Looking at Seasonal Landscapes from Above. Mapping Spatio-temporal Conditions of Foliage across the Lucanian Apennines by Processing Satellite Multispectral Imagery

Andrea Rolando, Alessandro Scandiffio, Mariavaleria Mininni

Abstract

The process of analyzing, interpreting, and configuring a landscape is based on a dual cognitive approach: a view from above, which provides an overall understanding of the phenomena taking place on the earth's surface, and a view from the ground, focused on the physical experience of space, which require forms of representation more similar to perspective views. The experience of natural phenomena, such as flowering or foliage, is mainly based on the experiential approach at ground level but needs a broader view to establish analysis procedures able to support the design process, supported by cartographic representations showing the abstract point of view of the looking from above approach. The research was applied to the case study of the beech woodlands in the Lucanian Apennine Val d'Agri-Lagonegrese National Park, where it is possible to observe the phenomenon of the foliage of the woods with greater evidence, due to the homogeneity of these landscape areas. The methodology involves the use of dynamic mapping techniques which, through the processing of multispectral satellite images and the computing of vegetation indices, enable the features of the phenomenon to be represented in a spatio-temporal dimension. These forms of representation, on the one hand, can support decision-makers in defining territorial development strategies in the field of sustainable tourism, and on the other hand, they can be integrated into mobile web applications and/or web portals to provide geolocalized information which can be helpful for local actors and single users.

Keywords: mapping, multispectral satellite imagery, foliage, seasonal landscape, GIS.

The methodological framework: dynamic mapping of changeable landscapes

The process of analyzing, interpreting, and configuring a landscape is generally based on a dual cognitive approach: a view from above, based on an analytical approach –conceived from a Cartesian point of view, virtually placed at an infinite distance from the object and compliant with the geometric principles of cartography– finally represented through the orthogonal projections of the maps; this look is complementary to the view from the ground, conducted through a more experiential and perceptive approach, where man, sight and the senses, as well as the physical experience of space, play a central role and the representations make use of forms more similar to perspective views. When the landscape under observation is characterized by aspects that may significantly and singularly change throughout time, according to the seasons, the analysis process cannot only be conducted by looking at it from above, but an integrated and complementary process from the ground level becomes even more necessary. This approach must be furthermore refined through movement, activating specific analysis procedures based on routes that directly cross and sectionate the landscape itself, at ground level. In short, it is necessary to adapt the mapping process in a dual and dynamic way.

The experience of natural phenomena, such as flowering or the change of color of the leaves in autumn, is based on the experiential analytical approach at ground level, the one of the walking through, which allows us to appreciate every

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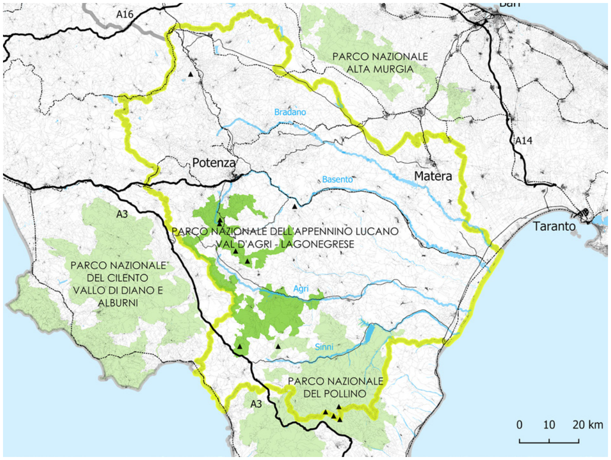
single plant component of a tree (leaves, flowers, fruits) at ground level and to represent them conceptually and geometrically as entities similar to a point. This way of acting in space is a landscaping act, a way in which the perception of the landscape becomes a cognitive and emotional act [Mininni, Sabia 2020, p. 116].
However, only through the practice of the movement across a significant space, it is possible to appreciate the phenomenon effectively, with the aim to better understand and control it, even in the perspective to drive the whole planning process and to create new opportunities for territorial enhancement, for example in the tourism sector.
For this reason, in order to establish analysis and interpretation procedures finalized to design strategies, broader views are needed, supported by cartographic representations that show the virtual and abstract point of view of looking from above, with reference to the surface in geometric terms, able to make visible the repetitions of the individual elements in a merged and homogeneous way, so as to make the phenomenon significant and appreciable at the right scale in a map. In summary, it is worth knowing how to read what happens at ground level, understanding in the right detail the growth of a plant: from blooms to flowers and finally to fruits. Traces and paths must therefore be defined in a precise way, so to highlight how the analyzed phenomenon occurs: with the transect method, with representations that hold together

