A GIS-BASED APPROACH TO MONITOR AND ASSES HISTORICAL FOREST LANDSCAPE EVOLUTION

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Abstract
In order to assess landscape dynamics, as well as the effectiveness of relevant management strategies, it is necessary to develop monitoring systems based on qualitative and quantitative tools for its conservation, valorisation and restoration. This approach is particularly important for historical rural landscapes having a recognized ecological and cultural value. To do this, it is first necessary to apply a chronological methodology since, by definition, landscapes result from an interaction of natural and anthropogenic factors over time. Thanks to the constant evolution of Geographic Information Systems and of different geodata available, the monitoring of historical landscapes is increasingly effective and inclusive. Using as a case study an historical forest landscape recognized at Italian level for its high value (Lucanian Apennines's beech forest - Basilicata Region), a diachronic analysis was applied to evaluate its multi-temporal evolution. Starting from historical cartographies up to Sentinel-2 satellite imagery, a GIS-based approach was implemented to evaluate the spatial variations of forest cover in this landscape. The techniques applied have allowed to reconstruct the original structure of the beech forests, useful for a possible restoration in some areas, but also to monitor the processes in place by using vegetation indices derived from remote sensing.

Key words: Forest Landscape, Remote Sensing, Geographic Information System, Landscape planning, Historical cartography

Introduction

Historical forest landscapes, besides being a biodiversity heritage, are a typical component of the Mediterranean mountain landscapes (Cillis et al., 2019). These types of landscape have been shaped over the centuries by human action, as they have been exploited as silvo-pastoral systems. They also possess an important touristic and recreational value, thanks to the ecological and standing characteristics that make the touristic routes very suggestive and accessible. In particular, the areas where there is a heterogeneous mosaic of beech forests and high altitude grasslands are the most appreciated (Statuto et al., 2019). But the transformations that have been taking place in recent years are causing a modification of these mosaics, in favour of uncontrolled reforestation (Malandra et al., 2018). If, at the beginning of the century, over-exploitation was compromising the ecosystems of mountain beech forests, the problem now concerns the abandonment of traditional agricultural activities linked to livestock farming (Falcucci et al., 2007; Statuto et al., 2013). In particular, free-range non-intensive grazing has led to the establishment of land cover patterns, that are different in conformation and configuration and which have created natural and semi-natural habitats of high natural value (Calaciura et al., 2008; Chará et al., 2019). In this context, it is necessary to monitor these forest landscapes, both to assess their historical evolution with a view to detailed analysis and restoration, and to evaluate their current status and future evolution (Picuno P., 2016). In this paper, a diachronic analysis methodology is proposed, that integrates data from historical cartography up to satellite images from the Copernicus programme. Starting from a historical thematic cartography of 1968, the transformation of a typical mountain forest landscape of the Mediterranean mountains of high naturalistic and touristic interest (Basilicata Region - Lucania Appennino National Park) has been evaluated. Through a GIS approach (Picuno et al., 2019), the 1968 dataset was integrated with some historical forest data (1936) and the new remote sensing data that allow detailed analysis and monitoring of the forest landscape status, both in terms of area coverage and phytosanitary conditions (Conte et al., 2019). These spatial analyses are fundamental for assessing the dynamics of forest landscapes in view of the ongoing climate changes, that could irreparably compromise these ecosystems, which are important for recreational purposes as well.

Material and methods

The case study corresponds to the area reported in the historical thematic map of 1968 "Map of the vegetation of the Central Lucanian Apennines", which covers about 84,000 hectares. This area, classified as an heritage of landscape interest by the Italian legislation, is also partly included within the boundaries of the Lucania Apennine National Park (South Italy - Basilicata Region). The main landmarks are the mountain peaks of the central Apennines (maximum peak 1836 m a.s.l.); the

habitats of greatest conservation interest are beech forests and high-altitude grasslands. The main footpaths cross these habitats, so they are also the most attractive to tourists.

