, hence contributing to a necessary holistic approach. In conclusion, this integrated method could be very important to realizing basic datasets that could be useful for evaluating whether buildings can have a positive or a negative influence on landscape ecology, by introducing the relationships with the cultivated fields annexed to each single building as well. Moreover, it can be useful in improving knowledge about the field of research of landscape sustainability , as it is a spatial method based on a temporal and a multi-scale approach that combines different aspects that could be useful for the control of different ecosystem services and strictly perceptive features.

5.2 REMOTE-SENSED GEODATA AND HISTORICAL MAPS TO ASSESS THE INTERACTIONS BETWEEN RURAL BUILDINGS AND AGROFORESTRY LAND

5.2.1 Study areas

The case study concerns the municipal territory of Pietragalla (South Italy – Basilicata Region) and it spans about 65km^2. It represents a typical territory of the marginal mountain areas of the Mediterranean and, for this reason, it was chosen as a typical example. This municipality is characterized by areas not "contaminated" by agricultural mechanization processes that continue to flank the regions affected by modernization and where agricultural systems have evolved slowly, leaving visible traces of pre-existing settlements and production conditions. This has also influenced the characteristics and development of rural buildings, which are distributed uniformly throughout the territory without aggregation. Moreover, from a typological and architectural point of view, they are simple buildings for daily or seasonal stay – therefore, for a temporary use. Moreover, this kind of territory is affected by significant phenomenon of land and agricultural abandonment (Figure 23).

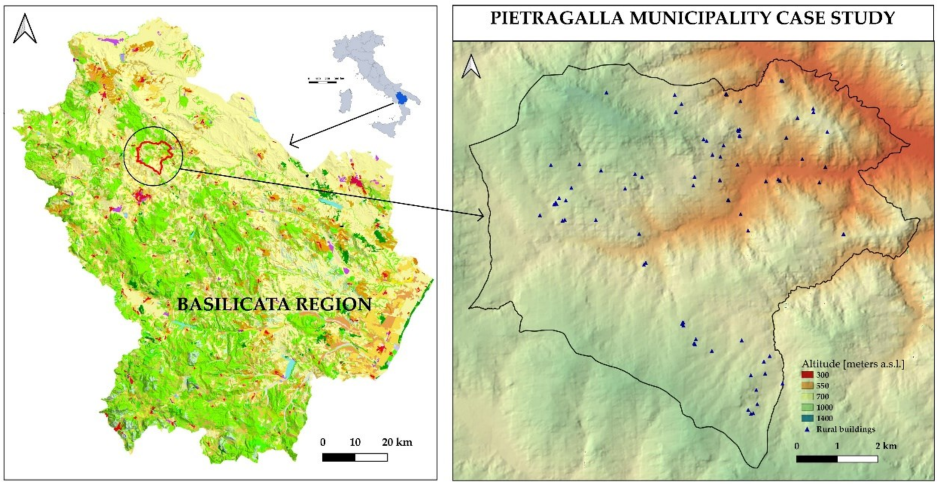

Figure 23: Locations of Pietragalla case studies in Basilicata region (centroid 15.85332E 40.75722N EPSG:4326).

5.2.2 Materials and data processing

The complete analysis was based on 4 years of study (1955 - 1988 - 2008 - 2017) so as to cover the period with greater dynamics of transformation and for which it is possible to retrieve comparable datasets for large-scale analysis (Statuto et al., 2017).

All operations have been carried out only in FoSS environment within an open-source Geographical Information System (QGIS 3.10) which, thanks to different plugins and interoperability with other software, allows a workflow in a single environment (Gobbi et al., 2019). This approach guarantees the possibility to integrate different types of data from historical cartography with datasets from classical cartography to remote sensed data (aerial photos, orthophotos and satellite images).

The first operation was to create the rural heritage geodatabase for the study area. Using the vector open data available in Basilicata region (RSDI, 2020) database, it was possible to select only those buildings that are considered as "agricultural" due to the presence of specific attributes linked to each feature. In detail, 79 rural buildings were selected. Finally, a further selection was made on the basis of the historical continuity of the buildings, only the rural buildings that are certainly present in the 62 years of analysis were selected. Subsequently, considering the objective of studying the relationships between the rural building and the surrounding land, a square buffer of 25 ha around the centroid of each rural building, both those isolated and those close to each other, was taken as the sample area, as it was proposed in other works (McKenzie et al., 2011). Before mapping the land cover, all available cartographies, aerial photos, orthophotos and satellite images were retrieved and processed, so as to be implemented into the GIS.

Considering the differences in the used basic data, pre-processing operations were carried out for each year, in order to create starting raster, on which the digitisation and manual classification of land cover classes were subsequently carried out (Table 15). We opted for this type of mapping considering the reduced surfaces and the need to have a degree of detail and accuracy, that with semi-automatic classifications is more complicated to be obtained. The land cover map so obtained has a Minimum Mapping Unit (MMU) of 0.01 ha, which corresponds to the smallest rural building.

Table 15: Land cover classes used for mapping operations.

Land cover Class	Acronym	Description
Rural buildings	RUR	Constructions classified as "agricultural" in Basilicata region geodatabase (RSDI, 2020). Comprises several categories of rural buildings (rural dwellings, temporary dwellings, stables and warehouses)

Road network	ROAD	Stable roadway having a width of more than 6 metres. Comprises the main road network
Forest area	FOR	Forests and woodland area with a composition of autochthonous Mediterranean species
Afforested area	AFFOR	Area with exotic conifers and allochthonous species planted by men.
Grasslands	GRASS	Natural grasslands often associated with non-cultivated areas. Often located in rugged and sloping land. Often includes rocky ground, moors and occasional pastures. They do not have constant and long-term management and are not of artificial origin.
Arable lands	ARAB	Cultivated land with different crops (cereals, legumes or fodder crops)
Vineyards	VIN	Vineyards
Olive groves	OLIV	Olive groves
Shrubland	SHRUB	Vegetation with low cover, dominated by bushes, shrubs.
Transitional woodland	TRANS	It can represent either woodland degradation or forest regeneration/colonisation. Class representing natural development of forest formations, consisting of young trees species, shrubs, dispersed solitary adult trees and herbaceous vegetation.
Built-up area	BUILT	Built-up areas realised by man (buildings and connected surfaces). Rural buildings are excluded, as they represent a separate class
River zone	RIV	“Atella” River area and the riparian vegetation existing along the river.
Chestnut forest	CHEST	Forest areas made up of chestnut trees. It has been separated from the forest area because the "chestnut forest" is a typical feature of study area. They have an artificial origin, but over time they have become a semi-natural habitat.

Figure 24: Sample details extract on some remote sensed data used in this study: 1955 aerial photo, 1988 B/W orthophoto, 2008 and 2017 true colors orthophotos.

1955 dataset

The same type of aerial photos used in the previous Forenza and Vulture case studies (Section 4.1.2 and 4.2.2) were processed. Considering that study areas are limited in terms of surface area, and do not present particular morphology and characteristics, a series of geo-referencing operations were carried out for each group of rural buildings, identifying, time by time, a sufficient number of Ground Control Points (GCP) on more recent orthophotos (1988 – 2017) already geo-referenced. A polynomial correction was applied in series, that guaranteed Root Mean Square Error even below 5 meters in some cases. This operation has produced several geo-referenced rasters, each one associated and clipped with respect to the buffer of each individual rural building.

After this operation, the land cover classes (Table 15) were mapped by manual digitisation. Also for this operation, it has been possible to carry out semi-automatic classification operations, but given the reduced surface areas, the manual procedure has been chosen as more speditive (Gobbi et al., 2019) in order to improve the identification of the different classes. The 1:25,000 scale maps of the 1955 IGMI were also used as an additional support.

1988 dataset

For the year 1988, the orthophotos already georeferenced supplied by the Italian Ministry of the Environment (WMS service) have been used. These orthophotos are in 1:10,000 scale. Satellite images have been used to improve classification and especially to distinguish land cover classes that may be difficult to interpret. They have been used to distinguish arable lands from grasslands, which in many cases, and considering the period when orthophotos are taken, are difficult to differentiate in some situations. Specifically, satellite images of the Landsat 5 TM mission of several months and in correspondence with the different phenological periods of the vegetation, were used by comparing the spectral signatures of the different patches (Filizzola et al., 2018). These have been downloaded and pre- and post- processed directly in QGIS by SCP (Congedo, 2016). This step allowed to discriminate the grasslands from the cereal areas, which were then digitized manually.

2008 dataset

To process the 2008 dataset, the AGEA (Italian Agency for Agricultural Payments) orthophotos, already georeferenced through the WMS service provided by the Basilicata Region, were used. Also in this case, the manual classification of cereal fields and pastures was helped through the integration with Landsat 5 TM satellite images.

2017 dataset

For the year 2017, already georeferenced AGEA orthophotos have been used, to which Sentinel-2 L2A images have been associated. In this case, the integration was more efficient, thanks to the characteristics and usability of these satellite images for purposes related to crop detection (Belgiu and Csillik, 2018).

Land cover changes

After mapping the land cover for each year of study and for each rural building buffer, a first generic evaluation of the territorial patterns was carried out through a quantitative analysis of the areas in terms of hectares. On the basis of these data, an immediate survey was carried out through the Sharpe Index (Hulshoff, 1995), that allows to easily understand what were the main changes of a given land or landscape in a certain period of time, since this index gives the measure of the "speed" – or, rather, the intensity - of the territorial transformations. The Sharpe index is applied to individual types or classes of land cover, and can be either positive or negative. If this value assumes a positive value, we are in presence of a land cover that has recorded an increase in area in the reference period, while if the value assumes a negative sign, the land cover in question has reduced its surface. This index is very useful to quickly identify the land cover most responsible for the changes in a certain period. Since Sharpe's index does not highlight the extent of different land uses in terms of hectares, a more detailed analysis was carried out through the cross-classification, directly between vectors to identify the quantitative transformation trajectories of each land cover class for the periods 1955-1988, 1988-2008, 2008-2017. In addition to the data tabulation, Sankey diagrams were produces (Cuba, 2015). It is a graphical approach to show the land cover data contained in one or more cross-tabulation matrices based on Sankey's diagrams, which simplifies visual interpretation and efficiently translates land cover changes over multiple time intervals. The graphical visualization of land cover dynamics with Sankey diagrams does not remove the usefulness of reporting detailed measures of land cover dynamics in tabular form, but rather gives benefits that are complementary to those of cross-tabulation matrices.