Fig. 1. Location of the Lucanian Apennines National Park, in the system of national parks in southern Italy (graphic elaboration by Alessandro Scandiffio).



the line of a path (trace) and the record of the phenomena (track): lines that cross the map, accompanied with specific explanatory sections. In this sense, tracking technologies, based on GPS sensors, integrated with procedures that also make use of ground sensors, such as for precision farming techniques, can provide information that implement the mapping process. These are procedures derived from various expertise, linked to territorial mapping practices, and though they are addressed to multiple user communities, nevertheless it is worth keeping in mind how important it is to know how to read the phenomenon in the broadest dimension, in order to be able to control it in a adequate territorial dimension, with the specific tools of urban planning.
In this sense, the phenomena that characterize productive landscapes, in particular in their variable and seasonal dimension of tourist interest as well [Rolando, Scandiffio 2022] such as the foliage, the landscape of paddy-rice fields [Rolando, Scandiffio 2021; Scandiffio 2021b] or the spring blooming require a validation based on direct experience, that means observing 'from the ground'. However, in order to fully understand the evolution of these phenomena, it is equally crucial to have a broader and more abstract view, which enables seeing the whole picture and the evolution of the phenomenon over time. This approach becomes particularly important if we aim at considering a parameterization of the phenomenon with respect to time, so as to be able to predict the areas in which the phenomenon exhibits itself more evidently.
A methodological approach is therefore required, based on a loop of analysis, interpretation, identification of solutions, and refinement on the basis of iterative and repeated checks from the direct experiential scale to the abstract analytical one and vice versa. The 'place' that combines the perceptible detail at ground level (the one of the individual plant element) and the surrounding landscape is the route, where the point and surface meet. In this sense, the GPS route recording technologies and the GIS-based representation of the individual elements inserted in cartographic environments, therefore, become complementary tools for analysis and design.
The vector representations of the routes can be obtained in two different ways. The first method consists in collecting data from the ground through GPS recordings and exploiting direct experience on the field, in order to define a significant territorial area. The second one instead consists in looking from above, through the identification of the routes which cross relevant areas, on the basis of

geographical information such as the one relating to land use or satellite interpretations.
However, to obtain a complete and accurate representation of the territory, it is necessary to combine both approaches and progressively refine the interpretation of the territory, integrating information from above and from the ground level. In this way, it will be possible to identify effective and customized intervention strategies for each specific area.
The discourse is articulated and affects different disciplines and research fields, looking for scientific references that can perhaps help to put the research question in original terms and in a perspective useful for the analysis and intervention strategies and enhancement of seasonal landscapes. In this sense, the work of the plant biologist Stefano Mancuso is useful, when he states, also referring to Geddes, that plants are not simply passive organisms that adapt to the environment, but that they are also able to perceive and communicate with it, interacting with other organisms and with the soil, based on the principle of cooperation, which is the main force that shapes life: both in nature and in the cities, and human-made landscapes [Mancuso 2020, pp. 45-69].
This underlines how important it is that, when reading and interpreting a landscape, we also take into consideration not only the visible aspects, but also the dynamic interactions between green components and the surrounding context. In this way, it is possible to better understand the landscape complexity and dynamics and create nature-based design solutions which respect the natural balance of the environment.
The study case examined effectively explains the process of mapping related to autumn coloring due to the phenomenon of foliage in the beech woodlands within the Lucanian Apennine Val d'Agri-Lagonegrese National Park. Through the mapping of the natural elements that make up the landscape and their interaction with the productive landscapes, procedures of analysis and interpretation have been experimented with the aim to support actions of regulation, protection, and conservation or design strategies, for example, aimed at enhancing of territories in terms of tourism.