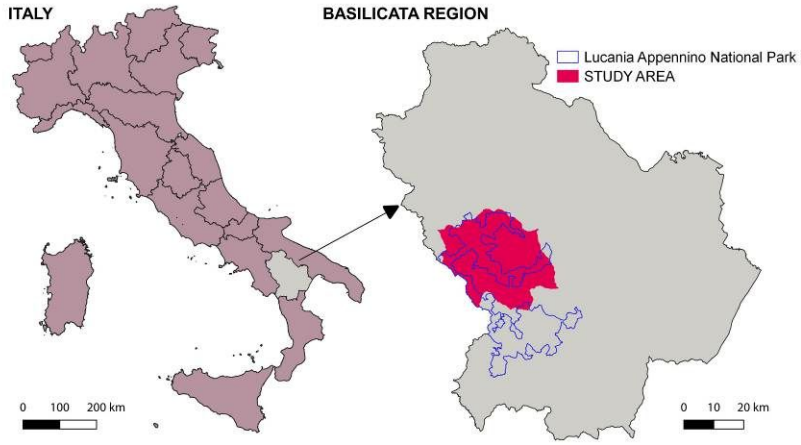

Fig. 1: Location of study area in Italy - Basilicata Region

The first phase was the creation of historical and current datasets of beech forests. The first historical cartography used is that of 1936 (Ferretti el al., 2018), freely available online in vector format. Then, we moved on to the main historical map of 1968 recovered from the Italian national library. Using the georeferencing and classification techniques proposed in previous studies (Statuto et al., 2017), it was possible to extrapolate only the data in vector format of the beech forests. With a view to integrating these data with satellite imagery (Figure 2), the Sentinel-2 satellite of the Copernicus programme was used to extrapolate the features of the beech forests by exploiting the algorithms of supervised classification applied to images taken in the Autumn period of Year 2020, in which the phenological differentiation between beech and other tree species is evident (Grabska et al. 2019).

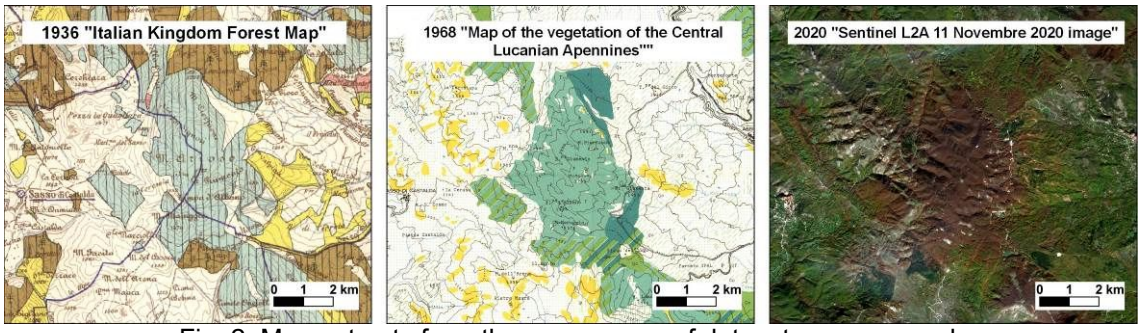

Fig. 2: Map extracts from the same areas of dataset sources used.

Subsequently, after a forest mapping operation and beech areas selections (Figure 3), a change detection analysis between the different datasets was realized. Thanks to this phase, it was possible to derive the main beech forest dynamics that occurred for the following different periods: 1936-1968 and 1968-2020. This made it possible to highlight areas where there has been an increase, decrease and permanence of beech forest. The dynamics have been analysed without going into detail on the types of transformations that have occurred (Figure 4). All operations were carried out with an open-source approach, thanks to the use of QGIS 3.16.

Results and Discussion

New GIS techniques and software allow the manipulation of different types of spatial data in a single working environment. In fact, processing and integrating historical cartography and satellite images has made all subsequent spatial analyses accurate and fast. The survey shows that, in general, there is an increase in forest area (by almost 12,000 ha) from 1936 to 2020 (Table 1). However, the area of beech forests has a different trend. After an increase between 1936 and 1968, the area is now reduced by almost 1500 ha. While in 1936, 29.5% of the forest area was beech, this percentage is now 24.17%. In addition, the qualitative assessment of the maps shows a fragmentation of the beech forests, which would need further analysis (Figure 3).

Tab. 1: Forest beech surface (in hectares and percentage compared total forest extension of study area) for each years of analysis

	1936		1968		2020	
	ha	%	ha	%	ha	%
Beech forest	7416.39	29.5	10516.11	32.2	9068.48	24.2
Total Forest area	25131.47		32614.18		37519.56	