To answer the question: have the transformations occurred equally around every rural building? The % of “change” and “no change” in each buffer has been calculated individually. This allows a kind of discrimination enabling to provide information about areas and farm buildings that need more attention from a land management point of view. In addition, it is possible to obtain general statistics to evaluate how the ratio between changed and unchanging areas varies for the different periods of analysis (1955-1988; 1988-2008; 2008-2017).

By imposing the 50% value as a limit, rural buildings buffers have been identified that have undergone, in the three periods, a change in terms of surface area greater than 50%. The limit in this statistical discrimination could be determined by a specific land indicator, that a public decision-maker can use based on objectives and needs.

Finally, for a first survey on the causes of the transformation phenomena in the areas surrounding some rural buildings buffers, these (selecting those with changes greater than 50%) have been related to the slope raster, which has been calculated starting from the Digital Terrain Model DTM at 5 meters resolution (RSDI, 2020). Being a preliminary investigation, only the slope was considered, as it represents one of the main drivers in the abandonment processes. This analysis also presupposes a statistical evaluation, so a box plot has been made to highlight how the slope varies with respect to the periods of change and where no changes have occurred. Thanks to the use of DataPlotly (DataPlotly, 2020) a QGIS plugin, it has been possible to realize the boxplot, working directly on the shapefiles and without changing the working environment.

5.2.3 Results and discussion

Agroforestry land cover dynamics

The land cover maps produced for the four different chronological levels, in which the relevant areas for each land cover class (expressed in ha and %) are summarized, are shown in Figure 25. These data are also shown in Table 16, where the net change for each time-lapse was also calculated for the whole 62-years period. The analysis enabled through the identification of the general dynamics of the agroforestry land of the study, shows that some areas have radically changed during the whole 62-years period considered.

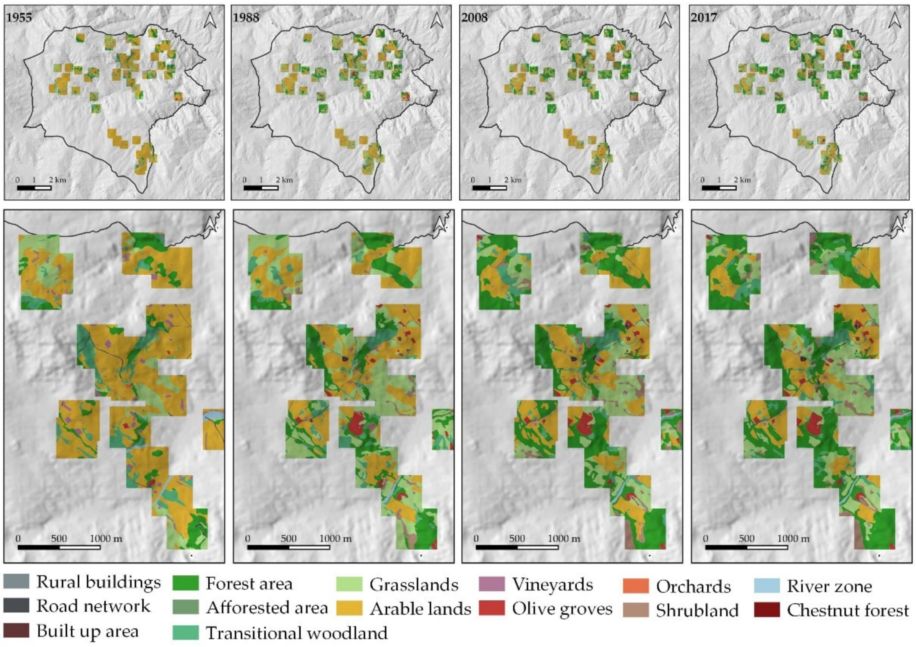

Figure 25: Land cover map for Pietragalla case study. A general overview of the boundary of the municipality analyzed and below a detail of some buffers.

Table 16: Total surface for each land cover class (expressed in ha and %) over the years.

	1955		**1988**		**2008**		**2017**	
	ha	*%*	*ha*	*%*	*ha*	*%*	*ha*	*%*
RUR	1.82	0.15	2.78	0.23	3.04	0.25	3.18	0.26
ROAD	8.56	0.69	13.06	1.06	12.51	1.01	12.70	1.03
FOR	155.22	12.59	244.76	19.85	361.67	29.33	395.21	32.05
GRAS	123.83	10.04	304.01	24.65	212.97	17.27	283.75	23.01
ARAB	815.28	66.11	516.60	41.89	455.61	36.95	339.39	27.52
VIN	9.38	0.76	7.98	0.65	9.50	0.77	11.44	0.93
OLI	7.30	0.59	30.80	2.50	40.71	3.30	39.91	3.24
ORC	0.65	0.05	2.20	0.18	11.49	0.93	12.26	0.99
SHRUB	14.91	1.21	34.54	2.80	53.73	4.36	54.49	4.42
TRANS	87.48	7.09	73.75	5.98	67.08	5.44	73.88	5.99
BUILT	0.00	0.00	1.53	0.12	2.94	0.24	5.15	0.42
RIV	8.76	0.71	1.17	0.09	1.94	0.16	1.83	0.15
	1233.18	**100.00**	**1233.18**	**100.00**	**1233.18**	**100**	**1233.18**	**100**

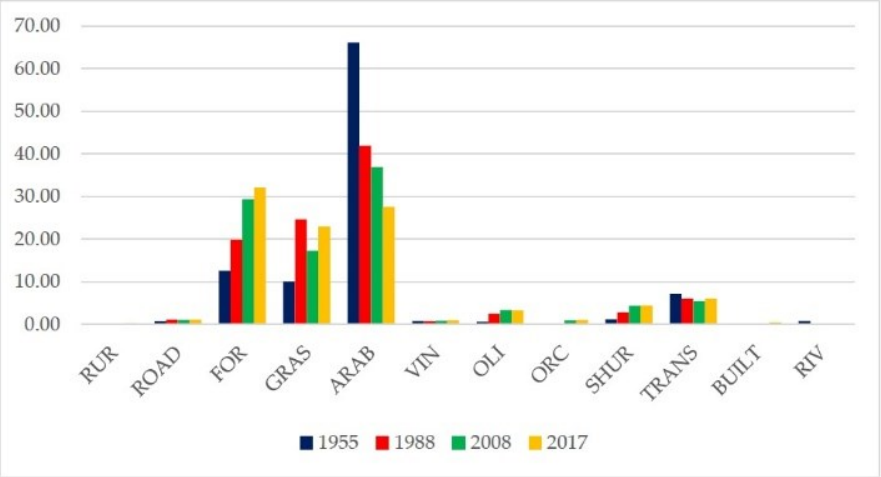

Figure 26: Land cover histograms (in percent) for different years of analysis.

From the analysis of the tables and graphs, it emerges for both case studies, that rural buildings buffers are mostly covered by agricultural areas (Figure 26). In particular, between 1955 and 1988, arable lands decreased from 815.28 ha to 516.60 ha, with a drastic reduction that continued in the following years.

The datasets need a comparative analysis by couple of years progressive, to assess how the land has evolved. A first and intuitive indication on which are the classes of land cover that have most influenced the transformations is given by the Sharpe index (Figure 27). In fact it emerges that the land cover classes most affected by the dynamics are: arable lands, grasslands, shrublands and transitional woodlands.

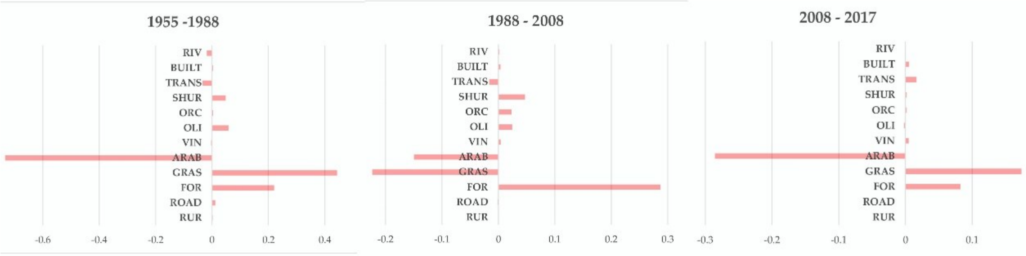

Figure 27. Sharpe index visualization.

In order to allow a more detailed analysis, a contingency matrix has been created. This is a type of detection of the changes obtained through a cross-tabulation analysis, which allows to highlight the changes occurred over time both in qualitative terms - showing them directly on the map - and in quantitative terms, allowing the calculation of the total extension of the land cover change occurred at different times. Through the direct geoprocessing of vector data, it was possible to exploit the functionality of the Group Stats plugin (Group Stats, 2020) which allows to realize a vector-based cross-tabulation matrix for each period of analysis and then export the results to a table (Table 17,18 and 19). The tables created show the proportion (hectares) of unchanged area for each land cover class for each time-lapse (on the diagonal), as well as changes from one land cover class to another (off the diagonal). The rows show the areas each land cover class has transformed into the relevant class reported in the columns in the period analysed. For example, it is noted that in the period 1955-1988, a surface of 205.32 ha of arable lands turned into grasslands and another part (about 60 ha) into forest area. The last ones have increased both because of the abandonment of agricultural areas, but also because of the natural succession of about 45 ha of transitional woodlands, which have been restored by other processes of abandonment of agricultural areas and natural evolution of grasslands and shrubs. There is also a modest increase in artificial land cover classes, farm buildings and roads. This anthropization process has occurred almost exclusively at the expense of agricultural areas (almost 9 ha). In the second period (1988-2008) the dynamics are more or less similar in terms of general trends, but concerning lower surface areas, even because to a period more short than the previous one, as well as because the transformation processes slowed down, since most of the agricultural land was lost in the previous period. What increased considerably is the interchange between the classes of land cover typical of a territory defined as agro-pastoral forest (FOR, SHRUB, GRASS and TRANS). In fact, even if in terms of total area, the areas do not vary much, within these classes there is a high dynamism; this is due to the natural phases of ecological succession and renaturalization of abandoned agricultural areas and partly to the reduction of pastures that has led to an acceleration of the transformation processes in FOR and TRANS (Bracchetti et la., 2012). As far as artificial built-up areas and rural buildings are concerned, there are no substantial variations. For the third period (2008-2017), apart from a further transformation of 119 ha between arable lands and grasslands, there is some stability both in terms of areas and in terms of dynamism between the different land cover classes.