The seasonality of landscapes in the enhancement processes promoted by landscape planning

The making up of knowledge concerning a landscape planning process is a complex operation because it involves a huge amount of information dealing with multiple components that make up the landscape and the territorial structure of a region and the holistic dimension that belongs to the landscape. In many cases, the amount of data is not ensuring the making of strategic knowledge, because each cognitive 'frame', in decision-making processes, also has the task of working first of all in the construction of 'opinion making', strongly influenced by the way in which knowledge, 'opinion setting', are presented and problematized.
From this statement derives the strategic structural character of every planning process, in the sense that on the one hand, the knowledge is built that defines the territorial invariants as non-negotiable values within a vision of protection and preservation of the landscape assets; on the other hand, only a few of them will contribute to the strategic construction of proactive protection and therefore to the enhancement of the values considered fundamental for the development of the territories and the people who inhabit them.
Landscape Atlas or even better Heritage Atlas are the evocative ways to indicate the identity and heritage dimension of all those values selected on the basis of a precise territorial culture by the actors involved in the planning process which interprets the meaning of the politics that govern it, supporting their choices, beyond arbitrariness.
The integration of tangible assets with care to the intangible dimension adds major complexity to the landscape actions,

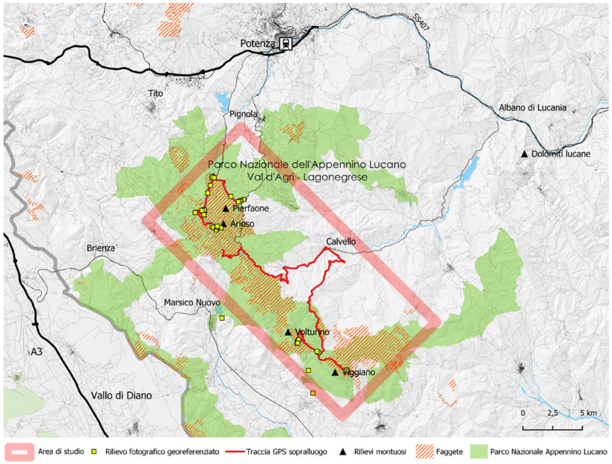


Fig. 2. Map of the study area, with evidence of the beech woodlands, GPS tracks with georeferenced photos recorded over the survey of 16th October 2022 (graphic elaboration by Alessandro Scandiffio).

especially considering the increasing value attributed to these components. Even though the value is not easily detectable with traditional tools, since innovative and creative methods are required and must be calibrated and validated every time in order to support the guidelines and regulations entrusted with planning.
In particular, perception, often interpreted as visibility of the landscape, instead concerns with a much more complex recognition process involving the knowledge owned by the communities, the value of traditions and rites that regenerate themselves, the way in which they are handed down by updating dimension of the present so that they take root in the contemporary world. The perceptive component, in an anthropo-ethnographic perspective, was one of the strategies established within the framework of the study agreement carried out between a group of researchers from the University of Basilicata and the Basilicata Region, Department of Environment, Territory and Energy for the purpose of drafting the Atlas of the landscape aimed at the making of the Regional Landscape Plan. The heritage dimension within landscapes has required the recognition of cultural landscapes by entrusting their representation to the combination of places, symbolic representation, and seasonality of rituals. The need to represent the notion of time to which the rituals of farmer festivities are linked has opened a critical reflection on the value of the dimension of food as a cultural marker of productive landscapes.
How to represent a deciduous forest that is astonished from the dimension of the intense greenery of spring to the slow transformation into the autumnal aspect that gives an appearance that is a prelude to the fall of the leaves? How does the fruiting of tree-lined crops configure landscape semantic density to flowering and fruiting? It is therefore a question of giving the landscapes the temporal dimension as a transitory

