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LARGE-SCALE ASSESSMENT OF TREES OUTSIDE FORESTS

IN RELATION TO RECENT DYNAMICS IN MEDITERRANEAN LANDSCAPES

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European Landscape Convention

Adopted by the Committee of Ministers of the Council of Europe on 19 July 2000 and opened for signature by its Member States in Florence on 20 October 2000

Chapter I – General provisions

Article 1 – Definitions

For the purposes of the Convention:

a. "Landscape" means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors;

Article 2 – Scope

Subject to the provisions contained in Article 15, this Convention applies to the entire territory of the Parties and covers natural, rural, urban and peri-urban areas. It includes land, inland water and marine areas. It concerns landscapes that might be considered outstanding as well as everyday or degraded landscapes.

Article 3 – Aims

The aims of this Convention are to promote landscape protection, management and planning, and to organise European co-operation on landscape issues.

Abstract

Large-scale assessment of Trees Outside Forests in relation to recent dynamics in Mediterranean landscapes: testing different approaches and methods

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Besides representing the main source of food, materials and energies, trees have a leading role against the negative effects of human-induced changes on climate and land use in the 21st century. Nevertheless, policy-makers and planners have long ignored the ecosystem services' (ES) potential of billions of trees not properly recognized as "forests" by FAO classification system. Despite their limited coverage, these trees actually play a key role in ameliorating social and economic development at both global and local scale and improving the environmental quality and well-being of local communities. The key role of Trees Outside Forests (TOF) became of global interest only in 1996, during the "FAO Expert Consultation on Global Forest Resources Assessment 2000" (FRA 2000) held in Finland. TOF includes all trees excluded from the definition of "forest" and "other wooded lands" because of their limited extension in terms of both coverage (less than 0.5 ha) and width (less than 20 m). Although first works on TOF date back to 70', research on this forest resource has considerably increased since their definition by FAO, when many countries also begun to incorporate TOF within their forest monitoring systems. Systematic TOF inventories at national and sub-regional level, more or less inspired by the FAO guidelines, have been developed in order to collect information on TOF and include them into strategies for sustainable landscape development. Being generally settled at the human-nature interface (e.g., urban and agro pastoral systems), TOF are directly exposed to anthropic pressures, first of all Land Use Change (LUC). However, influence of LUC on TOF is still poor or not investigated. More generally, a lacking of information makes difficult their integration into global and national statistics and, consequently, their conservation and enhancement. Lastly, existing literature is principally oriented toward the ecological functionality of TOF, while less attention is focused to their social and cultural role.

Considering these issues, the main aim of this thesis is focused on providing a deeper understanding of TOF and related ES in relation to recent landscape dynamics in the Mediterranean basin. For these purposes, different methodological approaches to assess quantitative trends of TOF and related ES in recent decades were developed and tested on large scales. In detail, the first part of thesis concerned the development of an integrated methodology (i.e., integrating inventory and cartographic approaches) in order to assess changes in coverage, abundance, and average size of TOF between 1990 and 2013 using Italy as a case study. The second work of this thesis related to the assessment of the ecological diversity of TOF and their role as carbon sink by adopting a large-scale estimation framework in Molise region, central Italy. Last work aimed to evaluate TOF contribution to landscape aesthetics analyzing correlations between landscape preferences and indices in relation to different degrees of TOF abundance and landscape characteristics.

Main results affirmed a significant increase of TOF in abundance (+17.1%) and coverage (+27.4%) respect to 1990 in Italy. Considering threats deriving from landscape homogenization, these trends are very encouraging, testifying an increased contribution of TOF to the diversification of Italian landscapes in recent decades. From an ecological perspective, TOF characterization in Molise region displayed a high ecological diversity of this forest resource. Specifically, 60 different species of TOF have been assessed in Molise region (respect to 45 tree species of the Italian forests), with a C stock that is far from negligible (i.e., 28.6 t of C ha^{-1}). As for TOF contribution to landscape aesthetics, their influence seems to be closely linked to different anthropization levels, resulting highest in densely populated areas, decreasing in rural areas and becoming null in natural landscapes, even negative in extremely natural ones.

As well as innovative, proposed methodologies have proved to be particularly effective in achieving a rapid and reliable large-scale assessment of TOF and related ES. More generally, this thesis advocates the urgency to include TOF in forest resource management and monitoring systems, also representing a further step towards the effective implementations of sustainable land management support tools.

Keywords: sustainable landscape development, land use change, landscape dynamics, ecosystem services, trees outside forests

Contents

Acronyms

AWMSI	*Area-Weighted Mean Shape Index at landscape level*	**ISTAT**	*Italian National Statistical Institute*
CD	*Class Density at landscape level*	**IUTI**	*Italian Land Use Inventory*
CES	*Cultural Ecosystem Services*	**LUC**	*Lan Use Change*
CICES	*Common International Classification of Ecosystem Services*	**LULUCF-GPC**	*Good Practice Guidance for Land Use, Land Use Change and Forestry*
CMP	*Landscape Complexity*	**MEA**	*Millennium Ecosystem Assessment*
DBH	*Diameter at Breast Height of a standing tree*	**MPFD**	*Mean Patch Fractal Dimension at landscape level*
DEM	*Digital Elevation Model*	**MPS**	*Mean Patch Size at landscape level*
DIV	*Landscape Diversity*	**NFI**	*National Forest Inventory*
EEA	*European Environment Agency*	**NFMA**	*National Forest Monitoring and Assessment program*
ELC	*European Landscape Convention*	**PD**	*Patch Density at landscape level*
ES	*Ecosystem Services*	**PSCoV**	*Patch Size Coefficient of Variation at landscape level*
FAO	*Food and Agriculture Organization of the United Nations*	**RSE**	*Relative Standard Error*
FRA	*Global Forest Resources Assessment*	**SDI**	*Shannon's Diversity Index at landscape level*
FRG	*Landscape Fragmentation*	**TE**	*Total Edge at landscape level*
GI	*Green Infrastructures*	**TEEB**	*The Economics of Ecosystems and Biodiversity*
INFC	*Italian National Forest and Carbon Sink Inventory*	**TOF**	*Trees Outside Forests*
IPCC	*Intergovernmental Panel on Climate Change*	**TSS**	*Tessellation Stratified Sampling*

Tables and figures

List of Annexes

Paper I-III

I Sallustio, L., **di Cristofaro, M.**, Hashmi, M., Vizzarri, M., Sitzia, T., Lasserre, B., Marchetti, M. (2018). *Evaluating the Contribution of Trees outside Forests and Small Open Areas to the Italian Landscape Diversification during the Last Decades*. Forests, 9(11), 701.

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II Marchetti, M., Garfì, V., Pisani, C., Franceschi, S., Marcheselli, M., Corona, P., Puletti, N., Vizzarri, M., **di Cristofaro, M.**, Ottaviano, M., Fattorini, L. (2018). *Inference on forest attributes and ecological diversity of trees outside forest by a two-phase inventory*. Annals of forest science, 75(2), 37.

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III **di Cristofaro, M.**, Sallustio, L., Sitzia, T., Marchetti, M., Lasserre, B. (2020). *Landscape Preference for Trees Outside Forests along an Urban–Rural–Natural Gradient.* Forests, 11(7), 728.

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Extended abstract

Research framework

Trees Outside Forests (TOF; *sensu* FAO 2001) represent a particular forest resource which substantially contributes to human well-being at both local and global scale through several ecosystem goods and services (de Foresta et al., 2013). Being small landscape patches, TOF are particularly sensitive to recent landscape dynamics in Mediterranean areas linked to the recent socio-economic driving forces (Verburg et al., 2006). The meeting point between maintenance of TOF-related ecosystem services (ES) and the protection of a rapidly evolving landscape is represented by sustainable policies that however often exclude TOF from landscape management and monitoring discourses, primarily due to a general lack of data and knowledge (Schnell et al., 2015a). Although the large-scale assessment of TOF is a priority for the implementation of planning and management strategies aimed at the conservation and improvement of landscape quality, the development of a unique protocol replicable in all countries still remains an international challenge. Mainly, the high variability and heterogeneity of TOF systems prevents their assessment at large scales due to the excessive efforts that would entail the use of traditional methodologies (de Foresta et al., 2013). Furthermore, their limited extension in spatial terms is often inconsistent with the currently minimum thresholds adopted in tree resources' inventories (Chazdon et al., 2016). Contrary to policy attention, scientific interest in TOF is constantly growing, but most of researches refer to synchronic studies. For this reason, knowledge of spatio-temporal dynamics of TOF is very limited (Novotný et al., 2017). Furthermore, scientific research continues to focus on strictly quantitative aspects, often ignoring cultural value of TOF (de Foresta et al., 2013). According the above, this research mainly aims at providing further knowledge on TOF and related ES in relation to the current dynamics in Mediterranean landscapes, in order to encourage their inclusion in existing forest resource management and monitoring systems. Specifically, in this thesis we propose, test and discuss different approaches and methods for the large-scale assessment of TOF in relation to:

- trends in coverage, abundance and average size of TOF between 1990 and 2013 in Italy;
- ecological diversity and above-ground C storage of TOF in Molise region, central Italy;
- TOF contribution to Mediterranean landscape aesthetics along the urban-nature gradient.