As far as the river zone is concerned, it can be noted that only in the year 1955 it had a significant surface weight (almost 9 ha). Over the years, the approximately 7 ha of river zone have been lost and they have been transformed mainly into forest (specifically into hygrophilous forest vegetation); the riverbed has been reduced consequently to the reduction of water flow from the surrounding areas, which in the past were mostly agricultural areas, and which over time have become forest or shrubland areas which incorporate part of the rainwater.

Table 17: Cross-tabulation matrix—1st Period: from 1955 to 1988 [Ha].

1955/1988	**RUR**	**ROAD**	**FOR**	**GRAS**	**ARAB**	**VIN**	**OLI**	**ORC**	**SHRUB**	**TRANS**	**BUILT**	**RIV**	**TOT 1955**
RUR	**1.07**	0.00	0.12	0.11	0.23	0.12	0.14	0.01	0.01	0.00	0.00	0.00	**1.83**
ROAD	0.00	**4.90**	0.73	0.53	1.30	0.10	0.08	0.07	0.20	0.66	0.00	0.00	**8.56**
FOR	0.01	0.76	**114.77**	12.77	6.50	0.31	0.96	0.05	4.45	14.68	0.04	0.00	**155.31**
GRAS	0.13	0.37	12.79	**65.00**	25.07	0.44	2.29	0.00	6.56	11.25	0.00	0.00	**123.91**
ARAB	1.35	6.15	61.89	205.32	**467.55**	6.54	20.74	1.78	16.78	25.10	1.27	0.36	**814.83**
VIN	0.04	0.00	0.37	3.43	3.46	**0.00**	1.60	0.00	0.40	0.22	0.06	0.00	**9.58**
OLI	0.00	0.06	0.94	0.56	1.68	0.21	**3.31**	0.28	0.03	0.23	0.00	0.00	**7.28**
ORC	0.00	0.02	0.00	0.03	0.16	0.00	0.05	**0.00**	0.11	0.30	0.00	0.00	**0.65**
SHRUB	0.00	0.04	2.63	4.69	2.39	0.03	0.14	0.00	**2.66**	2.33	0.02	0.00	**14.92**
TRANS	0.18	0.67	45.52	9.29	8.09	0.23	1.50	0.00	2.91	**18.92**	0.13	0.06	**87.52**
BUILT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	**0.00**
RIV	0.00	0.09	5.00	2.26	0.19	0.00	0.00	0.00	0.42	0.05	0.00	**0.75**	**8.77**
TOT 1988	**2.78**	**13.06**	**244.75**	**304.00**	**516.61**	**7.98**	**30.80**	**2.20**	**34.54**	**73.75**	**1.53**	**1.17**	**1233.18**

Table 18: Cross-tabulation matrix—2st Period: from 1988 to 2008 [Ha].

1988/2008	RUR	ROAD	FOR	GRAS	ARAB	VIN	OLI	ORC	SHRUB	TRANS	BUILT	RIV	TOT 1988
RUR	**2.23**	0.00	0.10	0.03	0.19	0.00	0.01	0.00	0.03	0.19	0.01	0.00	**2.78**
ROAD	0.00	**11.72**	0.23	0.49	0.33	0.00	0.05	0.00	0.04	0.20	0.00	0.00	**13.06**
FOR	0.02	0.24	**226.11**	2.22	3.67	0.02	1.04	0.22	1.82	8.56	0.02	0.83	**244.76**
GRAS	0.14	0.14	57.88	**121.86**	61.01	0.70	5.30	3.27	30.43	22.69	0.50	0.10	**304.02**
ARAB	0.59	0.38	14.64	81.90	**381.61**	4.53	8.94	5.81	7.73	9.47	0.98	0.00	**516.58**
VIN	0.00	0.00	0.05	0.32	1.75	**4.07**	1.18	0.00	0.33	0.28	0.01	0.00	**7.98**
OLI	0.01	0.00	3.99	0.64	0.87	0.12	**22.47**	0.85	0.94	0.79	0.12	0.00	**30.80**
ORC	0.01	0.00	0.00	0.00	0.16	0.00	0.62	**1.34**	0.00	0.06	0.00	0.00	**2.20**
SHRUB	0.00	0.00	12.51	3.07	2.50	0.03	0.29	0.00	**9.58**	6.51	0.01	0.05	**34.54**
TRANS	0.02	0.03	45.77	2.47	3.36	0.01	0.83	0.00	2.82	**18.39**	0.06	0.00	**73.75**
BUILT	0.02	0.00	0.06	0.00	0.16	0.00	0.00	0.00	0.00	0.08	**1.22**	0.00	**1.53**
RIV	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.96**	**1.17**
TOT 2008	**3.04**	**12.51**	**361.54**	**212.99**	**455.59**	**9.50**	**40.72**	**11.49**	**53.73**	**67.21**	**2.93**	**1.94**	1233.18

Table 19: Cross-tabulation matrix—3st Period: from 2008 to 2017 [Ha].

2008/2017	RUR	ROAD	FOR	GRAS	ARAB	VIN	OLI	ORC	SHRUB	TRANS	BUILT	RIV	TOT 2008
RUR	**3.00**	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**3.04**
ROAD	0.00	**12.51**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**12.51**
FOR	0.03	0.00	**345.98**	2.24	1.76	0.01	0.09	0.02	1.88	9.67	0.00	0.00	**361.67**
GRAS	0.00	0.00	8.59	**156.00**	16.95	0.48	0.59	0.00	18.44	11.91	0.00	0.00	**212.97**
ARAB	0.03	0.19	4.86	119.01	**316.88**	2.00	1.01	0.78	4.33	4.15	2.38	0.00	**455.62**
VIN	0.00	0.00	0.00	0.33	0.34	**8.73**	0.06	0.00	0.01	0.03	0.00	0.00	**9.50**
OLI	0.00	0.00	1.03	1.21	0.62	0.00	**37.43**	0.12	0.09	0.22	0.00	0.00	**40.71**
ORC	0.00	0.00	0.02	0.00	0.14	0.00	0.00	**11.33**	0.00	0.00	0.00	0.00	**11.50**
SHRUB	0.11	0.00	8.28	3.43	1.15	0.01	0.65	0.01	**26.22**	13.87	0.00	0.00	**53.73**
TRANS	0.00	0.00	26.34	1.42	1.54	0.22	0.08	0.00	3.52	**33.96**	0.00	0.00	**67.08**
BUILT	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.06	**2.77**	0.00	**2.93**
RIV	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.83**	**1.94**
TOT 2017	**3.18**	**12.70**	**395.21**	**283.74**	**339.40**	**11.44**	**39.91**	**12.26**	**54.49**	**73.88**	**5.15**	**1.83**	**1233.18**

For a qualitative assessment of the data of the matrices previously mentioned and for an immediate analysis of the tabular data, Sankey diagrams have been created (Figure 28) to track the changes occurred in the three periods of analysis and for both case studies. Considering the number of classes used, the resolution of the data, and analyzing the transition matrices, it was preferred to make the diagram only for the most dynamic classes, which are also those of interest from an agroforestry point of view.

These classes refer to arable lands, forest area, shrublands, grasslands and transitional woodlands, which represent important coverage classes for the evaluation of the evolution of natural and semi-natural habitats typical of Mediterranean rural landscapes and which are the ones that have most influenced the transformations, as also emerged from the Sharpe index.

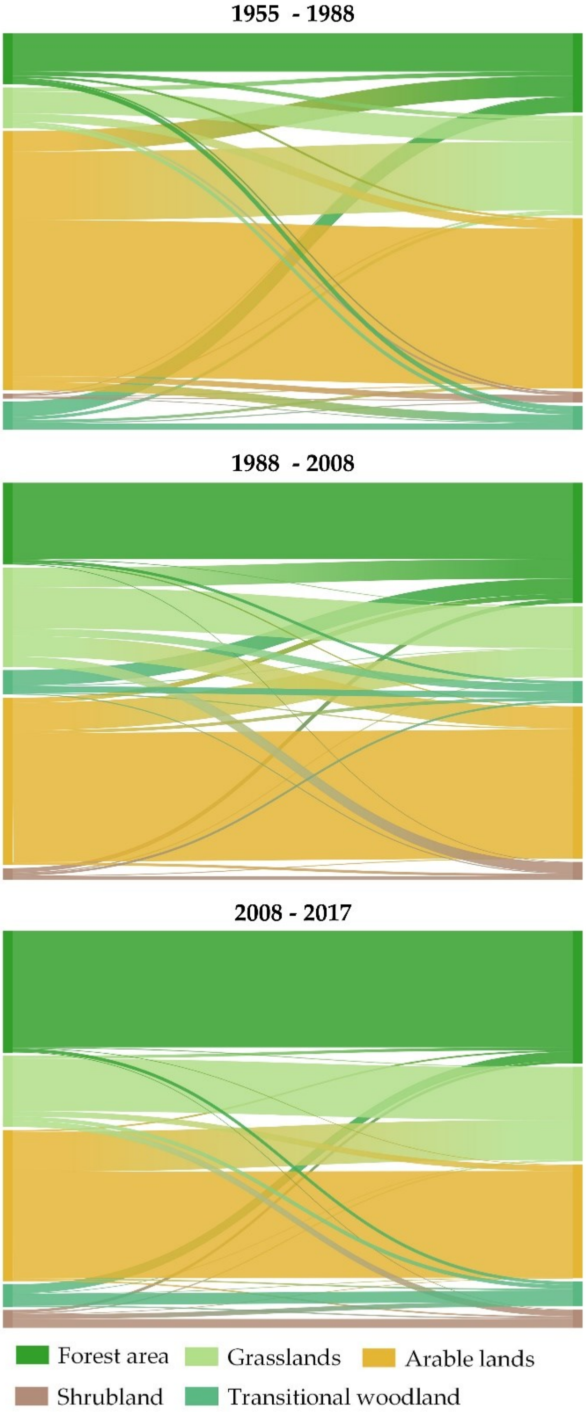

Figure 28: Sankey diagram for the dynamics of transformation of the main classes of agroforestry land cover for the three study periods

Rural building buffer area dynamics

Figure 29 and Table 19 show how in Pietragalla case study, rural buildings - whose buffer area has changed more than 50% - are very evident. But what is most noticeable, is that the major changes between rural buildings and territory occurred in the period 1955-1988, when in 34% of the buffers these important changes in land cover occurred. In the other periods the data in table 19 show how the land cover changes occurred in a distributed way in all rural buildings buffers and only in a few situations (with maximum values around 7.5%) there was a radical change within rural buildings buffers.