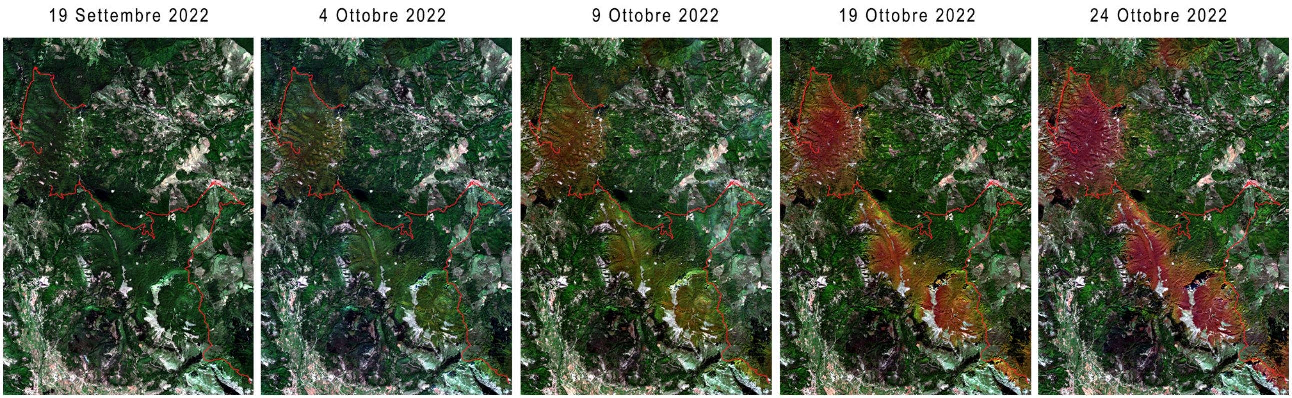
Fig. 3. Georeferenced photographic survey in the Monte Arioso area (PZ). Date 16th October 2022 (photographic survey by Alessandro Scandiffio).

value of perception, by integrating the visual aspect with the various methods of valorization, through the choice of the appropriate season to taste food, walk in the woods, and participate in ritual processions or community events.

Study area: the beech woodlands across the Lucanian Apennine National Park

The research has been applied to the case study of the beech woodlands in the Lucanian Apennine Val d'Agri-Lagonegrese National Park, which represents a great natural and landscape resource of this protected area, occupying about 15% of the total area of the Park. The Park, established in 2007, is located in the western area of the Basilicata region, southern Italy, on the border with the Campania region, in the Province of Potenza, along the Apennine backbone which is in-between the Cilento-Vallo di Diano National Park and the Pollino National Park (fig. 1). The territory of the Park involves the upper valley of the Basento and Agri rivers, dominated by the presence of some mountain peaks, which are the main visual references: mount Pierfaone (1.737 m), mount Arioso (1.772 m), mount Volturino (1.836 m), mount Viggiano (1.772 m) and mount Sirino (1.970 m).
The Italian National Internal Areas Strategy (SNAI) classifies the areas of the Park in the 'peripheral' and 'ultraperipheral' categories, in relation to the low population density and the lack of infrastructure accessibility. However, both factors have contributed positively to the conservation of natural environments and to the maintenance of high biodiversity, essential resources for developing strategies for the tourist enhancement of these territories. From a landscape point of view, the Park includes an extraordinary variety of environments characterized by a high level of naturalness involving, not only the mountains, but also secondary valleys, hilly areas and historic settlements where local cultures and traditions are rooted.
From the point of view of vegetation, there is a great variety of tree species (turkey oak, maple, white fir, downy oak, chestnut, hazel), including beech, which cover large portions of the highest areas of the mountains. In particular, in the elevation range between 1.000 m and 1.800 m a.s.l., tall beech woodlands, which are one of the main distinctive aspects of the mountain landscape of this area, cover the extensive areas in the upper part of the Apennine chain. These are very dense and uniform woods, characterized by the presence of old-centuries beech trees, up to 30 m high, which create a homogeneous vegetative cover, interrupted only in a few stretches by meadows and pastures. Due to the homogeneity of landscape features of these areas, it is possible to observe the phenomenon of natural changing colors over the autumn season, as an identifying feature of these places. By referring to the purposes of the research, the area in-between Mount Pierfaone, Arioso, Volturino, and Viggiano, located in the northern part of the Park, was