Materials and methods

In order to assess trends of TOF in Italy between 1990 and 2013, an integrated methodology (i.e., combining inventory and cartographic techniques) was proposed and tested. Based on the Italian Land Use Inventory (IUTI), we identified a set of sampling points falling on tree crowns settled in land use classes other than forests, which then represent TOF sample. Trees polygons in which these points felt were photo-interpreted at both 1990 and 2013. Then, a design-based estimation approach was implemented in order to estimate abundance, coverage and average size of such polygons at the two time-steps as well as their change through time at national scale.

The second activity of this thesis focused on the assessment of the ecological diversity and above-ground C stock of TOF. By adopting a two-phase inventory framework (among those theoretically investigated by Fattorini et al. (2016), 45 out of the 52,796 TOF sample units of the regional census in Molise region, Central Italy, were selected. A field survey was performed in order to collect data and estimate four forest attributes related to the sampled TOF units (i.e., tree abundance, basal area, wood volume and above-ground biomass). Last, forest attributes of TOF in Molise region were estimated.

For the last research activity, 6 photos representative of the whole urban-nature gradient were selected in a preliminary step. From each original photo, a triplet of photos was developed using a raster graphic editor. Each triplet consists of 3 reproductions of the original photo with 3 different degrees of TOF abundance (i.e., null, medium, high). Then, 18 altered photos have been exposed in a visual choice experiment to 360 respondents, asking them to rank the 3 photos of each triplet according to their individual aesthetic preference. Furthermore, a landscape analysis of the 18 photos and the estimation of the related landscape indices (i.e., fragmentation, complexity and diversity) was carried out in a GIS environment. Finally, correlations between landscape preference and indices have been calculated.

Results and discussion

Our results displayed that the overall number and coverage of TOF increased during the reference period (+17.1% and +27.4%, respectively), while their average size remained stable.

Hence, our findings revealed that TOF have increasingly contributed to the diversification of Italian landscapes in last decades. In addition, we can observe that the increase of TOF coverage in the reference period inversely relates with a significant loss of spaces for their potential expansion (in detail, the non-forest land uses decreased by about 580,000 ha in Italy between 1990 and 2013; Pagliarella et al., 2016). Therefore, this upshot should be interpreted as an important extension of the green infrastructure network, through which the ecological connectivity is further improved.

From an ecological perspective, we found that tree abundance, wood volume and C stock of TOF in Molise region are concentrated in few dominant species. However, a seeming poor species diversity in forest attributes is mitigated by the high number of recorded tree species (i.e., 60 species) and the presence of several rare ones. This is in line with the estimates for the Italian forests that are principally made by 20 out of a total of 45 tree species that represent more of the 90% of the total biomass (for more details, see the Italian National Forest Inventory; INFC 2005). Furthermore, the average TOF contribution to C stock is not negligible, amounting to 28.6 t ha^{-1} compared with the 47.2 t ha^{-1} of the national forests and 42.3 t ha^{-1} of the regional ones (INFC 2005). Supposing a further growing of the C stock amount in the next few years, this finding emphasizes the potential role of TOF as part of the national and global forest strategies to climate change mitigation.

Lastly, main findings from the third activity exposed how TOF contribution to landscape aesthetics depends on the anthropization level of landscapes along the urban-nature gradient, confirming all theories about human addiction to nature (e.g. Kaplan & Kaplan, 1989; Kellert & Wilson, 1995). Our results displayed that the highest TOF contribution to landscape aesthetics occurs in densely populated areas (i.e., correlations between preference scores and indices have greater intensity in urban landscapes respect to rural and natural ones), where TOF represent the last representation of nature and act as the most important source of ES (Willis & Petrokofsky, 2017). As for rural landscapes, correlations between landscape preferences and indices were positive but lower respect to urban, in accordance with a lower anthropization level. It should be highlighted that diversity index is slightly intensely correlated to preference scores than the other two indices of rural landscapes, affected by strong structural changes occurred in post-war period leading to an extreme simplification of mosaics (Eichhorn et al., 2006). Moving towards more natural landscapes, human impact diminished and, likewise, TOF contribution to aesthetics. Moreover, in this case, although an increase in TOF abundance continued to implicate a general upgrading in landscape heterogeneity, their contribution to aesthetics of natural landscapes became null, even negative in the homogeneous ones. Indeed, aesthetics of natural landscapes depends more on conceptual and emotional aspects than on specific biophysical characters (Beza, 2010), and a high forest fragmentation generally represent a negative indices of perceived naturalness (Ode et al., 2009).

Final remarks

Findings of this thesis revealed how TOF do not represent a negligible component of natural capital both in qualitative and quantitative terms, as they provide fundamental ecosystem goods and services that largely contribute to improve the well-being of communities (de Foresta et al., 2013). Thus, our results foster the importance of including TOF in sustainable land management discourses, especially considering how TOF can represent an important support to the sustainability challenges imposed by the ongoing environmental changes. In this perspective, approaches and methods for the large-scale assessment of TOF consistency, functions and services proposed in this thesis proved to be particularly valuable and able to support sustainable landscape development initiatives.

Inventory approaches tested in this thesis allowed a time/cost effective large-scale assessment of TOF as well as their temporal trend. Furthermore, the integration of inventory approaches and cartographic techniques ensured more than satisfactory statistical accuracy of estimates. Indeed, one of the main task about TOF research is the effort in balancing time and cost for monitoring activities with the statistical robustness and reliability of the estimates. These issues are related to the uneven physical configuration of TOF systems (FAO 2010), due to (i) the high variability in both abundance and spatial composition of TOF and (ii) their limited extension which implies easy underestimation errors by applying the accounting and monitoring methods currently used for forest resources. Therefore, this thesis suggests interesting remarks about the adoption of "not pure" approaches for TOF assessment, promoting the integration of several techniques in multi-phase approaches. Hence, our studies can be also considered a good starting point for the development of shared and replicable protocols for assessing TOF at larger scales (i.e., global), allowing the collection of comparable data in several contexts. This might contribute to overcome both the lack of data on TOF as well as their fragmentation across different institutions and stakeholders (Schnell et al., 2015a), thus contributing to foster their inclusion in policy and planning strategies at broad scales.

Correlating a social preference exercise to a landscape analysis seems to be an appropriate solution especially for the assessment of cultural ecosystem services (CES), which are closely linked to people perception. Considering the TOF involvement in a wide range of uses, a further suggestion concerns the validity of multifunctional methodologies for their assessment, such as the one proposed, able to mediating between the social and cultural values of TOF and their essential support in ecological terms. However, it should also be noted that the effectiveness of the methodology proposed in this thesis for the TOF-related CES assessment at landscape scale required generous efforts. Hence, we support the development of specific tools that can easily integrate well-known social information (e.g. preferences) with biophysical data (e.g. TOF and land use maps), for instance models that automatically quantify and map TOF-related CES as well as their changes over the time.

Concluding, the maintenance and enhancement of TOF involves two main benefits. On the one hand, TOF can in fact represent drivers for ecological, economic and cultural development of both densely populated and marginal areas if properly conceived and planned. On the other hand, they can be managed to enhance the landscape protection (and restoration) considering the ongoing landscape dynamics related to both land abandonment and increasing human pressure phenomena. In both perspectives, thinking landscapes as coupled human-nature systems, a comprehensive understanding of the connections between communities and ecosystems is required in order to incorporate social and ecological issues in landscape assessment and achieve future-oriented strategies addressing to sustainability challenges. In this sense, we argue that further efforts and more elaborate studies are needed to assess TOF and related ES in order to better understand how to exploit their contribution to human wellbeing. In a general context, such studies would also promote more information about impacts of slow processes of change on environmental (i.e., resilience and fragility) and social (i.e., human well-being) sides, which represent indispensable prerequisites for the conservation and enhancement of landscape quality.

CHAPTER 1 - State of the art

1.1. Recent dynamics in Mediterranean landscape: issues and challenges

As stated by the Art. 1 of the European Landscape Convention (ELC; Council of Europe, 2000), a landscape is *an area as perceived by local people or visitors, whose visual features and character are the result of the action of natural and/or cultural (that is, human) factors*. According to the ecology school definition, a landscape consists of a matrix of relatively homogenous areas (i.e., patches) that differ from each other for spatial configuration and constituent diversity (Lausch et al., 2015). These patches describe the structure of a landscape and their presence increases heterogeneity, making landscapes more fragmented, complex and diversified and bringing positive effects on the ecosystem functionality and, consequently, on the ES supply (Forman, 2014). Over the years, the strictly ecological meaning of a landscape has been revised through a more complex and complete perspective, as displayed by the ELC definition. Being a coupled human-nature system (Liu et al., 2007), assessing landscape processes and dynamics by considering separately social and ecological aspects would be almost useless (Ellis, 2015). Although the concept of "change" is intrinsic in natural systems, the alarming acceleration in landscape dynamics during last century (Antrop, 2005) revealed that recent changes depend more on human than natural drivers (Plieninger et al., 2015a). Indeed, the consequence of human actions on landscape dynamics already emerged in 1925, when the geographer Carl Sauer coined the term "cultural landscape" referring to the result (product) of the activities of a cultural group (agent) on a natural landscape (medium).