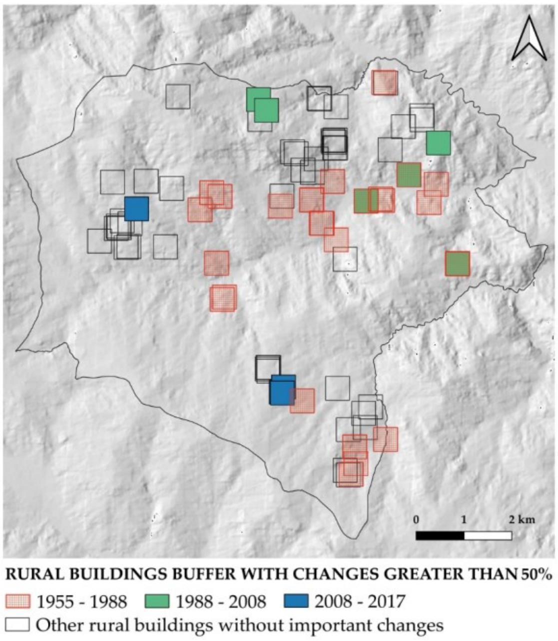

Figure 29: Rural buildings buffer with changes greater than 50% and other without important changes (<50%)

Table 19: Number of rural buildings whose buffer area changed more than 50% during the three analysis periods and for the two case studies. The percentage refers to the total number of rural building buffers.

	n.	*%*
1955 - 1988	27	34.2
1988 – 2008	6	7.6
2008 - 2017	4	5.1
Total n. Rural buildings	79	

Finally, analysing the boxplot (Figure 30) highlighting the relationship between slope (in degree) and rural buildings buffer, in which the surface area has changed more than 50%, it can be noticed that in the first two periods (1955-1988 and 1988-2008) most of the rural buildings buffer changes are within very high slope values. This situation can be compared to the values in the buffer of rural buildings which did not change, that in addition to presenting a much greater variability, have a median around 11°, compared to almost 14-15° of the changed areas.

An unusual situation is recorded on the few areas changed in the period 2008-2007, in which the values are much lower than the other cases and in which the specific motivations should be analysed individually, taking into account also other drivers.

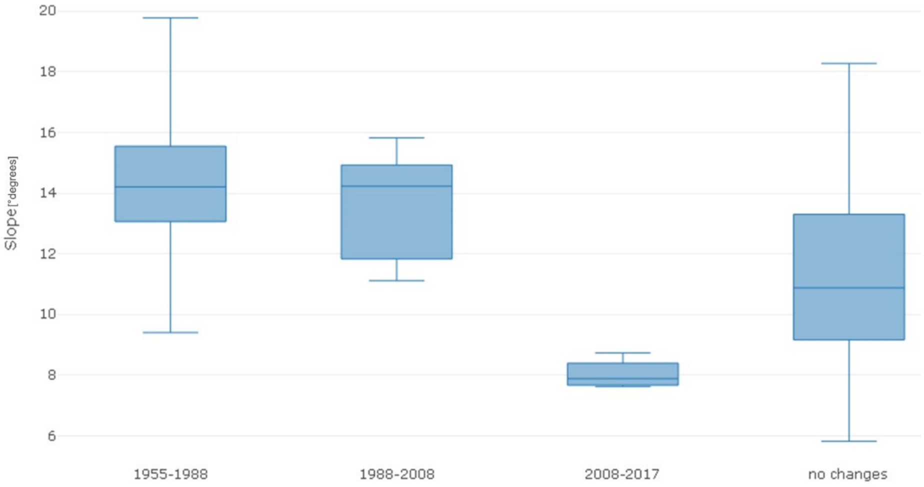

Figure 30: Box plots of the relationships between slope with rural buildings buffer with changes greater than 50% of surface for the three analysed periods and with rural buildings buffer (no changes) with few changes. Horizontal lines inside the box indicate the median value of each parameter. The bottom of the box is at the first quartile (25% of distribution), and the top is at the third quartile (75% of distribution) value, while whiskers indicate variability outside the upper and the lower quartiles.

As highlighted by the obtained results, the study shows that the territory, during the 62 years of analysis, has changed in this case study and in line with the trend that has occurred in many inland areas of the Mediterranean region and especially along the Italian Apennines. In particular, the main typical dynamics are related to the reduction of agricultural areas in favour to natural areas. Within these natural areas, on the other hand, the dynamics are different in relation to the context and the individual classes of considered land cover; after an initial transformation into grasslands, the abandonment processes continued until many areas were transformed into forests. This shows that, in addition to the loss of agricultural activity and the cultivation of cereals, all those agricultural activities linked to free grazing have been reduced over the years. This last process is very evident in this area because the rural heritage was mainly realized for grazing purposes and, therefore, the abandonment of this form of agricultural activity has led to much intense and rapid transformations. In fact, while in 1955 the area surrounding the farm buildings was largely occupied by cultivated land, in 2017 the forest became the main element of the territory. The most intense abandonment certainly took place between 1955 and 1988; this is due both to the duration of the period analysed and to the different processes described.

Analyzing the time interval from 1988 to 2008, it can be seen that in addition to the high dynamism of the natural and semi-natural land cover classes, agricultural activity has slightly diversified thanks to the transformation of cultivated land into vineyards and olive groves, certainly representing the period in which there has been a greater heterogeneity of the land due mainly to the different levels of ecological succession that have originated in abandoned arable land. In the last period (2008 - 2017) the intensity of the transformation and abandonment processes in the territory surrounding the farms has decreased, since there has been less transformation of the agricultural areas, which have stabilized in more favourable and profitable parts of the territory in terms of accessibility and soil quality. On the contrary, the areas around farms that most have changed are those with the steepest slopes. This phenomenon, which has also occurred in other territorial contexts, is mainly due to changes in socio-economic conditions and in European agricultural policy, that have made it less convenient to cultivate the lower productive parts of inland areas. Besides considering other factors (both morphological and socio-economic), a methodology to improve the analysis is to consider individually the different categories of land cover change (Peña-Angulo et al., 2019).

Evaluating in greater detail the transformations that have occurred, in addition to the processes of abandonment of the cultivation of cereals, it is important to consider the transformation processes of the prairies, which have become semi-natural habitats of the highest naturalistic value (Cousins, 2009). The abandonment of agricultural activity by farmers and consequently also the same rural buildings have led in many contexts to an advancement of the forest and a homogenization of the agroforestry territory to the detriment of dry grasslands with high biodiversity, i.e. those semi-natural habitats of Community interest linked to grazing (priority habitats Natura2000 code 6210*). These particular situations require in-depth study and field surveys in order to be able to assess them individually.

Therefore, an overall assessment of the relationship between land transformation and rural buildings in the two case studies shows that in both situations there is a phenomenon of abandonment of agricultural areas, with consequent loss of semi-natural habitats in favour of forest habitats only. However, this process has been intense in this area where the built rural heritage is simpler and linked to seasonal use, it is an expression of a more traditional type of agriculture on a small scale and often familiar that, considering the current economic crisis of this sector and the concurrent process of depopulation, has led to the complete abandonment of areas less favourable to this type of agriculture.

Finally, it is necessary, in order to study the relationship between territory and rural buildings, to have a diversified approach according to the territorial context of reference, adapting the analysis methodologies in relation to the environmental, landscape and economic characteristics of the individual areas. From a technical point of view, however, the methodology used, even if applied on a small area, can be useful to understand how the landscape around farms has been transformed, identifying mainly those farms that play an important ecological role within the agroforestry territory. Moreover, the construction of a geodatabase that includes rural buildings has made it possible to carry out spatial mapping and geostatistical evaluations. From the methodological point of view, the transition matrices, thanks to their ability to highlight both macro and micro changes, are certainly one of the tools that could be adopted by the planners of the territory. These tools, associated with the dynamic Sankey diagrams, in which it is possible to view in an interactive way also the tabular data, allow to make cross-tabulation analysis simpler and more efficient, easily usable by public administrations.

GIS tools, which provide the ability to explore spatial and temporal data, are indispensable for studying the evolutionary dynamics of rural landscapes. This approach improves landscape surveys due to the ability of representing the past and the present through the integration of different data (from historical cartography to satellite images). 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 into its present structure. In particular, the reconstruction of landscape transformations through the methodology described can be very useful in contexts with conservationist interest, where there is a need for a diachronic evaluation at a detailed scale. For example, this approach could be used in Natura 2000 sites or protected cultural landscapes where habitats and land cover monitoring are useful for the activation of concrete restoration or safeguard actions. Moreover, given that these are GIS techniques, it is possible to insert further historical information layers so as to add further time steps to the analysis. For example, in this case study, additional historical maps and aerial photographs can be included to cover some missing time periods and to use the image classification of the Landsat mission to reconstruct land cover, year by year, from 1988 to today.

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. These arguments are complex, and the literature shows that there are different techniques 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 standardized 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. These GIS procedures can be of fundamental importance in areas, such as that one which has been here analyzed, where the pattern is very complex, since a quality agriculture coexists with areas characterized by an high naturalistic value - in which there is a growing increase in tourist flow - as well as with extensive industrial areas. Furthermore, this approach is a useful method to identify, preliminarily, areas on which detailed studies can be performed on certain aspects that have to be studied in detail.

This approach also allows to assess the impacts of human activity (in particular the abandonment of agricultural activities) on the agroforestry territory. In addition to an overall assessment, it also allows to enter in detail the quantitative and qualitative derminants that have influenced a certain type of territorial transfromation. In addition to the classic geomorphological and physical parameters that the literature provides, a preliminary study has been launched, in which also the evaluation of rural buildings as a factor to explain the abandonment of the territory.

This methodology can be implemented at different levels as a management and decision-making support tool for the different territorial governance. In fact, the simplicity of the methodologies, the interoperability between the different techniques and the possibility to realize semi-automatic systems thanks to open source GIS tools, make the use of territorial data for the study of the territory more immediate. Open source software, in particular the QGIS, provide all the necessary tools to operate and process the types of geographical data needed for spatial studies, allowing to simplify operations and improving the accuracy of the analysis. In addition, they allow a quick and simplified use of satellite images that in the past required much more specialized applications and techniques, difficult to integrate in GIS environment.

Finally, thanks to the possibility of model builder and batch processing of the GIS software, once the areas and objectives have been identified, it is possible to carry out further investigations in series, repeating them over time, in order to speed up certain operations and create a system to support spatial decisions.