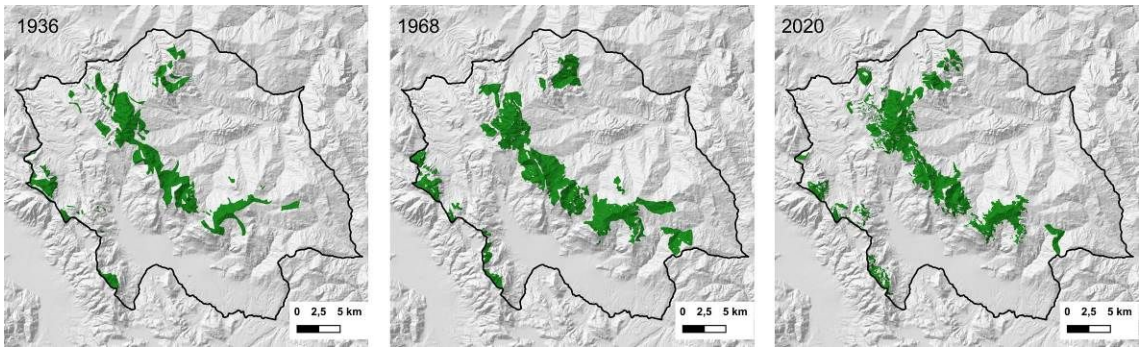

Fig. 3: Location of beech forests for each years of analysis

With regard to the transformation dynamics of beech forests, spatial analyses have revealed some interesting aspects. Regarding the increases, a much higher value is noted in the first period (1936-1968) than in the second (Table 2). Considering the order of magnitude, the reason may also be related to the fact that the historical mapping of 1936 presents much more simplified classes and does not consider mixed forest habitats. This aspect needs further detailed consideration. Decreases, on the other hand, in the first period are lower and related to patches distributed in different areas. The most interesting period to be analysed is 1968-2020, in which there is an important decrease in beech forests (just over 4000 ha), which are gradually being replaced by species from the lower vegetation belt. Moreover, the increases (almost 2000 ha) are almost punctual and should be further investigated in the field to assess whether they are real increases, or rather amplifications due to the accuracy of satellite image classification (Figure 4). The areas in which beech forests remain are about 6400 ha, mainly located along the peaks. Some of them are of considerable naturalistic interest as well. Moreover, from a technical point of view, the huge variability of plugins and modules within QGIS made this work very quick and accurate, demonstrating the scientific validity of the FoSS (Free and Open Source Software) approach.

Tab. 2: Variation of beech forest area, increase, permanence and decrease area (in hectares) for each period

	1936-1968	1968-2020
	ha	ha
Increase area	5183.47	2654.74
Permanence area	5332.63	6413.74
Decrease area	2083.77	4102.37

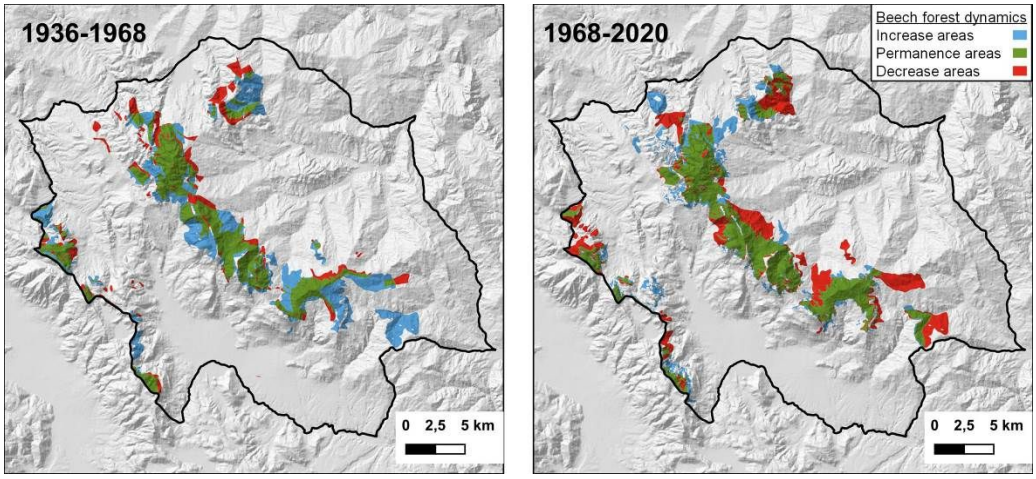

Fig. 4: Increase, decrease and permanence of beech forest areas

Conclusion

The characterisation of the forest landscape is suitably enabled by the integration of satellite images with historical cartography, which reveals to be increasingly effective and simplified, thanks to the use of new GIS tools, that allow the manipulation of many types of geodata in a single working environment. The methodology used in this study allowed to investigate the issues related to the forest landscape transformations that are taking place in the mountains of the study area. It could be used in similar contexts in Italy and in similar areas of the Mediterranean, and for comparable datasets, to evaluate the consequences of these processes, taking into account the high touristic value of these historical forest landscapes as well.

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Souhrn
Techniky GIS jsou zásadní při rekonstrukci ekologických vzorů a dynamiky krajiny, protože zaručují díky možnosti integrace několika typů časových geodat zavedení metod multidisciplinární analýzy. Kromě toho jsou nástrojem podpory pro terénní průzkumné činnosti, protože urychlují jejich práci. Analýza modifikací, které proběhly podél středomořských hor, kde nadměrné vykořisťování prováděné v minulosti a neustálé opouštění tradičního zemědělství (zejména pastvy ve volném výběhu) silně přetváří modely krajiny, je zásadní pro pochopení jejich hlubokých transformací a rekonstruovat jejich původní krajinnou strukturu a vyhnout se negativním dopadům z ekologického i turistického hlediska. Studie ukázala, že v prvním sledovaném období (1936–1968) došlo k významnému nárůstu bukových lesů, který byl částečně zrušen v období 1968–2020, kdy byl v některých oblastech zaznamenán významný pokles. V současné době (2020) se oproti předchozím rokům zvětšil povrch lesů ve studované oblasti, ale bukové lesy v procentuálním vyjádření poklesly (asi 24%). Metodika použitá v této studii umožňuje zkoumat problémy spojené s transformacemi historického typu lesní krajiny, které probíhají v horských oblastech Itálie a ve všech podobných oblastech Středomoří a mohly by být použity v podobných souvislostech, kde existují jsou k dispozici srovnatelné datové sady.

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