Since the Industrial Revolution, the increase of intensive croplands and the continuous growth of urban areas worldwide increasingly altered the structures and the functioning of the existing landscapes at an unprecedented rate (Antrop, 2005). Mediterranean landscapes are a case in point of dynamics shaped by socio-economic phenomena (Blondel, 2006). Indeed, representing the background of the most ancient and powerful civilizations in the world, this area has undergone human forces for a very long time and in all its districts. Human activities led to the almost total conversion of natural landscapes in cultural landscapes, deriving from the reorganization process of land use and cover in order to adapt them to evolving social needs (Antrop, 2005). Anthropogenic drivers manifested themselves through land use change (LUC) that, considering the high variability of Mediterranean landscapes, implied different environmental responses. In fact, landscape dynamics vary across space and time in non-linear ways (Liu et al., 2007).

In recent decades, Mediterranean basin is experiencing social emigration phenomena from marginal areas towards districts with greater opportunities for economic development, that resulted in the rewilding of the abandoned mountain landscapes and the widespread anthropization in lowland and along coasts (Marchetti et al., 2012). Land rewilding can have both positive and negative implications (Pereira & Navarro, 2015), but the subsequent landscape homogenization often involves considerable environmental, economic and cultural risks. These risks also concern densely populated areas (where urban expansion caused permanent soil consumption; Marchetti et al., 2014) and rural areas (where agricultural intensification led to the extreme simplification of landscape mosaics due to the consolidation of small land holdings in single huge proprieties; Eichhorn et al., 2006). For instance, landscape homogenization is a well-known issue in Italy, where several studies (e.g., Marchetti et al. 2012, Corona et al., 2012; Sallustio et al., 2015a) showed that forest expansion mainly occurs at the expense of rural lands disengaged by traditional practices and, at the same time, the urbanization involves the loss of fertile soil and green spaces in densely populated areas (Table 1).

Table 1 Estimates at the years 1990 and 2013 of the main land-use classes and of their changes together with the relative standard error estimates (in brackets). Land use proportions were estimated through a two-phase sampling scheme with a sampling fraction of 1% of the entire sample of the Italian Land Use Inventory (IUTI), promoted and implemented by The Italian Ministry of Environment and Protection of Land and Sea as a key instrument of the National Registry for forest C sinks (Data source: Pagliarella et al., 2016)

LAND-USE CLASS	**1990 (%)**	**2013 (%)**	**1990–2013 (%)**
Forest land	30.32 (0.14)	31.87 (1.26)	1.55 (25.72)
Cropland	46.87 (0.10)	44.01 (0.98)	− 2.86 (14.81)
Grassland	13.48 (0.23)	11.86 (2.36)	− 1.62 (17.19)
Wetland	1.66 (0.70)	1.94 (6.15)	0.28 (46.97)
Settlements	5.45 (0.38)	7.17 (3.11)	1.72 (12.96)
Other lands	2.18 (0.61)	2.98 (4.93)	0.80 (18.38)

Such strong and extensive human-induced changes led to particular adaptive capacities (i.e., resistance and resilience) in landscape natural features (Blondel, 2006). From the ecosystem responses to the radical remodelling of their patterns by humans, a contemporary idea of biosphere, in which almost the total of existing biomes show obvious signs of human inference, is born. The concept of anthropogenic biomes (*anthromes*; Ellis & Ramankutty, 2008) represents a new interpretation of terrestrial biomes, considering how these are more or less shaped by humans. They indeed may result from negative impacts of human activities on environment (e.g. pollution, soil consumption, fires) or from direct actions aimed at landscape restoration (humans as an ecosystem engineers). Although they largely occur in human-shaped domains (i.e., croplands and settlements), anthromes can indeed provide high levels of biodiversity and ES as long as landscape structures are managed to improve ecological connectivity (Ellis et al. 2010). Clearly, human influence was not restricted to landscape remodelling but, according to a cascade model (Haines-Young & Potschin, 2010), involved landscape functionality and ES capacity (Costanza et al., 2014). Furthermore, effects of social, cultural and economic drivers of change on ES capacity match with the significant spatial shift of ES requirement, upsetting their flows and the overall supply/demand ratio (Cumming et al., 2014). Nowadays, about 72% of the European population lives in urban areas (it is estimated that this percentage will reach 80% by 2050; Eurostat, 2016) and their well-being is closely linked to ES and related cultural and economic benefits. For this reason, ES demand in densely populated areas constantly increases in both quantitative and qualitative terms, also considering stresses and health disorders associated with modern lifestyles in our cities (Nilsson et al., 2010). Nevertheless, current processes of urbanization in Mediterranean landscapes implied that ES demand cannot rely exclusively on large natural areas beyond the boundaries of urban and peri-urban spaces (Kuemmerle et al., 2016).

Since the development of several classification systems, ES assessment have become a primacy requirement for implementing landscape strategies (Costanza et al., 2017). Several international projects and programs (e.g. MEA 2005; TEEB 2010; CICES 2012; IPBES 2012) have been improved for ES accounting, and scientific interest in ES assessment at both local and global scale has exponentially strengthened (Häyhä & Franzese, 2014), especially considering the possibility to explore and manage relationships between ecosystems and human activities. For this reason, LUC was frequently adopted as a valuable proxy for ES accounting. However, at landscape level, the optimal allocation and management of the many different land use options still remain a controversial question and, as a consequence, the integration of ES concepts and values in landscape planning, management and design still represent a core task of the ecosystem services agenda (De Groot et al., 2010). In addition, interactions between human and natural systems are particularly complex, and the current ES framework is not always able to adequately assess recent changes of the ES supply and demand linked to socio-cultural inference on landscapes dynamics (Wang et al., 2019). Specifically, a common critique to the current state of ES assessment closely concerns the difficulties in relating social and ecological dimensions of land use (i.e., an anthropocentric view that often prefer instrumental to intrinsic values of ES; Schroter et al., 2014). An ES framework that concretely consider both intrinsic and instrumental values would simplify the cooperation of various stakeholders (e.g. economists, ecologists and policy makers) in transdisciplinary research processes (Schroter et al., 2014). Assuming landscape as the perceived product of cultural and natural factors, innovative landscape concepts and approaches more focused on the relationship between people and ecosystem can play a key role in rethinking a modern ES framework (Angelstam et al., 2019), especially referring to the operational scale in which human activities (e.g. LUC) affect ES. For instance, the concept of "landscape services" has been recently introduced in order to consider the inference of landscape structure on the ES supply and demand. However, further efforts are required to understand how the composition and configuration of landscapes and related dynamics influence the provision of services and the benefits for communities (Duarte et al., 2018).

1.2. Trees Outside Forests

Considering issues linked to the current landscape dynamics, the network of green infrastructures (GI) especially in urban and peri-urban contexts has become essential to deliver a wide range of benefits to communities (Coutts, 2016). GI represent the most important tools aimed at conserving or restoring natural features in altered landscapes and maintaining essential ecosystem functions (EEA, 2011). Several typologies of GI (e.g. urban green spaces, farm trees, road vegetation, gardens) partly or totally consist of trees excluded from the definition of "forest", and are then usually classified as Trees Outside Forests (TOF, *sensu* FAO 2001). Although TOF identification was formalized about 20 years ago by FAO, their social, ecological and economic relevance goes far back in history. Already at the beginning of the 18th century, Hans Carl von Carlowitz (1713) included non-forest trees by introducing for the first time the concept of sustainability of forest resources. Since then, three centuries have passed and a conventional and explicit definition of TOF does not exist yet. It is possible to describe them by adopting a functional and an operational criterion (Figure 1). TOF are all trees and shrubs excluded from the definition of "forest" and "other wooded lands" (FAO, 2001), and configured in three main pattern blocks, which are single trees, groups of trees with less than 5000 m^2 area and linear formations of less than 20 m width.