6. RURAL LANDSCAPE QUALITY ASSESMENT

The geographical and ecological aspects related to the study of the landscape and agroforestry land have a strategic importance within the regional public planning and for the management of particular environments to be safeguarded. In addition, landscapes can be considered as a valuable heritage, having a cultural value recognised both by the population and by the UNESCO conservation policies (Ridding et al., 2018). In fact, the need to implement new methods to preserve and, at the same time, enhance landscapes has led in Europe to the formulation of the 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. 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 et al., 2001).

In this part of the thesis work, two case studies will be illustrated. The first one shows a detailed approach that can be used and implemented on a large scale and on sub-regional portions of land, for example, to monitor and plan at the level of protected areas or areas of landscape interest. The second one, on the other hand, concerns a small-scale approach that is implemented at a regional level and allows for a wider planning.

- **Historical landscape visual quality: a case study in Vulture area**: Starting from the study area previously analyzed for the Case Vulture, the specific datasets were used to analyze how the environmental evolution of the landscape has changed the visual quality during the 138-year analysis period.

- **A set of indicators to assess landscape visual quality of Basilicata region**: In this paper, suitable landscape visual characteristics have been identified through the elaboration of a series of landscape indicators, able to take into account different land components. After a methodological framework description, the analysis in an open-source GIS environment has been applied. This approach is based on the integration of landscape metrics and land cover data, which are the starting point for implementing these nine indicators. The methodology allows to analyze large land portions, for which the study area of a whole Italian region – the Basilicata Region -

has been considered. The final result is represented by a series of different map-based indicators, that can be individually analyzed, or even combined, so as to formulate a general index for the landscape visual quality.

6.1 Historical landscape visual quality: a case study in Vulture area

6.1.1 Study area

The study area corresponds to that of the Vulture case study (section 4.2.). For description and location, please refer to Section 4.2.1.

6.1.2 Materials and data processing

To evaluate the visual quality of the landscape, the approach proposed by La Rosa (2011) was used, adding some elements in order to contextualize it. The definition of visual quality of the landscape is based onto three steps: the first part of the evaluation is based on the viewshed analysis, the second one on the calculation of the quality of the landscape and then 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 on 5 metres.

To perform this calculation, the QGIS plugin "Viewshed Analysis" (Čučković, 2016) has been used, which allows to facilitate 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 meters and 1 meter 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 et al., 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 (La Rosa, 2011; Martín-Ramos et al., 2012) 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 having topographically high and uneven areas are preferred to those having 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 characterized 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 Ramos et al., 2012), a score between 1 and 8 was assigned to each land use class (Table 20). Scores do not express absolute values.

Table 20: Visual quality values assigned to each land use class.

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 8 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 farms = 4*

Even if in some studies (Taylor Perron et al., 2012, Martín Ramos 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 8, where 0 corresponds to the values of lowest SHDI and 8 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 has been 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 is their connected value. 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.

6.1.3 Results and discussion

Through a preliminary comparison among the various historical cartographies, a path able to retraces 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 (Figure 31). Although the scenic roads cover most of the study area, due to the territory landform, many areas are anyway totally invisible.

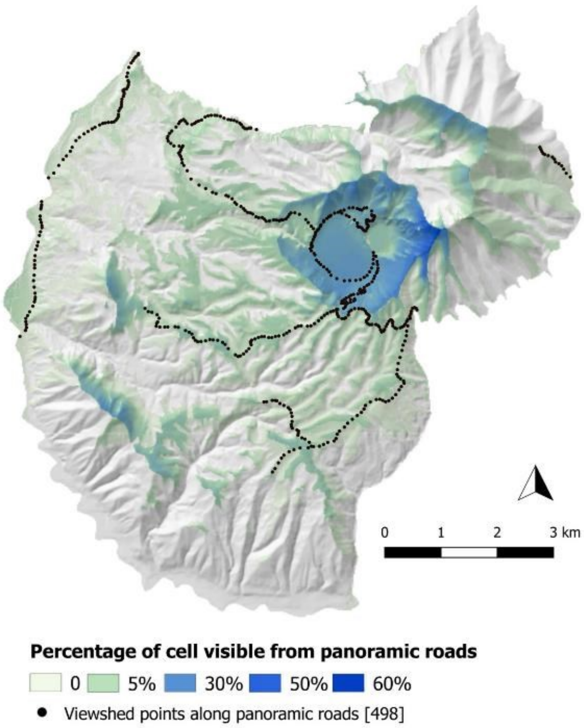

Figure 31: Difference between SHDI index values for the three periods analyzed.

On the basis of this operation, the maps showing the index of the quality of the visible landscape have been produced (Figure 32 - left), as well as the overlay with the raster of the viewshed analysis (Figure 33), of the weighed raster on the basis of SHDI and land use values previously fixed (Figure 32 - right). 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 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 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 1875-1955, the figure 33 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 difference 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.

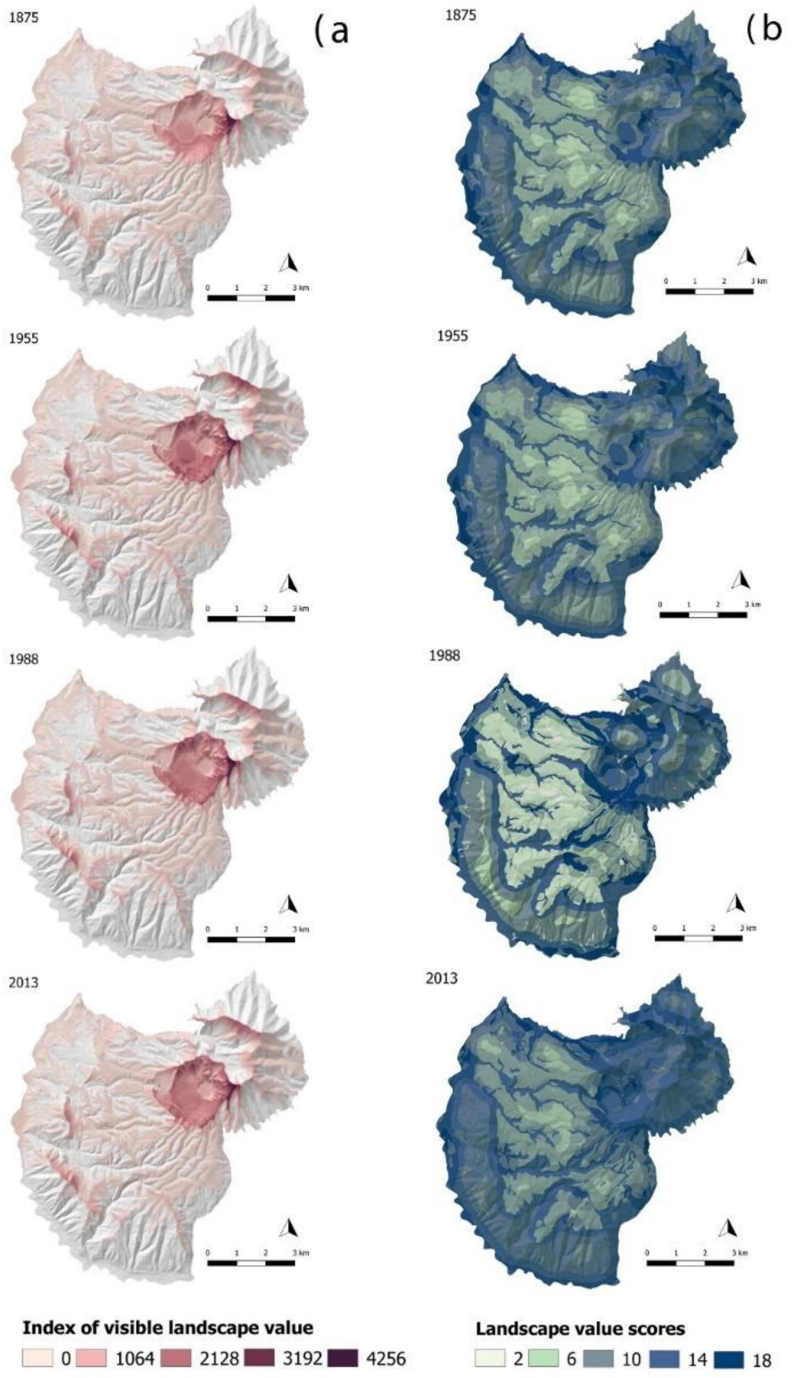

Figure 32: Maps of index of visible landscape value (left) and landscape value scores (right)

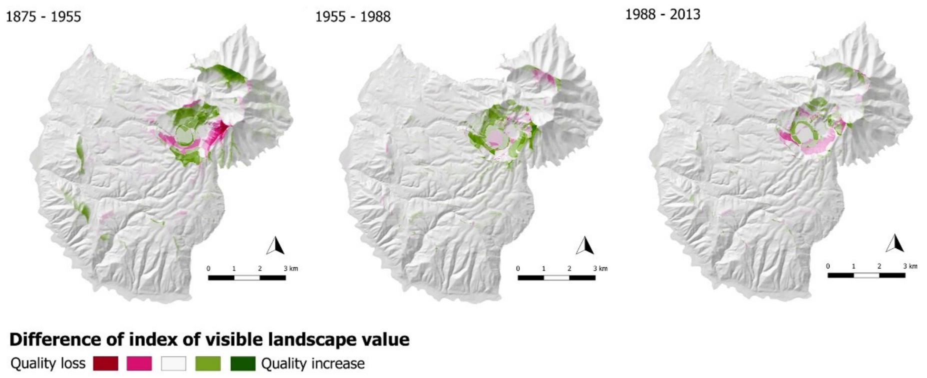

Figure 33: Difference maps that highlight the increase or loss of index of visible landscape values.

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 an high landscape value score (Figure 32 right), is not included in the map in Figure 32 (left) 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 finalized to better define and contextualize 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 from 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 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, anthropized area and low diversification in SHDI.

6.2 A SET OF INDICATORS TO ASSESS LANDSCAPE VISUAL QUALITY: A FIRT APPROACH FOR BASILICATA REGION

6.2.1 Study area

The study area covers the entire territory of the Basilicata region (Southern Italy—Figure 34; Please refer to the information reported in previous § 5.1.1 Study area).