Fig. 4. The temporal sequence of the satellite imagery shows the evolution of the foliage phenomenon in the beech woodlands across the study area. Bands combination RGB - real color (graphic elaboration by Alessandro Scandiffio).

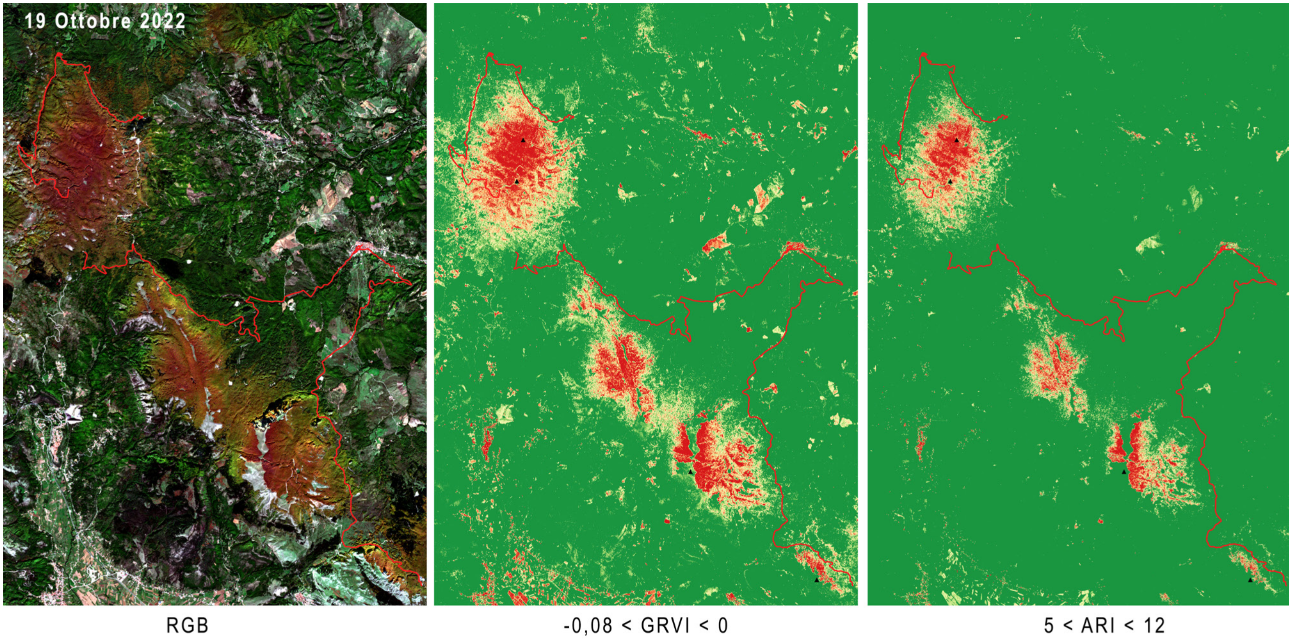


selected as a pilot case for the dynamic mapping of the phenomenon of the foliage of the beech woods, which in this area can be recognized more clearly (fig. 2). As part of the research, a direct survey on the field was conducted with the aim of analyzing, on the one hand, the physical characteristics of the places over the autumn season, and on the other hand, verifying the correspondence between satellite and ground observations, shown by GPS track, by the georeferenced photographic survey and a selection of demonstrative photographs (fig. 3).