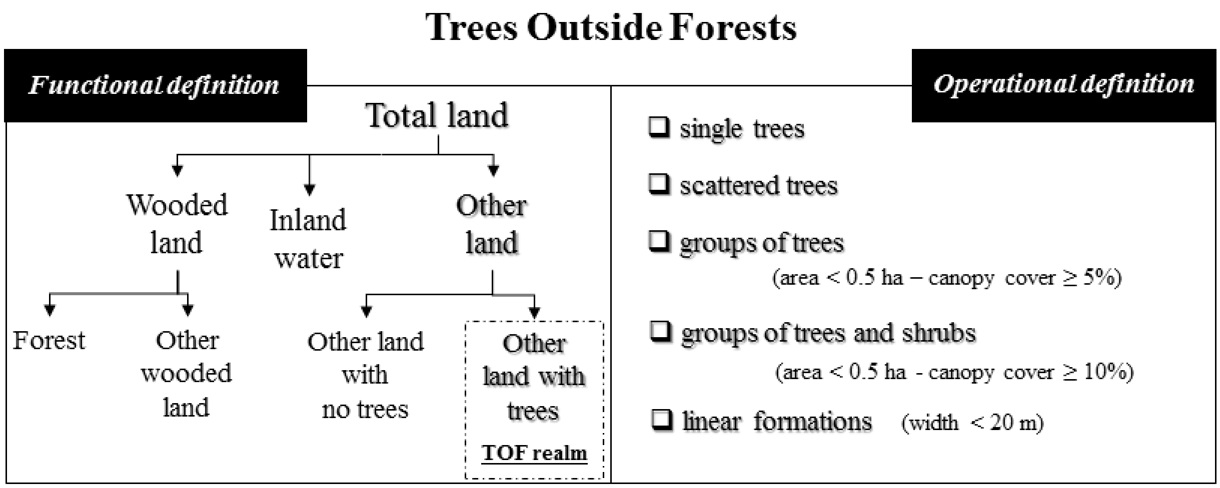

Figure 1 Operational and functional criteria for TOF definition (FAO, 2001)

According to FAO definition, it is possible to find TOF in urban (e.g. city parks, home gardens, street vegetation), rural (e.g. farm trees, hedgerows), as well as natural domains (e.g. riparian buffers). Therefore, they are involved in a wide range of uses. Such a high variability in origin, spatial configuration, species composition, functions and uses also implicates a large range of stakeholders, for instance people living in urban settings, farmers, fishermen and hunters, tourists and several institutions linked in various ways to their planning and management (de Foresta et al., 2013). In spite of their limited extension, TOF largely contribute to improve the well-being of local communities providing essential ecosystem goods and services (Table 2), above all in countries with a low forest cover where they represent the foremost forest resource (FAO 2001). The main ES provided by TOF are: (i) filtering of air pollution in urban areas (Vos et al., 2013); (ii) flood control and water quality improvement by riparian buffers (Ruhl et al., 2007); (iii) windbreaks to protect crops and animals from wind damage and soil protection from wind erosion (Lee et al., 2010); (iv) increase ecological connectivity in simplified landscapes (they represent essential land features, i.e. patches, corridors and stepping-stones) resulting in improved biodiversity (Corona et al., 2011); (v) storage of C in the biomass, thus contributing to the mitigation of global warming (Schnell et al., 2015b); (vi) characterization of traditional landscapes, enhancing the scenic beauty and providing other cultural values in marginal areas (Agnoletti, 2014); and (vii) represent an important sources of wood and non-wood products (FAO 2001).

Table 2 Ecosystem services provided by TOF according to the Millennium Ecosystem Assessment classification (MEA 2005)

ES CATEGORY	PRODUCTS OR BENEFITS	DESCRIPTION
SUPPORTING	Those that are necessary for the production of all other ES	*Primary production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat*
PROVISIONING	Food and materials	*A vast range of food products derived from plants, animals, and microbes, as well as timber and non-timber materials*
	Fuel	*Wood and biological materials as energy sources*
	Genetic resources	*Genes and genetic info used for animal and plant breeding and biotechnology*
	Bio-chemicals and pharmaceuticals	*Medicines, biocides, food additives and biological materials*
	Ornamental resources	*Plant and animal products used as ornaments*
REGULATING	Air quality	*Chemicals removal from atmosphere*
	Climate and micro-climate regulation	*At a local scale, control of temperature and precipitations. At the global scale, reduction of greenhouse gases*
	Water regulation and purification	*Control timing and magnitude of runoff, flooding, and aquifer recharge. Contribute to filter out and decompose organic wastes into waters*
	Erosion control	*Soil retention and the prevention of landslides*
	Wind protection	*Reduce the damage caused by wind*
	Pollination	*Influence on distribution, abundance, and effectiveness of pollinators*
CULTURAL	Cultural heritage, spiritual and religious values	*As important components of societies or important elements of spiritual and religious doctrines*
	Educational values	*Basis for both formal and informal education in many societies*
	Inspiration	*A source of inspiration for art, folklore, national symbols, architecture, and advertising*
	Aesthetic values	*Scenic support for various human behaviours, preferences and attitudes*
	Sense of place, recreation and ecotourism	*Mental benefits and other positive influence on people leisure time*

In addition to providing several ES, TOF play a key role in landscape mosaics, founding a network of corridors and patches that improves ecological connectivity and acting for the most diversifying features of landscape structure (Bellefontaine et al., 2001). Significance of TOF as landscapes' features, particularly hedgerows, has emerged since the 70s (Pollard et al., 1974). However, they continue to be often ignored by large-scale land policies and planning, as their assessment still does not allow for an adequate understanding of their ecological and socio-economic role beyond the local level (de Foresta et al. 2013). Furthermore, TOF mostly occur in spaces that are affected by intensive LUC (i.e., urban and agricultural areas), usually resulting in a reduction of available fertile soil and/or their total removal (Plieninger, 2012). Yet, they continue to be largely excluded from global and national forest resource monitoring and management systems (Schnell et al., 2015a). Only in few countries TOF were included within national forest inventory, and mostly where the National Forest Monitoring and Assessment (NFMA) Program of FAO was taken as a reference. Designing on the FAO guidelines within the NFMA program, Schnell et al. (2015b) attempted a first statistical assessment of TOF contribution to tree biomass and C stock at international scale (i.e., 11 countries across 3 continents). As for Europe, several countries started to integrate TOF into their national monitoring systems for tree resources, primarily in order to assess their contribution to C sequestration (FAO, 2010). Indeed, it should be emphasized how inclusion of TOF and related C stock in NFI is particularly relevant to the Land Use, Land Use Change and Forestry Good Practice Guidance (LULUCF-GPG; IPCC 2003), especially considering developing countries (where TOF C stock refers to approximately 70% of the total C stock for the agricultural sector; Smith & Wollenberg, 2011). Unfortunately, TOF inventories often adopt dissimilar definitions and different approaches and methods, hampering the harmonization of their results (Schnell et al., 2015a). In Italy, the most relevant available study on TOF inventory refers to the analysis of small woods and linear formations in Central Italy (Paletto et al. 2006). Primary purpose of this research concerned the better understanding of TOF spatial characteristics in such part of the country. Table 3 reports a comparison of results of this study with inventory data of other European countries (i.e., France, England and Great Britain), disclosing how these data are probably affected by definitions disagreements. Since the definitions are similar, comparison between Italy and France is more reliable than England, which adopts very different thresholds in TOF size respect to the other two studies.

Table 3 Comparison between different TOF inventories in Europe. Source: Paletto et al., 2006; Brewer et al., 2017

	STUDY AREA (YEARS)			
	CENTRAL ITALY (2005)	**FRANCE (2000)**	**ENGLAND (2000)**	**GREAT BRITAIN (2017)**
Definition of small woods	*Small woods between 0.05 and 0.5 ha and a minimum width of 20m*	*Small woods between 0.05 and 0.5 ha and a minimum width of 25m*	*Small woods with a surface between 0.1 and 2 ha and a canopy cover > 20%*	
Total coverage of small woods (ha)	46803	596000	62300	226000
Small woods density in relation to the study area surface (%)	0.80	1.03	0.48	1.07
Definition of linear formation	*Tree rows with a minimum length of 20m and a width between 3 and 20m*	*Tree rows with a minimum length of 25m and a maximum width of 25m*	*Tree rows with a length > 25m and equal to at least four times their width*	
Total coverage of linear formations (ha)	86606	944900	12800	164000
Linear formations density in relation to the study area surface (%)	1.48	1.63	0.10	0.8

To date, many difficulties related to the assessment of TOF on wide scales still remain. Several works aimed at their assessment using inventory methods, which represents the most convenient choice in terms of time/costs to even estimate quantitative attributes (Corona et al., 2016). The adoption of cartographic techniques and remote sensing approaches represent valuable choices for TOF inventory and mapping, considering both results' accuracy and opportunity of assessing not only quantitative attributes but also dynamics of TOF. Regarding, a noteworthy work is represented by the regional map of TOF in Molise region, central Italy (Figure 2). The census, carried out on a voluntary purpose, was performed between 2008 and

2013 through the photo-interpretation of aerial orthophotos. In this case, to unambiguously identify TOF units, they were defined in accordance with the Italian National Forest Inventory (INFC 2005), i.e., a wooded land with an area between 500 and 5,000 m^2 or a tree row with less of 20 m in width (Baffetta et al., 2011). At the end of the photo-interpretation process, a statistical population of 52,796 TOF units was detected, for a total coverage of 7,733.2 ha, and an average size of 1,472 m^2 (Fattorini et al., 2016). By covering a territory of about 446,100 ha, the TOF map of Molise region currently represents the largest existing total census of TOF in the world.