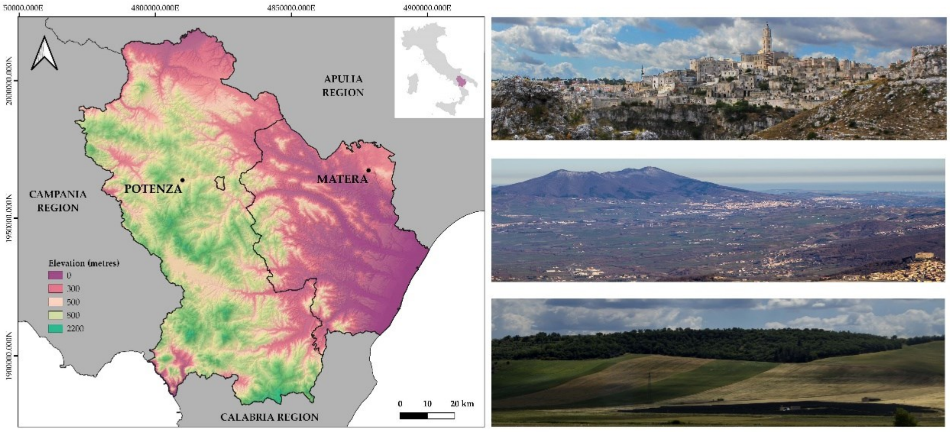

Figure 34: Basilicata Region and high value landscapes: Murgia Materana (top), Mount Vulture (middle) and a typical hilly agroforestry landscape (bottom).

6.2.2 Materials and data processing

The implanted methodology (Ode et al., 2008) is based on tool of Landscape Character Assessment (LCA). It has been developed as a tool to include issues of the experience of landscape (among others) within management, planning and monitoring. One of the most widely applied schemes is the system developed by the Countryside Agency and Scottish Natural Heritage, and carried out for England and Scotland. Landscape character is defined here as a "distinct, recognisable and consistent pattern of elements in the landscape that makes one landscape different from another, rather then better or worse" (Swanwick, 2002). It has been argued that identifying character is, to a large extent, built upon human perception and therefore LCA can be questioned with regards to its scientific rigour and hence its role as an analytical tool for landscape planning (Wascher, 2005).

In this case study, visual landscape indicators linked to landscape character suggested by Ode et al. (2008) have been implemented: coherence, complexity, historicity, naturalness, disturbance, visual scale, imageability, stewardship and ephemera that measure some of the key concepts proposed by Tveit et al. (2006). This is a first approach to apply all the indicators proposed for LCA with GIS using map-based indicators. Considering the current literature, it certainly represents a step forward in understanding the usability of this methodology at the landscape planning scale. Each indicator was calculated thanks to tools and related plugins in QGIS 3.4 software and using a specific datasets.

- Coherence

Coherence relates to the unity of a scene, the degree of repeating patterns of colour and texture as well as a correspondence between land use and natural conditions. Coherence is one factor for predicting preference within the Information Processing Theory, and it refers to a more immediate understanding and readability of our environment. It is related with landscape fragmentation, which with "Effective Mesh Size" (MESH) landscape metrics based on land cover 2018 (Copernicus Land Monitoring Service, 2020) was calculated. The MESH, mathematically, is equals to the sum of patch squared area, summed across all patches of the corresponding patch type, divided by the total landscape area (m^2), divided by 10,000 (to convert to hectares). The lower limit of MESH is constrained by the ratio of cell size to landscape area and it is achieved when the corresponding patch type consists of a single one pixel patch. MESH is maximum when the landscape consists of a single patch. Ecologically, it is a landscape fragmentation measure. For its calculation, the moving window approach, through the free software Fragtstats 4.2 (see Case study Vulture; Section 4.2), was used.

- Complexity

Complexity refers to the diversity and richness of landscape elements and features and the interspersion of patterns in the landscape. Complexity is a concept that has been focused on in landscape ecological studies and hence several types of indicators have been developed for the application on land cover and orthophoto. The chosen index is Shannon's Diversity, calculated on the basis of land cover 2018 and with the same technique previously used for Effective Mesh Size.

- Historicity

Historicity describes the degree of historical continuity and richness present in the landscape. Historical continuity is reflected by the visual presence of different time layers, while historical richness focuses on the amount and diversity of cultural elements. One group of indicators regards vegetation with continuity. This could be described and calculated as proportion of landscape with long vegetation continuity of traditional land use (Jessel, 2006). In this study, historicity has been calculated as the degree of historical continuity present in landscape, by area with land cover continuity among 1960-2018. In particular, the percentage of land cover continuity was calculated. For the mapping of the land cover of 1960, the thematic map "Land use map of Italy" of 1960 made by the National Research Centre was scanned, mosaics and then geo-referenced. The georeferencing is done using Ground Control Points with known coordinates recovered from an already georeferenced map. On the other hand, the vectorization and classification of land cover classes was done through a semi-automatic methodology using the potential of the *GIMP selection feature* plugin of QGIS. The *Gimp Selection Feature* is a panel plugin that permits to send the image of view of map to GIMP (a free and open source graphic software), and get the region selected by GIMP how a feature in QGIS. This technique is very useful for the vectorization of thematic maps; in fact, thanks to GIMP's ability to make a selection by colors, it’s possible to directly extrapolate all the polygons related to a land cover class on the map. In this way the accuracy is guaranteed and the speed of digitization is remarkable compared to manual digitization.

- Naturalness

It describes the perceived closeness to a natural state. The “hemeroby index” measures the hemerobiotic state of an area: the magnitude of the deviation from the potential natural vegetation caused by human activities. The degree of hemeroby increases with the increase of the human influence. Gradients of human influence are assessed using a scale which normally comprises 7 degrees, in which the lowest values (ahemerob) correspond to “natural” or non-disturbed landscapes and habitats such as bogs and the highest values (metahemerob) are given to totally disturbed or “artificial” landscapes such as urban areas. In an agri-environmental context, the index shows the cultural influence of farming practices on landscapes and potential vegetation. Starting from the use of the 2018, the naturalness with Hemebory index as proposed by Walz and Stein (2014) was calculated.

- Disturbance

Disturbance refers to the lack of contextual fit and coherence in a landscape. To apply indicators of disturbance it is necessary to identify which landscape elements are perceived as disturbing. Civil buildings outside urban areas have been considered as disturbing elements. The presence of these disturbing elements has been calculated as the percentage of artificial area obtained from the official Basilicata Region dataset (RSDI, 2020).

- Ephemera

It refers to landscape changes related to season or weather. These features, enhance the ‘being away’ aspect of landscape experience. Indicators of ephemera describe seasonal and weather changes per area, frequency of changes and the magnitude of change. To elaborate this indicator, landscape attributes with seasonal change which refers both to natural vegetation and agricultural land have been considered. In particular, recovering detailed information on Basilicata Nature Map (ISPRA, 2019), the proportion of these land cover classes have been calculated: orchards, vineyards, pastures, arable lands, forests and meadows).

- Visual scale

It is focused on the size of open space in the landscape . It is calculated through the percentage viewshed analysis. Using a 5 meters resolution DEM, a viewshed has been calculated using the same methodology used in Vulture Case Study (see Section 6.1.2).

- Imageability

It reflects the ability of a landscape to create a strong visual image in the observer, thereby making it distinguishable. It’s calculated through the density of viewpoints. These have been extrapolated by OpenStreetMap (panoramic points), selecting points linked to geographical important areas and panoramic landmarks included in the Basilicata region dataset. Through the QGIS Heatmap plugin, it was possible to perform a kernel density estimation to create a density (so-called heatmap) raster of input viewpoints vector layer. The density was calculated considering the number of points in a given position, where a greater number of points generated greater values.

- Stewardship

Stewardship refers to the sense of order and care present in the landscape reflecting active and careful management. Nassauer (1995) described it as the level of land farming, and calculated it by the level of abandonment of agricultural land. Operationally, it has been calculated as a percentage of vegetation in different stages of abandonment giving it a different score: 1- highly maintained/no abandonment; 2-partly maintained; 3-poorly maintained; 4-no maintenance/total abandonment.

All the different indicators have been evaluated in a fishnet, a square grid. According to the findings of O'Neill et al. (1996), the area of a grid unit should be 2–5 times larger than the mean area of patches. For this reason, since the dataset with the Minimum Mapping Unit is that of the land cover map 2018 (25 ha), we set the sampling unit as 1 km×1 km grids.

In a second phase, the dataset of the old sheep tracks with historical and landscape value of the Basilicata Region was used. The tracks in vector format was taken from a previous study (Cillis et al., 2018). The vertices of these polylines (n. 3986 vertices) were extracted, considering them as hypothetical observation points. These points were used as the basis for a viewshed analysis in a 5m resolution DEM. The preliminary binary cumulative raster that has been elaborated refers to the observation points. It has enabled the calculation of a raster, expressing the percentage of cell visible from these points.

6.2.3 Result and discussion

Since indicators are expressed in a variety of statistical unit, range or scale, a normalization process is fundamental to makes data comparable across indicators, so that the information can be combined in a meaningful way. The normalization technique in this preliminary phase of implementation of the methodology was based on the reclassification of values using the range 0 (lower value) to 1 (higher value) using SAGA's Raster normalization tool in QGIS. (Figure 35).