The dynamic mapping process

This section is about the dynamic mapping process [Scandiffio 2021a], which allows the representation of the scenic phenomenon of the autumn coloring of the beech woodlands, understood as a distinctive aesthetic condition of the landscape within a certain territory. The evolution of cartographic tools, over history, has allowed the performing of increasingly accurate interpretative models of reality, able of highlighting not only the spatial elements that bear the shape of places [Pandakovic, Dal Sasso 2013, p. 218], but also to trace its evolutionary changes over time.
In the dynamic mapping process of the landscape, new relationships are established between the physical elements of the space and variable elements that change over time, which it is necessary to dynamically interpret and communicate them externally (for example between orography and vegetation, between vegetation and solar exposure, between elevation and crops). The abstract zenithal view, typical of cartography, provides a privileged point of observation of reality, enabling each one to appropriate a certain territorial portion and analyze it over time, through design tools. The landscape is only apparently static, a 'produced space', the result of a natural and/or anthropic transformation that took place over time [Sereno 1981]. Indeed, over the alternation of the seasons, the landscape varies significantly, assuming different aesthetic connotations, in relation to the rhythm of life of the natural species and the human activities that act

Fig. 5. Application of customized thresholds to the GRVI and ARI vegetation indices for foliage mapping (graphic elaboration by Alessandro Scandiffio).



on the earth's surface [Palang et al. 2007]. The relationships between shapes and colors of the landscape are strongly interconnected through the cycle of the seasons, [Stobbelaar, Hendriks 2007, p. 105] and can they can be analyzed in a space-time dimension through complex mapping systems.
Many seasonal changes in the landscape are linked to crop cycles and variations in vegetation, which is one of the most changeable components of the landscape during the year and which creates scenarios of continuous interest in the field of sustainable tourism. By investigating the main phenological phases of the life cycle of plants, it is possible to dynamically identify and map the evolutionary path of plants. By exploiting the potential of the multispectral satellite imagery of the Sentinel-2 mission, within the European Copernicus Program of the European Space Agency (ESA) [Marconcini et al. 2020, p. 654], it is possible to simultaneously observe both the spatial and temporal dimensions of the landscape, where scenic-perceptive phenomena of interest to the community occur seasonally [Scandiffio 2021a]. Dynamic mapping, therefore, is configured as a critical-interpretative process that enables extracting from the satellite image, which provides a comprehensive zenithal representation of reality, the conditions of the greatest evidence of the specific phenomenon (for example foliage), which occurs in some characteristic places and at a specific time of the year.

Methodology

The methodology is based on four fundamental points: the acquisition of multispectral satellite images, the image processing by combining the electromagnetic bands for the computing of the vegetation indices, the identification of customized thresholds of the vegetation indices for the mapping of the specific scenic phenomenon, and the interpretation of the results.
The European Copernicus satellite observation program enables the free use of temporal series of multispectral satellite imagery of the Sentinel-2 mission, with a high spatial resolution (10 m) and temporal resolution (revisit time 3-4 days at mid-latitudes), which cover the whole earth's surface. The use of multispectral imagery allows the use of different bands, which record the reflectance values, emitted by objects which are on the earth's surface, in different wavelengths of the electromagnetic spectrum (for example visible, infrared, near-infrared). For mapping seasonal phenomena affecting the vegetation, specific vegetation indices are used in literature (for example NDVI, GRVI, EVI, ARI, etc.) which, through appropriate combinations of different bands, allow investigating the phenological cycle and analyzing the health status of vegetation [Tucker 1979]. In the case study, the Semi-Automatic Classification (SCP) plug-in in GIS software was used for the acquisition and processing of multispectral satellite images [Congedo 2021]. The temporal analysis of the satellite imagery acquired in the area of the beech woods in the Lucanian Apennines enables observing the evolution of the coloring phenomenon over the autumn season by visualizing satellite images in the real color combination (RGB) (fig. 4). This is a preliminary step to analyze the evolution of the coloring phenomenon over time.
Some of the most interesting methodological aspects concerning the mapping of the coloring phenomenon deal with the research of the vegetation indices which are sensitive to the change of coloring of the leaves (from green to yellow, from green to red) and with the performing of related thresholds. In scientific literature, the performance and applicability of some vegetation indices for the study of spring flowering and autumn coloring in relation to the different types of trees are analyzed. The vegetation indices that exploit different combinations of the green and red bands perform better than other well-known indices such as NDVI [Motohka et al. 2010; Junker, Ensminger 2016]. Referring to the purposes of the research, two different combinations of the red and green bands have been used which correspond to the following vegetation indices:

$$GRVI = \frac{GREEN - RED}{GREEN + RED}$$

$$ARI = \frac{1}{GREEN} - \frac{1}{RED}$$

For each satellite acquisition, in the selected time range (autumn 2022) (fig. 4), the ARI GRVI vegetation indices were computed. The ARI index was taken into consideration, in relation to the presence of anthocyanin pigments, responsible for the coloring of the leaves, but it appears to be less performing than the GRVI one (fig. 5). The GRVI, being a normalized difference, can assume values ranging between -1 and +1. For the research purposes of mapping, it is also necessary to identify one or more specific thresholds in relation to each specific vegetation index, through which it is possible to 'isolate' the features of the searched phenomenon. In the case of autumn coloring,

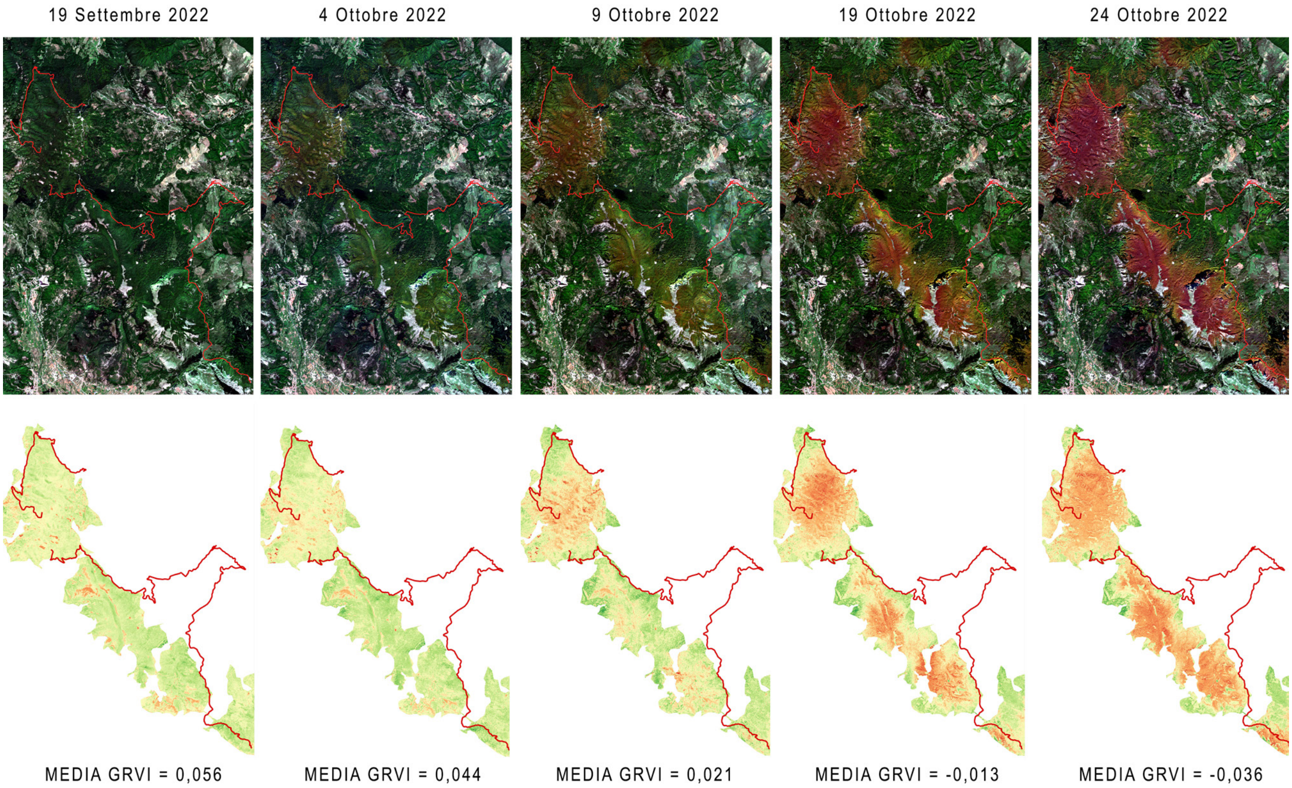


Fig. 6. Temporal sequence which highlights the trend of the GRVI average values (graphic elaboration by Alessandro Scandiffio).

the GRVI value=0 represents the sensitive threshold able to separate the green surfaces from those in color. Negative GRVI values make it possible to map the different nuances of autumn colors of the beech woods in the study area.

Results

The application of the methodology based on the vegetation indices, which use the combinations of the red and green bands, enables mapping with high accuracy of the areas where the autumn coloring of the beech woods occurs and its temporal evolution. It is evident that over the clìmax condition of the coloring foliage (range between 19th October 2022 and 24th October 2022), the GRVI performs, within the beech woods, the minimum value, equal to approximately -0.2, which identifies the maximum level of coloring. The GRVI values, which are related to significant color variations, range between 0 and -0.2. Furthermore, the trend of the average GRVI value, in the area of beech woodlands, for each satellite acquisition, has been computed, with the aim to show in a spatio-temporal perspective, the temporal evolution of the coloring phenomenon, and the effectiveness of the methodology proposed for mapping this phenomenon (fig. 6).

Conclusion and future development

The research shows a method for the dynamic mapping of the scenic phenomenon of foliage which, in recent years, has been characterizing some places as new tourist destinations in many areas of Italy. In this perspective, the use of satellite observations, with high spatial and temporal resolution, allows for the creation of new forms of representation which, in a dynamic way, show the processes taking place in the landscape, making them visible even to inexperienced eyes. The temporal dimension provides further hints for the analysis of the physical and cultural components of the landscape, typically represented in a static form in the maps, enriching them with changing contents that reproduce the variability of reality in a visual form.