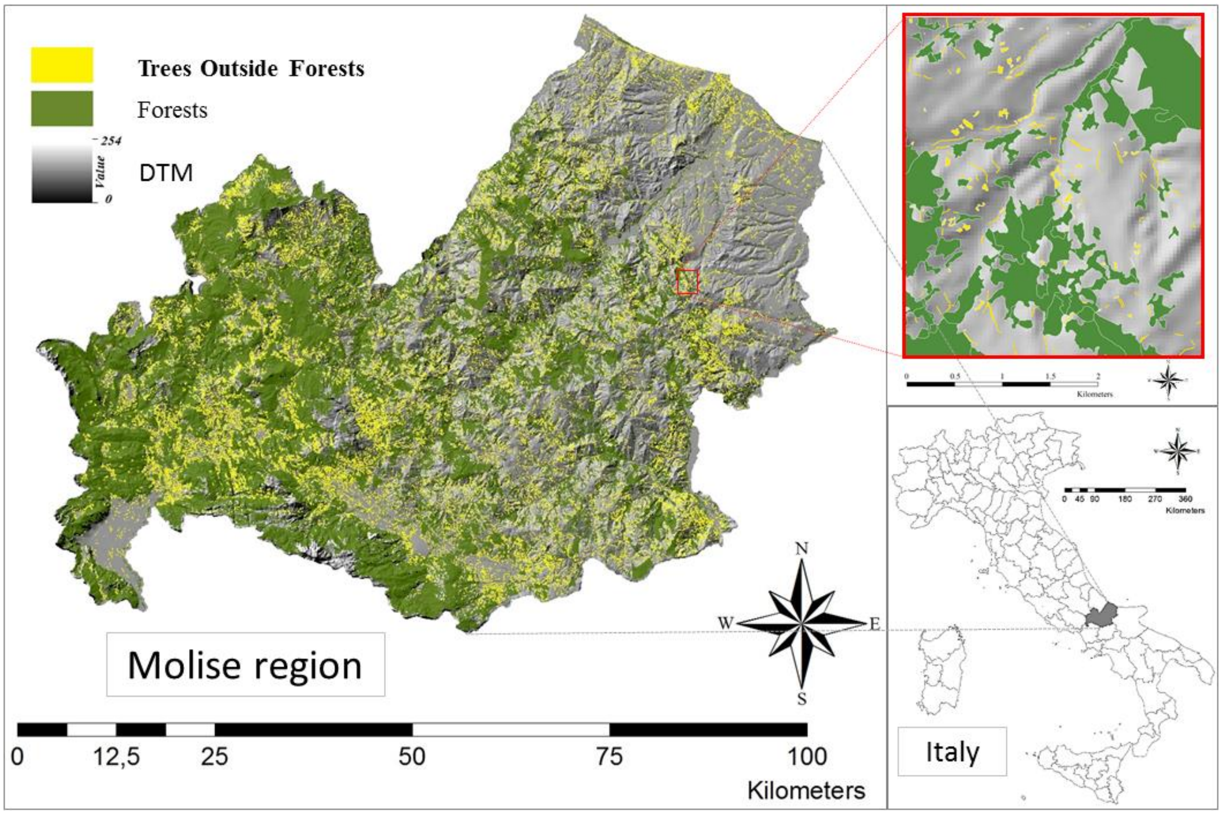

Figure 2 The entire collection of TOF units delineated within the Molise region, central Italy. The position of Molise region within Italy is presented in the right lower part. On the right higher part, an onscreen portion of the TOF mapping is reported; groups of trees and linear formations classified as TOF units are delineated in yellow

A literature review carried out in the first period of the doctoral project allowed to evaluate the state of the art regarding TOF and their role in relation to the many social, economic and environmental benefits they deliver to communities. Aside from the contribution to human well-being on a global and local scale, a better understanding about implications of TOF on landscape patterns was deepened. A collection of publications in the main Web bibliographic databases (i.e., SCOPUS and ISI Web of Knowledge) in a reference period between 2000 and 2015 was developed using search-strengths organized in several keywords combined through logical connectors (Table 4). The growing scientific attention towards TOF (Figure 3) further recognizes the great value of these green infrastructures, affirming the need to implement their knowledge in order to optimize TOF-related ES. The increase in number of works is also characterized by a marked acceleration around 2010. This acceleration is probably linked to the greater availability of remote sensing technologies and tools (e.g. semi-automatic classification methods and high resolution images). On the other hand, in the same period FAO (2010) emphasized the importance of monitoring TOF at all scales, considering the most important local/global environmental issues (i.e., climate and land use changes). In addition, starting from a general framework and advancing with the same methodological approach, research-strengths with a higher level of detail have been developed, in order to analyse the most important implications in terms of characterization, management and planning guidelines that involve TOF.

Table 4 Number of scientific publications on TOF between 2000 and 2015 obtained in the downscaled review exercise on Scopus and ISI WEB of Knowledge database

SECTION	SEARCH STRENGHT	SCOPUS (A)	IWOK (B)
TOF	*"tree* outside forest*"*	*58*	*46*
TOF review	*"tree* outside forest*" AND "review"*	*2*	*3*
Goods & Services by TOF	*"tree* outside forest*" AND "ecosystem service*"*	*13*	*8*
	"tree outside forest*" AND "landscape"*	*9*	*14*
	"tree outside forest*" AND "rural landscape"*	*3*	*1*
	"tree outside forest*" AND energy*	*2*	*6*
TOF holders	*"tree* outside forest*" AND management AND planning*	*1*	*2*
	"tree outside forest*" AND communities*	*3*	*7*

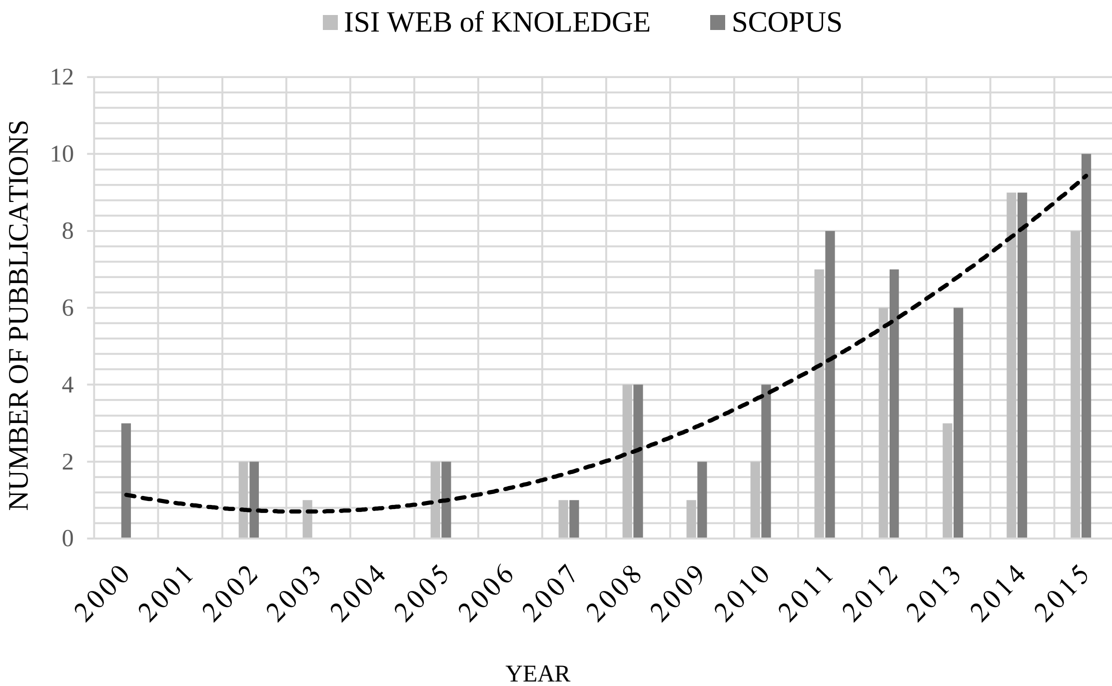

Figure 3 Number of publications year^{-1} on TOF between 200 and 2015

Despite scientific advances on this topic, existing works are often limited to synchronic studies (e.g., Paletto et al., 2006; Meneguzzo et al., 2013). Moreover, most of the mapping researches refer to multiphase inventory strategies, combining sampling frameworks with a following field survey that often involves several difficulties, mainly considering the frequently private ownership of TOF (de Foresta et al., 2015). Probably, even the reduced extension of the study areas of the existing studies depends on these difficulties.