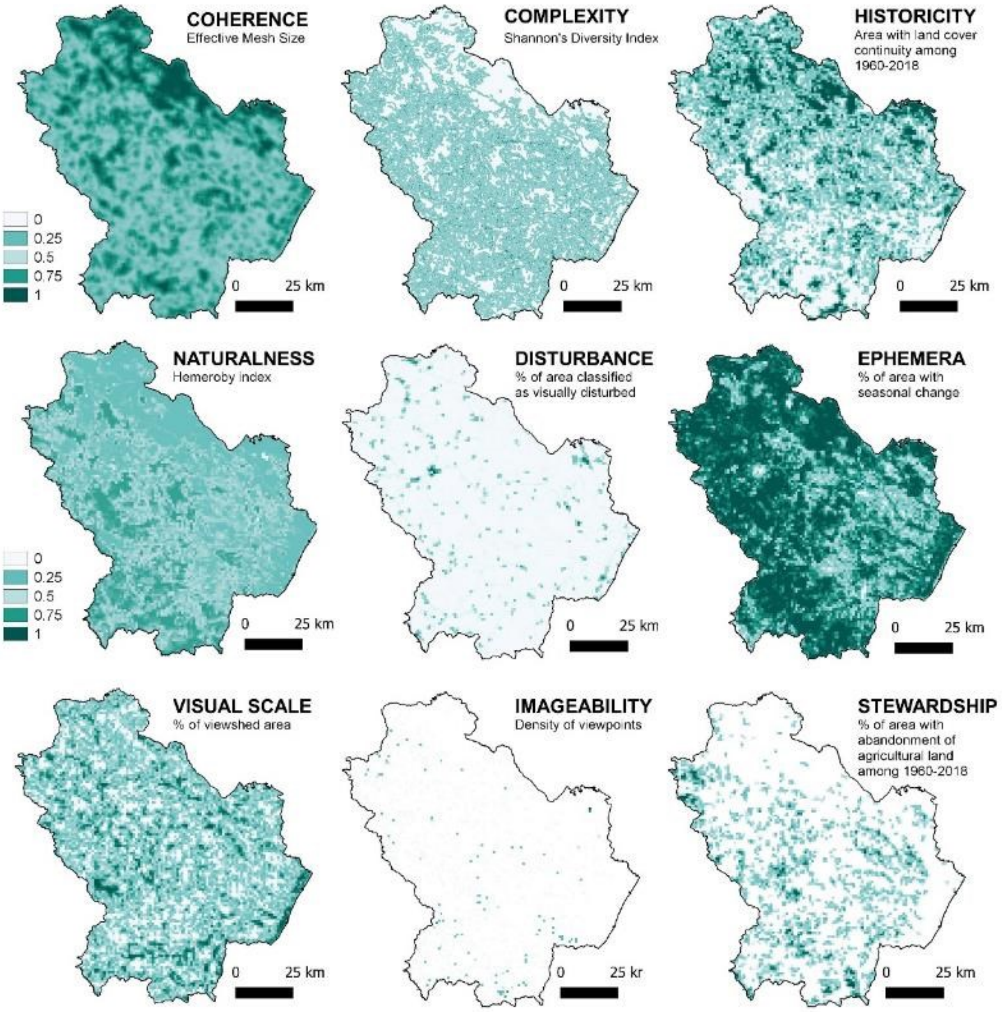

Figure 35: Map of calculated indicators.

Hence, the Index for Landscape Character Assessment (ILCA) was obtained from the algebraic sum of the raster of indicators, except for Disturbance and Stewardship, whose values were subtracted, considering that they determine a reduction of the landscape quality (Figure 36). For a first general assessment, the same weight was assigned, considering an equal importance of each indicator on landscape quality.

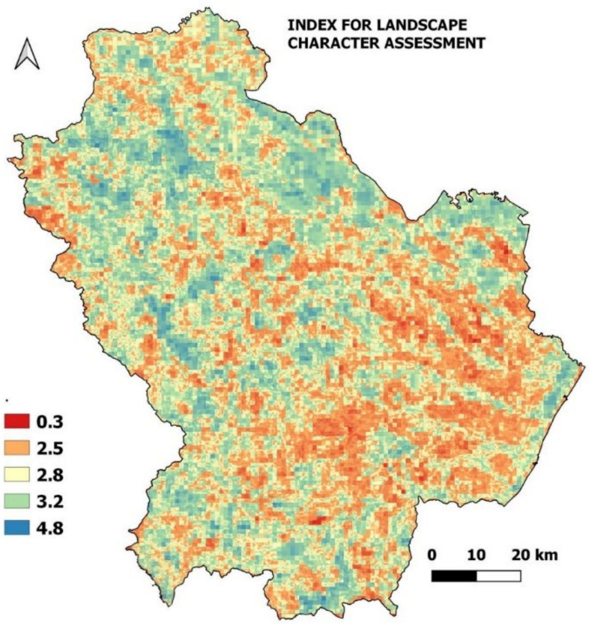

Figure 36: Map of Index for Landscape Character Assessment.

Table 21: Surface in km^2 and percentage (%) for each ILCA class break.

INDEX FOR LANDSCAPE CHARACTER ASSESSMENT

Class break	*Km2*	*%*
0 - 0.3	0.14	0.001
0.3 - 2.5	2782.6	27.624
2.5 - 2.8	1950.68	19.365
2.8 - 3.2	2736.12	27.163
3.2 - 4.8	2603.58	25.847
	10073.1	**100**

This methodology allowed the evaluation of the presented indicators, individually or as a whole. Evaluating ILCA, it is possible to see that most of the area presents values around the average (Table 21), and that the eastern part of the Basilicata region has lower values due to a greater presence of human and agricultural activities. A more accurate assessment of the ILCA may be obtained if different datasets used to build indicators are improved and defined in better detail. For example, Disturbance - which takes into account the negative impact of urban areas - can be corrected by excluding those urban areas with a high panoramic skyline view, a factor which increases the visual quality. This is possible thanks to the use of new geographical tools, their interoperability and the use of integrating different types of data. Thus, the quality of the landscape may be assessed by combining both qualitative and quantitative techniques.

This preliminary methodology of integrated LCA GIS-based has proven to be an adequate starting point for a spatial and quantitative approach to the visual and aesthetic quality of a territory and/or landscape. The possibility to elaborate the different key concepts starting from different types of geodata, ensures a replicability and above all an in-depth analysis in relation to the level of detail and complexity appropriate to the investigation.

These general results can be used as preliminary dataset for a more specific case as in the example proposed below (Figure 37).

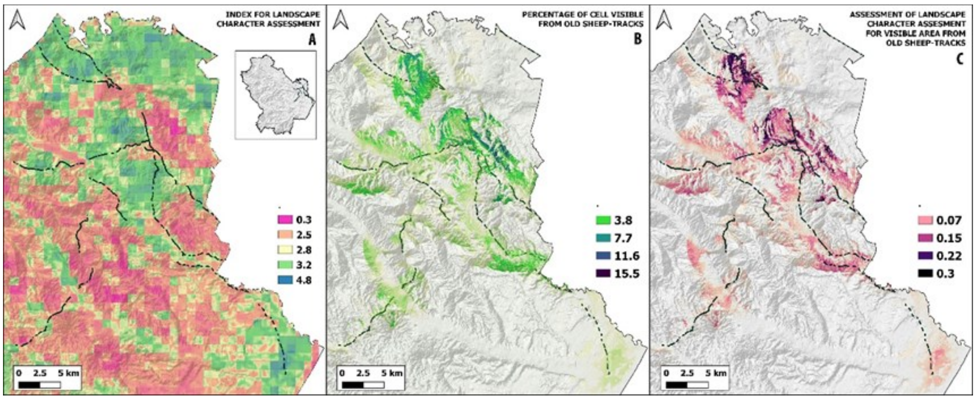

Figure 37: (a) ILCA map; (b) percentage of cell visible from old sheep-tracks; (c) final assessment of the area with old sheep-tracks.

This application can be identified as a preliminary spatial decision support system, because it identifies areas along a potential tourist route with a higher visual quality. This information can be used in landscape planning to set constraints or to create new interesting tourist areas.

From this case study, it is clear that this methodology can be very useful for those who deal with landscape planning, both for the tourist aspects and for the visual impact aspects of infrastructural works. In fact, thanks to the possibility of modelling the different indicators by assigning different weights in relation to the objectives set, it can be used as a spatial decision support system for public decision makers.

The use of this approach to assess landscape quality has proved very useful to evaluate some fundamental characteristics for the management and protection of the landscape. The possibility to obtain some evaluation parameters from the use of land datasets, allows to apply a cartographic approach, an objective assessment of the landscape that can be successfully carried out. Moreover, thanks to the GIS technologies and new tools able to process land use and land cover data, it is possible to guarantee a good applicability and reliability. A general approach that can be applied to different visual scales, by considering particular viewpoints or panoramic roads spread on the territory, can be intended as a useful tool in terms of planning opportunities, in the perspective of the protection and valorisation of the rural landscape.

7. CONCLUSIONS

Human activities have transformed the land through changes in its cover, so as to define some characteristics and specificities thanks to which it has been possible to protect and recognize certain types of landscape. But this transformation, in the last decades, is undergoing an acceleration for which it is necessary to know, understand and evaluate these dynamics.

The study of the state of the components of the agroforestry environment requires an holistic multidisciplinary approach since all of them may contribute to the analysis of the typical elements of the land. 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. Surely, the main challenge of this field of research is to understand the methods to extract useful information from the data, as well as to correctly interpret the signals of time series, so as to be able to understand both slow variations, caused by gradual changes in the ecosystem, and faster variations due to external disturbances or other events. The thesis work was based on this proposition.

The use of GIS tools and remote sensing based on FoSS approach is certainly the most cost-effective and time-efficient method to monitor land cover and landscape evolution over the years. For this reason, all the analyses were based on this methodology. In particular, FoSSs are becoming more and more the most used tools in this field of research, thanks to their ease of use, interoperability with other types of software and the absence of costs related to purchase licenses. But FoSSs are mainly used by researchers and scarcely by those involved in planning and monitoring in public offices due to the lack of applications and guidelines for the applied use of these systems.

In particular, the FoSS tools discussed here can be used to support the implementation of appropriate techniques to represent the dynamics of land transformation and at the same time be used for landscape monitoring and planning. It is essential to implement tools that can allow an overview of the territory and that can guarantee an effective and dynamic decision support system, so responding to the needs of the public decision-makers to verify past management policies and to develop new strategies.

With respect to the state of the art and on the basis of the general and specific objectives set, in the thesis have been treated and developed new methodologies aimed to:

- Improve the knowledge about the dynamics of transformation of the territory in some areas of Basilicata, a Mediterranean region of Southern Italy where the process of abandonment of agricultural areas is compromising many natural ecosystems and rural landscapes.

- The different types of geodata available for this portion of the Italian territory have been explored, treated and characterized; improving in some cases the techniques to extract geoinformation in a more accurate way.

- Remote sensing and GIS techniques have been integrated in an open source perspective, in order to produce maps of land cover, vegetation types and land use changes at a higher resolution and accuracy than those freely available online.

- Simple and effective methodologies and techniques have been implemented, through which they can be used as useful tools to provide information that can be used within systems to support spatial statements to public decision-makers dealing with agroforestry topics.

- Integrate the use of remote sensing data (from aerial photos to satellite images) with those from historical cartography in order to reconstruct landscape changes over a very long period.

- Propose new methodologies and indicators useful for the evaluation of the visual quality of the landscape and agroforestry territory.

The comparison of diachronic land cover 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.