Furthermore, if we consider that the foliage phenomenon is a manifestation of a crisis situation of the plant and that this is directly influenced by the climate, these methodologies can also offer, considering the increasing evidence of the issues related precisely to the climate and environmental crisis, analytical tools and significant research opportunities not only in the field of tourism management, but also for broader awareness-raising and territorial governance strategies.
Further research development can be addressed towards the development of methodologies that allow the integration of satellite observation with ground observation in a more effective way, to make the results more accurate and usable also in a predictive perspective, also including location-based service and users generated contents for mobile devices. By considering the role of these kind representations for practical use, they may configure as tools able of supporting decision-makers in defining territorial development strategies, if appropriately integrated within web mobile applications and/or web portals for the provision of geolocalized information, usable by local actors and single users.

Credits

Author contributions: all the authors shared the principles and the research topics presented in the article. However, the paragraph titled *The methodological framework: dynamic mapping of changeable landscapes* was written by Andrea Rolando; the paragraph *The seasonality of landscapes in the enhancement processes promoted by landscape planning* was written by Mariavaleria Mininni; the paragraphs titled *Study area: the beech woodlands across the Lucanian Apennine National Park, the dynamic mapping process*, *Methodology*, *Results* were written by Alessandro Scandiffio; the paragraph *Conclusion and future development* was jointly written by all authors.

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Authors

Andrea Rolando, Department of Architecture and Urban Studies, Politecnico di Milano, andrea.rolando@polimi.it
Alessandro Scandiffio, Department of Architecture and Urban Studies, Politecnico di Milano, alessandro.scandiffio@polimi.it
Mariavaleria Mininni, Department of European and Mediterranean Cultures, University of Basilicata, mariavaleria.mininni@unibas.it

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