Research on TOF has considerably increased focusing on their supporting, provisioning and regulating services but often neglecting cultural ones (e.g. spiritual, historical and recreational; Bellefontaine et al., 2001). In a more general debate, cultural ES (CES), closely linked to social perception, are frequently excluded in the context of decision making processes, mainly because of their intangible character (Chan et al., 2012). Although it has been previously emphasized how sustainable landscape planning necessarily imply a multiple-values assessment framework, ES directly linked to measurable biophysical and economic values usually receives a higher consideration than ES related to people perception and attitude (Diaz et al., 2015). This gap is worsened by the growing demand for CES related to the increasing average incomes and free time that can be dedicated to recreational activities and tourism (MEA 2005). In this regard, people indicated the positive influence of TOF on landscape aesthetics as the most strongly perceived TOF-related CES, especially in urban domains (Camacho-Cervantes et al., 2014). Starting from the first method for scenic beauty estimation by Daniel & Boster (1976), numerous studies for assessing aesthetic service of trees have been realized. However, TOF were included in too specific features of well-defined landscape types, such as “urban green” (Riechers et al., 2016), "street trees" (Mullaney et al., 2015), “agricultural linear- and point- green elements" (Van Zanten et al., 2016) and “groves, hedges and single trees in mountain area” (Schirpke et al., 2013). For this reason, knowledge about the aesthetic value of these trees is incomplete as it is closely associated to circumstantial uses and users of a landscape feature which, as mentioned above, presents a very high typological and functional variability. As a result, a careful quantification of aesthetic service of TOF, as well as the related plausible variation along the whole urban-nature gradient, is still missing.

1.3. Research objectives and outcomes

This thesis mainly aims at providing a better knowledge of TOF that could encourage a greater attention of land policies towards this frequently ignored forest resource. For this purpose, we tested several approaches and methods for the large-scale assessment of TOF in relation to the current dynamics in Mediterranean landscapes, affording opportunities for further developing targeted research in such issues. Specifically, this thesis relies on three main challenges focused on:

- evaluating TOF contribution to Italian landscape diversification in recent decades in relation to the ongoing LUC dynamics
- characterizing TOF in qualitative and quantitative terms on a large scale
- assessing the contribution of TOF to landscape aesthetics along an urban-nature landscape gradient.

Considering issues and challenges previously stated, proposed research activities advocate several crucial outcomes linked to TOF, which are (i) providing useful insights to facilitate the inclusion of TOF in the current large-scale inventory and monitoring systems of forest resources; (ii) assessing the TOF potential in improving human well-being in relation to the threats deriving from the ongoing landscape dynamics, in order to maximize and balance the provision of TOF-related ES; and (iii) addressing issues linked to the socio-cultural, ecological and economic development of different landscapes through a better understanding of connections between people and ecosystems. The methodologies proposed and tested in this thesis are based on the integration of different approaches in order to reduce costs and times of the large-scale assessment of TOF and related ES and, at the same time, provides suitable estimates from a statistical point of view. Combining different techniques and approaches also imply the prospect of increasing the informative power of pure methods. In addition, methodologies for the estimation and monitoring of TOF offer the opportunity of an easy integration with the existing assessment schemes of extensive areas (e.g. national and regional land use and forest inventories). Particularly interesting is the combination of a perceptual-based evaluation of the TOF aesthetic service with a conventional landscape analysis. In this way, a mere quantification of the aesthetic value of TOF is linked to a rapid recognition of the allocations of the related service, particularly important for local communities in terms of expected benefits. In general, implications of our research concern the promotion of the inclusion of TOF in existing large-scale monitoring systems and the maximization of the balance among several TOF-related ES. Through these objectives, this thesis could provide useful insights to support sustainable landscape development mainly via conservation strategies.

CHAPTER 2 - Summary of papers

2.1. Trends in number, coverage and average size of Trees Outside Forests in Italy in the last decades

2.1.1. Study area

The study area overlaps the entire national surface of Italy (about 300,000 km^2) with high ecological and socio-economic variability. The mountain chains, namely Alps and Apennines, dominate the northern and the central part of the country, respectively, have been widely characterized by outmigration, land use abandonment, and forest expansion in the last decades (Sallustio et al., 2015b). During the same time-span, the low hills, plains, and coastlines experienced agricultural intensification and the growth of urban areas. Currently, agricultural areas cover almost 56%, forests 32%, and settlements 7.3% of the national territory. Urban areas are mainly located along the coasts and in flat areas where the majority of population is settled (Romano & Zullo, 2014). As briefly introduced, changes in the socio-economic asset of the country (i.e., outmigration from marginal towards urban areas, industrialization, etc.) had strongly influenced recent land use and land cover changed dynamics nationwide (Corona et al., 2012). Hence, on the one hand, depopulation of mountain areas resulted in the abandonment of traditional land uses, thus facilitating forest expansion (Palombo et al., 2013). On the other hand, urban growth on croplands increasingly affects low hills and plains (Marchetti et al., 2014).

2.1.2. The Classification System and Inventory Framework

The Italian Land Use Inventory (IUTI) has been adopted to implement the following methodology in order to analyze TOF dynamics during the 1990–2013 time-span. IUTI has been promoted and implemented by The Italian Ministry of Environment and Protection of Land and Sea as a key instrument for the National Registry for forest C sinks (Marchetti et al., 2012). According to its tessellated stratified sampling scheme (Figure 4), the whole Italian territory was covered by a network of 25-ha squares and one sample point was randomly located within each square (Fattorini, 2015). For this work, a sub-sampling strategy was applied in order to further reduce cost and times for photo-interpretation (Fattorini, 2015). Accordingly, about 13,000 IUTI sampling points were classified based on high-resolution imagery in 1990 and 2013, and according to the classification system proposed by the Intergovernmental Panel on Climate

Change (IPCC, 2003). Moreover, a minimum dimensional threshold of 0.5 ha was used to discriminate the land use categories (IPCC, 2003). The coarsest classification adopted six land use classes: forests, cropland, grassland, wetland, settlements, and other lands. In addition to the basic land use classification, during the photo-interpretation phase, sampling points falling within homogeneous patches less than 0.5 ha in size and with a land use different from the surrounding area were marked as “enclosed patches”. Particularly, we selected small patches with trees within land use classes other than forests, namely TOF. In order to apply the methodological approach based on the integration of inventory and cartographic data proposed by Sallustio et al. (2017) for assessing green spaces in urban areas, each polygon surrounding a sampling point classified as TOF was drawn for both inventory occasions. This integrated approach allows to estimate not only the total coverage, but also the abundance and average size of TOF, offering a valuable contribution for better understanding and characterize the historical dynamics as well as their possible implications on landscape structure and functionality.

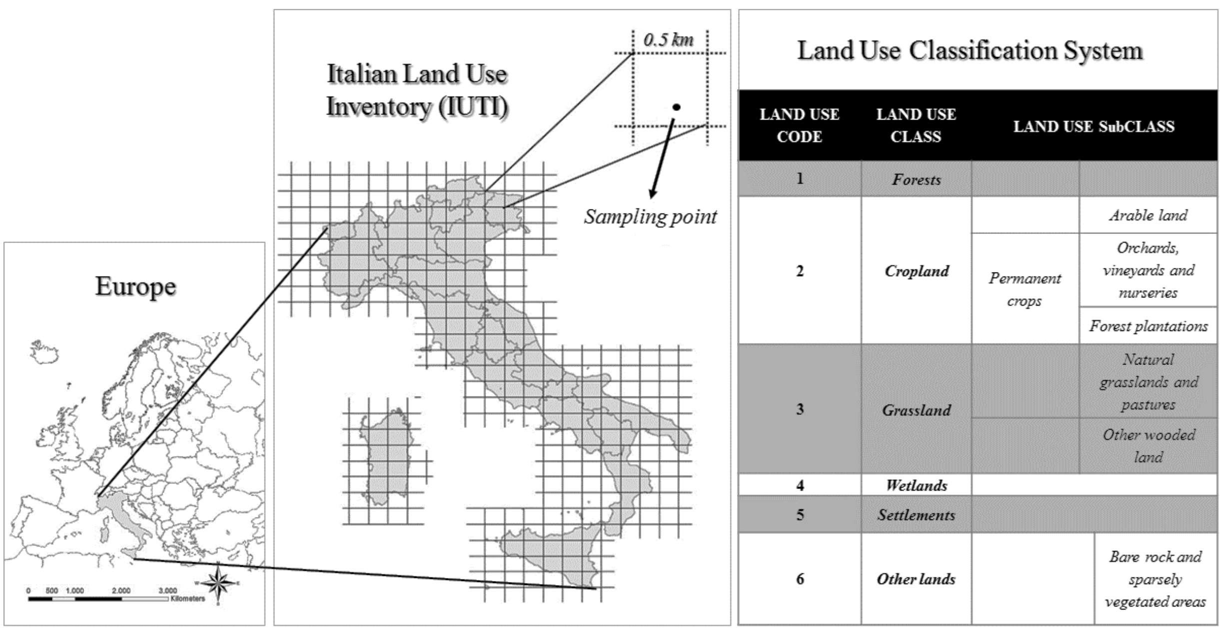

Figure 4 Tessellated stratified sampling scheme adopted for the implementation of the Italian Land Use inventory (IUTI). In the right box, the land use classification system