Given the complexity and vastness of the topics, in this thesis the research points and themes have been addressed through specific case studies. Given the differentiation of the territory, of the data and of the types of analysis, all the topics have been dealt with separately. In fact, the general objective has been the implementation of methodologies to assess and survey the agroforestry land and rural landscape through the historical and remote sensed geodata integration within a FoSS approach to provide increasingly accurate datasets regarding land cover, was addressed in all the three case study topics with specific data, tools and techniques. Methods based on spatial analysis, process modelling and statistical analysis of data, developed within the various case studies, have served to improve some knowledge on these issues and expand the possibilities of investigation in the field of surveying and analysis of the agroforestry land.

In detail, the impacts of human activities on the agroforestry environment were analyzed through chronological surveys, that took into account the different types of available geodata. The impacts, direct and indirect, mainly concerned those due to the abandonment of agricultural activity. The two case studies focused on land cover changes and rural land dynamics in typical agroforestry systems located in Southern Italy, in which the depopulation and the abandonment of the cultivated areas are reshaping the visual aspect as well as the ecology of the rural landscape. In these works, it has been proposed an original land cover change analysis based on the integration of historical cartography and documents, digital cartography, management plans information and remote sensing images, to evaluate both quantitative and qualitative aspects related to the dynamics of land use. These approaches improve landscape surveys, due to the ability of representing the past and the present through the integration of different data (from historical cartography to satellite images). 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 diffents components of landscapes. 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 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 the 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 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. Moreover, for example, this approach could be used in Natura 2000 sites or protected cultural landscapes, where habitats and land cover monitoring are useful for the activation of concrete restoration or safeguard actions.

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. Moreover, due to their different possibilities of representation, free and open GIS tools provide the possibility to identify relationships between the main changes in land cover, land use policies and socioeconomic contexts through methodologies and techniques that can be replicated in other territories.

Another investigated topic has concerned the relations between rural landscape and buildings. The agroforestry territory, by definition, is determined by the different agricultural and silvicultural activities. In addition to the soil cover component, also the built places within this context, i.e. the rural buildings, assume considerable importance.

The rural building plays a crucial role not only in sustainable and resilient growth of agriculture but also in the sustainability of typical rural landscapes, ecosystem service providers, and socio-cultural activities. For evaluating the implementation of suitable management practices that aim to preserve their rurality, GIS geospatial analysis can be used, taking into account different disciplines and time scales. In this study, a method to verify some results for the study area in which there are typical rural landscapes of the Mediterranean area was implemented. Indeed, the present case studies confirmed the main results emerging from recent studies in the scientific literature, i.e., that many farm buildings develop a fundamental — if not, essential — effect for the preservation, the monitoring, the management, and the general sustainability of the rural landscape. In particular, rural landscape sustainability can be achieved through a more rational consumption of resources, the fight against environmental degradation, and the maintenance of stable ecosystem balances, all actions that can be carried out through the return to traditional agriculture (Gobattoni et al., 2015). This transition necessarily passes through the recovery and the enhancement of vernacular farm buildings, which possess important ecological, socio-economic, and cultural values. Moreover, there is also a relationship between the intensity of land abandonment and the type of rural heritage. Therefore, it can be very useful to introduce rural buildings as a qualitative factor in the analysis of the elements that explain the abandonment of agricultural areas as well.

The methodologies applied in these studies can be considered as a first synthetic approach for the territorial analyses developed and the basis for a study of the relationship between changes in the territory and the built rural heritage. To this end, a simple buffer was used to standardise the survey, but for a more in-depth analysis, it may be possible to evaluate the relationship with the cadastral parcels associated with each rural building, in order to include administrative and economic data in the analysis. These methodologies can be implemented at different levels as a management and decision-making support tool for the different territorial governance. In fact, the simplicity of the methodologies, the interoperability between the different techniques and the possibility to realize semi-automatic systems thanks to open-source GIS tools, make the use of territorial data for the study of the territory more immediate. Open-source software, in particular the QGIS, provide all the necessary tools to operate and process the types of geographical data needed for spatial studies, allowing to simplify operations and improving the accuracy of the analysis. In addition, they allow a quick and simplified use of satellite images that in the past required much more specialized applications and techniques, difficult to integrate in a GIS environment.

In this way, it is also possible to preserve the rural building heritage as architectural and cultural evidence of a certain way of living in synergy with the surrounding landscape heritage. Geographic technologies have proven to be a powerful tool for implementing new ways to enhance and conserve the agricultural built heritage, in synergetic action with the surrounding rural landscape. The relevant cataloguing of historical rural buildings with geo-referenced information and the subsequent use of them as a basis for more complex spatial analysis allow the assessment of the role and the impact of these buildings within the surrounding context, with a view to a more sustainable land management. This approach would be a suitable tool for future possible application in rural landscape analysis, planning, and management. Finally, thanks to the possibility of model builder and batch processing of the GIS software, once the areas and objectives have been identified, it is possible to carry out further investigations in series, repeating them over time, in order to speed up certain operations and create a system to support spatial decisions.

Finally, the last topic analyzed in the thesis concerns the visual quality of the rural landscape. A very wide topic that lends itself to multiple approaches of analysis.

The landscape, as already reported, is the result of the interaction over time and in a specific geographical context of different natural and anthropic components. Therefore, in relation to the weight given to the different aspects, the concept of landscape can be seen from a geographical, anthropocentric and ecological point of view. Moreover, if we also consider the historical-cultural component, typical of the Italian rural landscape, the concept becomes even wider and more holistic. So, assessing the quality of a landscape becomes a complex process, but at the same time fundamental for the management and monitoring of the territory seen and considering the considerable transformations taking place. In the scientific literature, there are many examples of elaboration of indicators of the quality of a landscape, that differ because of the different objectives for which they have been elaborated and the expertise of researchers. Some of these have been listed and grouped by macro-categories (ecological, economic, historical-cultural, etc ...). In addition, each spatial index and indicator, especially when related to changes in land use and landscape, have limitations in application that must be evaluated and considered. With these assumptions, the first phase of this topic has concerned the choice of indicators and indexes that can better be adapted to the characteristics and problems of the Basilicata landscape. In particular, above all, indexes and indicators that are based on ecological and managerial aspects of the territory have been considered. Subsequently, the informative layers that have constituted the basis for the evaluation of the landscape quality have been realized. Again, with a view to an integrated approach between GIS and remote sensing, some of the data that have been elaborated in the previous paragraphs, have been included and new ones have been realized on the basis of the characteristics of the indicator used.

This last step required a careful bibliographic research, aimed to evaluate several commonly used indexes and indicators.The quantitative one proposed in the two case studies, has allowed the implementation of replicable and standardizable methodologies, so as to be able to act on all parameters in relation to the available data and the objectives set.

The use of this approach to assess landscape quality has proved very useful to evaluate some fundamental characteristics for the management and protection of the landscape. The possibility to obtain some evaluation parameters from the use of land datasets, allows to apply a cartographic approach, an objective assessment of the landscape that can be successfully carried out. Moreover, thanks to the GIS technologies and new tools able to process land use and land cover data, it is possible to guarantee a good applicability and reliability. A general approach that can be applied to different visual scales, by considering particular viewpoints or panoramic roads spread on the territory, can be intended as a useful tool in terms of planning opportunities, in the perspective of the protection and valorisation of the rural landscape.

LIST OF ACRONYMS

AGEA: Italian agency for payments in agriculture

AI: aggregation index

CLC: Corine Land Cover

CONTAG: contagion index

DEM: Digital Elevation Model

FAIR: Findable, Accessible, Interoperable, and Reusable

FoSS: Free and open Source Software

ED: edge density

ELC: European Landscape Convention

GIS: Geographical Information Systems

ILCA: Index for Landscape Character Assessment

IJI: interspersion and juxtaposition index

LC: Land Cover

LCA: Landscape Character Assessment

LSI: landscape shape index

LU: Land Use

MOLUSCE: Modules for Land Use Change Simulations

NP: number of patches

OBIA: Object-Based Image Analysis

PD: patch density

SAC: Special Area of Conservation

SCP: Semi-Automatic Classification Plugin

SHDI: Shannons diversity index

SIDI: Simpson’s diversity index

TIL: Time-Invariant Lines

TPI: Topographic Position Index

TRI:Terrain Ruggedness Index

WMS: Warehouse Management System

MESH: Effective Mesh Size

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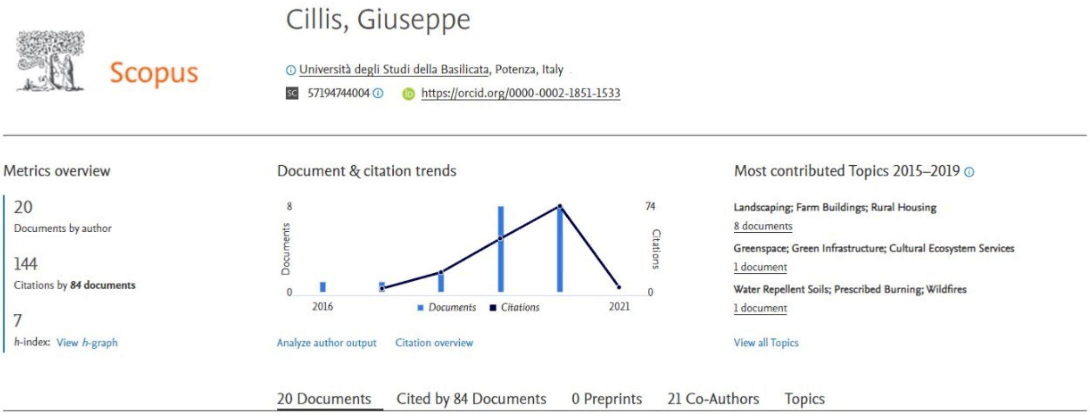
SCIENTIFIC ACTIVITY OVERVIEW



Scopus

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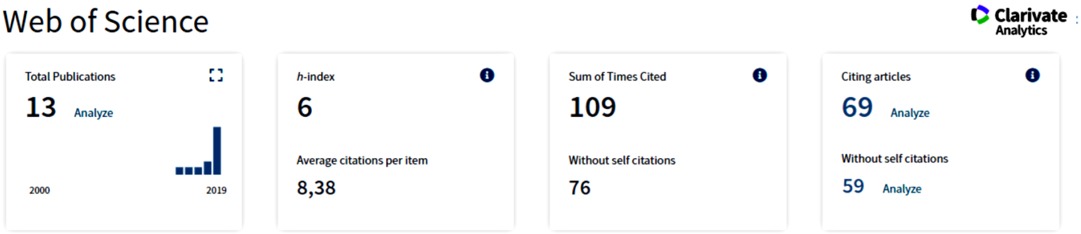

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