2.1.3. Trees Outside Forests estimation

Total coverage of TOF ($\hat{A}$), abundance ($\hat{N}$) and average size ($\hat{a}$) at both inventory occasions were estimated, applying the design-based estimation approach developed by Baffetta et al. (2011). Let Q be the extent of the area covered by the n square grid cells fully overlapping the national territory under the IUTI sampling scheme, the estimate of $\hat{A}$ is given by

$$\hat{A} = \hat{p}Q, \tag{1}$$

where:

$$\hat{p} = \frac{n_u}{n}, \tag{2}$$

where n_u is the number of sample points classified as TOF. The variance of $\hat{A}$ can be estimated as:

$$v\hat{a}r(\hat{A}) = Q^2 \frac{n_u(n - n_u)}{n^2(n-1)}. \tag{3}$$

Let S and a_j be, respectively, the set of TOF selected by the n sampling points and the size of the j^{th} TOF. Whether a_j values are negligible with respect to Q, the estimate of $\hat{N}$ is given by:

$$\hat{N} = \frac{Q}{n}\sum_{j \in S}\frac{1}{a_j}, \tag{4}$$

with estimated variance equal to:

$$\mathrm{v\hat{a}r}(\hat{N}) = \frac{1}{n(n-1)}\left(Q^2\sum_{j \in S}\frac{1}{a_j^2} - n\hat{N}^2\right). \tag{5}$$

Accordingly, the estimate of $\hat{a}$ is given by $\hat{A}/\hat{N}$, i.e.,

$$\hat{\hat{a}} = \frac{n_u}{\sum_{j \in S} \frac{1}{a_j}} , \tag{6}$$

with estimated variance equal to:

$$\hat{\mathrm{var}}(\hat{\hat{a}}) = \frac{Q^2}{\hat{N}^2 n(n-1)} \sum_{j \in S} \left(1 - \frac{\hat{\hat{a}}}{a_j}\right)^2 . \tag{7}$$

Considering the standard normal distribution of the variable, a statistical test was performed to assess whether a real variation occurs between estimates at 1990 and 2013. Accordingly, in the present study we considered variation as (i) extremely significant for p value < 0.01, (ii) very significant for p value < 0.05, (iii) significant for p value < 0.1, and (iv) not significant for p value > 0.1.

2.1.4. Results and discussion

The main findings of the study (Table 5) reveal that the overall number and coverage of TOF increased during the 1990–2013 period and their average size essentially remained stable. In detail, TOF increase by 17.1% in the number and by 27.4% in coverage. The estimates of standard errors are satisfactory at both reference times, ranging from 2.2% to 12.5%.

*Table 5 Number (N), coverage (A, in ha) and average size (a, in ha) of TOF at 1990 and 2013 (± their estimated relative standard errors, in percentage). Significance levels (not significant, significant, very significant and extremely significant) of changes between 1990 and 2013 (Δ) are also reported in the summary tables with the relative symbol (n.s., *, **, ***, respectively)*

1990			2013			Δ		
N	***A***	***a***	***N***	***A***	***a***	***N***	***A***	***a***
3,607,709	332,174	0.09	4,223,692	423,181	0.10	615,983	91,007	0.01
(±2.4%)	(±8.2%)	(±11.0%)	(±2.2%)	(±7.3%)	(±12.5%)	*	*	n.s.

To better understand TOF dynamics, their changes were also compared with those of the land matrix in which they can occur (i.e., non-forest lands except water and other lands without vegetation), using data reported by Pagliarella et al. (2016) as a reference for land use estimates at 2013 in Italy. During the observed period, the relative coverage of TOF with respect to the surrounding land use matrix increased of 0.5%. In fact, the relative coverage of TOF passed from 1.6% of 1990 to 2.1% of 2013, since the non-forest land uses decreased by about 580,000 ha (-1.68%; see Table 1, pag.19) during this time-span.

The results reveal that the number and relative coverage of TOF generally increased across the entire Italian territory from 1990 to 2013. Accordingly, our results show that TOF have increasingly contributed to the diversification of semi-natural (i.e., agricultural lands) and artificial land uses. These findings extend those of several studies carried out at regional and local scales. However, the comparison with such studies is not an easy task, because of the different thresholds usually fixed to distinguish small from large forest patches.

In detail, the relative coverage of TOF with respect to the national surface increased from 1.1% at 1990 to 1.4% at 2013, with an average patch size almost stable around 0.1 ha. These results are in line with those obtained in Molise Region (see Annex II), where TOF cover 1.7% of the regional territory, having an average patch size of 0.14 ha at 2008. Our results are slightly lower than those obtained by Paletto et al. (2006) in Central Italy, where TOF cover almost 2.3% of the territory and with an average patch size of 0.21 ha, but with large variability among the four regions considered. However, as explicitly reported by Paletto et al. (2006), the analyses were performed on four administrative regions where TOF coverage is particularly high, thus justifying these differences. If our estimates are compared with those reported by the 2017 Great Britain's National Forest Inventory (Brewer et al., 2017), which used the same classification system adopted by the present study, Italy has less TOF relative coverage than Great Britain (1.4% and 3.2%, respectively), but a larger forest area (EC, 2015). In spite of the recent debate around TOF, only few studies have been conducted so far and limited to regional scales (Plieninger, 2012). However, if compared with those by Novotný et al. (2017) at the regional scale in the Czech Republic during the 1953–2014 period, our results show similar dynamics about the overall increase of TOF coverage. Consistently with results of Novotný et al. (2017), we found that TOF both disappeared because it was incorporated in recently expanded forest lands, and appeared in rural areas with extensive agricultural uses. Both processes have been driven by the abandonment of rural practices in mountain areas, which in turn originated in forest expansion and TOF formation and their enlargement in other land uses other than forest. Indeed, we observed that the increase of TOF in the 1990–2013 period inversely relates with the loss of agricultural lands (+27.4% and −8.5%, respectively; Pagliarella et al., 2016). This trend can be interpreted as an important extension of the green infrastructure network, through which the ecological connectivity at lower scales is further strengthened (i.e., landscape to regional) (Rossi et al., 2016). The mitigation of threats and pressures coming from the surrounding land uses and processes (e.g., urbanization and agricultural intensification) offered by TOF's network should be considered, and the TOF's functions evaluated according to different landscape patterns (Paletto et al., 2006; Plieninger et al., 2015b). In our case, the average patch size of TOF remained almost stable, despite a general increase in already existing TOF due to the small size of newly formed TOF.

In conclusion, the raising relative contribution in terms of coverage of TOF mainly increases because of the decrease of the land use matrix during the same period. Moreover, results show that non-forested landscapes are becoming more diverse thanks to the increase of small forest patches.

2.2. Ecological diversity and above-ground carbon stock of Trees Outside Forests in Molise region, central Italy

2.2.1. Study area

The Molise region is covered by 148,641 ha of forests and other wooded lands (INFC, 2005). The region is almost equally partitioned between mountain (55%) and hilly areas (44%) and well correspond to the Italian peninsula arrangement. 35.1% of the regional surface is covered by forests, mainly represented by Turkey oak (38.3%), Downy oak (21.4%) and Beech (9.5%) forests (Chirici et al., 2011). 224,800 ha (49% of the regional surface) are covered by agricultural areas; while, urban areas involve only 3% of the study area (Sallustio et al., 2016). In particular, the Adriatic coast, 40 km long, is intensively urbanized. The presence of dunes and fragile ecosystems makes the Molise coastland an important landscape, crucial for environmental resources (Foresta et al., 2016). The vast interface between forest and agricultural systems makes the area a representative example for analyzing transformations into natural and seminatural classes. The two administrative provinces (Campobasso and Isernia) have different landscape characteristics and dynamics. The province of Isernia lies partially within the Abruzzo, Lazio, and Molise National Park, including high mountainous areas such as the Matese and the Mainarde massifs. The province of Campobasso is generally hilly and located in the east, along the Adriatic Sea. It is considerably more affected by human impact, with a prevalence of intensive farming in the flattest area close to the coast and a high occurrence of natural grasslands and pastures in the inland (Sallustio et al., 2016).

A TOF census was performed throughout the whole Molise region (see Figure 2 in Chapter 1). It was accomplished via GIS software and intensive photo-interpretation of aerial orthophotos covering the entire study area by trained photo-interpreters, and subsequent field checks. At the end of the census, a statistical population U of N = 52,796 TOF units was detected.

2.2.2. Attributes of interest and diversity measures

Let L be the list of the tree species which were present in the population U and let K be the tree species richness. For each TOF unit $j \in$ U and for each species $k \in$ L, the attributes of interest were the abundance (number of trees with diameter at breast height, 1.3 m off the ground

- diameter at breast height (DBH) - greater than 5 cm), the basal area (cross-sectional area of the stem measured at breast height) (m^2), the volume (m^3), and the above-ground C stock (t). In the subsequent equations, these attributes are left unspecified and are generically denoted by y_{jk}. For each attribute, we focused on the totals by species

$$T_k = \sum_{j \in U} y_{jk} \ , \ k \in L \ , \tag{8}$$

as well as on the overall total

$$T = \sum_{k \in L} T_k \ . \tag{9}$$

To be short, it is convenient to denote by $\mathbf{T} = [T_1, \ldots, T_K]^t$ the K vector of these totals, from which T = $\mathbf{1}^t\mathbf{T}$ where $\mathbf{1}$ denotes the K vector of ones. Any diversity measure we considered for analyzing the ecological diversity in terms of the four attributes was derived as a function of T. We firstly considered the proportions of attributes by species

$$p_k = p_k(\mathbf{T}) = T_k / T \ , \quad k \in L \ . \tag{10}$$

The ranking of proportions, from the smallest to the greatest, $p_{(1)} \leq \ldots \leq p_{(k)}$, where $p_{(k)}$ is the kth ranked proportion, provided a preliminary insight on the apportionment of the attribute among species. To achieve a clearer depicting of the apportionment, we considered the Lorenz curve, i.e., the plotting of

$$P_k = P_k(\mathbf{T}) = \sum_{h=1}^{k} p_{(h)} \tag{11}$$

vs $F_k = k/K$ for $k = 1, \ldots, K$. For each k, the Lorenz curve gave the proportion P_k of the attribute provided by the proportion F_k of the bottom species (Damgaard & Weiner, 2000). As indexes of ecological diversity, we used the concentration index, also referred to as the Gini coefficient, i.e., the proportion of the area between the Lorenz curve and the equal-apportionment line

$$\Delta_L = \Delta_L(\mathbf{T}) = 1 - \frac{2}{K-1}\sum_{k=1}^{K-1} P_k \, . \tag{12}$$

The concentration index ranged from 0 (in the case of an even apportionment of the attribute between species) to 1 (when the attribute is provided by a sole species). We also considered the Shannon and Simpson diversity indexes (Jost, 2006), respectively

$$\Delta_{SH} = \Delta_{SH}(\mathbf{T}) = \sum_{k=1}^{K} p_k \ln \frac{1}{p_k} \tag{13}$$

and

$$\Delta_{SI} = \Delta_{SI}(\mathbf{T}) = 1 - \sum_{k=1}^{K} p_k^2 \tag{14}$$

The Shannon and Simpson indexes ranged from 0 (when the attributed is provided by a sole species) to respectively ln$K$ or (K-1)/K (in the case of an even apportionment of the attribute between species).

2.2.3. Sampling

A two-phase point sampling of the TOF population was devised. The sampling scheme has been chosen among those theoretically investigated by Fattorini et al. (2016). In the first phase (TSS), the Molise region was covered by a grid of R = 4,693 hexagons of size 100 ha (Figure 5a), and a point was randomly selected within each hexagon. Because there is a one-to-one correspondence between points and hexagons, it is indifferent to refer to points or hexagons. Then, to reduce the sampling effort, a sample Q of n = 2,347 points/hexagons, corresponding to a sampling fraction of about 50%, was selected in a second phase by means of OPSS. The second phase was performed by partitioning the grid into n = 2,347 blocks/strata: 2,346 blocks were formed by two contiguous hexagons, and one by only one hexagon (Figure 5b). Then, a hexagon/point was randomly selected from each block to constitute the second-phase sample Q of hexagons/points. Finally, in accordance with the point sampling protocol, all of the TOF units intercepted at least by one of these 2,347 points were sampled and visited on the ground (Fattorini et al., 2016; 2017). Field survey was performed in 2015, from late May to middle September, by teams composed of PhD or master students and at least one assistant researcher. For each TOF unit sampled by the second-phase points, the team recorded the overall number of trees in the TOF unit, and for each tree, the team listed species, DBH and height in order to calculate the totals of basal area, wood volume, phytomass, and the above-ground C stock in the unit. Wood volume and phytomass of each tree were predicted by applying the equations from Tabacchi et al. (2011). C stock was obtained by multiplying the tree phytomass by the IPCC default C fraction of 0.475 (McGroddy et al., 2004).

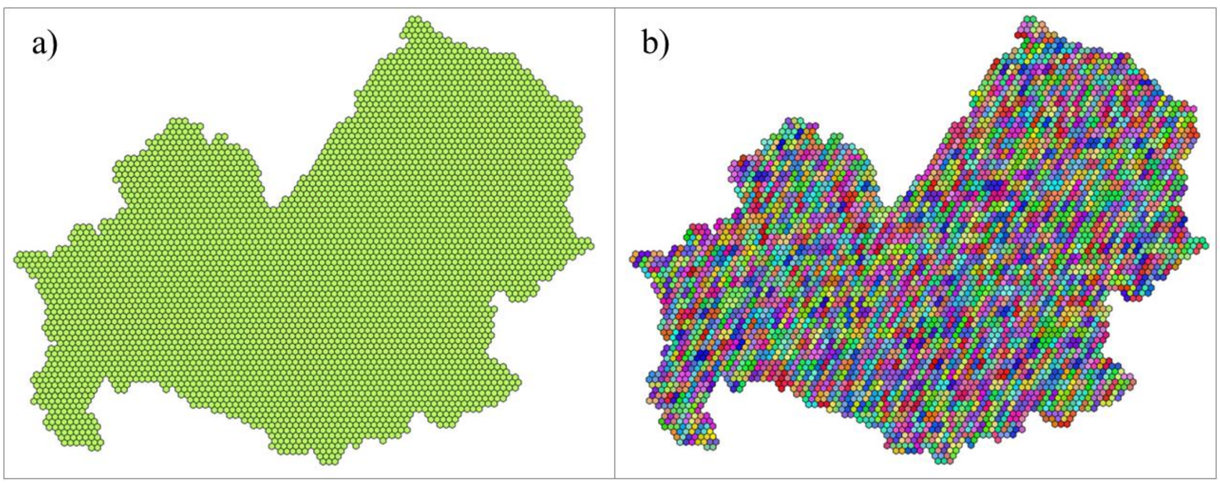

Figure 5 The two-phase point sampling of the TOF population. On the left, the grid of hexagons of size 100 ha used in the first phase (TSS). On the right, the grid of 2,347 blocks formed by two contiguous hexagons of the second phase

2.2.4. Estimation

Under point sampling, the probability of selecting the TOF unit $j \in$ U was $\pi_j = a_j/A$, where a_j was the extent of the unit and A was the size of the sampling area onto which the point is randomly selected. In our case, the sampling area was the grid of the 4,693 hexagons covering the Molise region, so that A = 469,300 ha. Only one TOF unit can be selected by the point randomly located within the hexagon $i \in$ Q. Therefore, the sample selected from the second-phase point $i \in$ Q was constituted by a sole unit, say $j(i)$, or it was empty.

If the point $i \in$ Q selected the TOF unit *j(i)*, we computed the Horvitz-Thompson (HT) estimate of T_k

$$\hat{T}_{kj(i)} = A \frac{y_{j(i)k}}{a_{j(i)}} , \tag{15}$$

where $y_{j(i)k}$ was the amount of the ground-measured tree attribute. On the other hand, if no TOF unit was selected from the second-phase point $i \in$ Q, as observed from the air photos: the point was neglected and $\hat{T}_{ki}$ was set to 0 without field work. Obviously, $\hat{T}_{ki}$ was set to 0 also when a TOF unit was selected but the species k was missing in the units.

We computed the estimates $\hat{T}_{ki}$ for each $i \in$ Q. Then, in accordance with Fattorini et al. (2017, eq. 2), we computed to the two-phase estimate of T_k

$$\hat{T}_{k(R)} = \frac{1}{R} \sum_{l=1}^{n} R_l \hat{T}_{ki(l)} , \tag{16}$$

where *i(l)* was the label of the point/hexagon randomly selected within the block l and R_l was the number of contiguous hexagons in the block. If a species was not present in the TOF units selected by the two-phase point sampling, the species was lost and $\hat{T}_{k(R)}$ resulted to be 0. Otherwise, $\hat{T}_{k(R)}$ resulted to be a positive value for any detected species, i.e., for any $k \in$ L$_0$, where L$_0 \subset$ L was the set of species which was present in at least one of the TOF units intercepted by the second-phase points and $K_0 \leq K$ was the number of detected species. To be short, it is convenient to denote by $\widehat{\mathbf{T}}_{(R)} = [\hat{T}_{(R)}, \ldots, T_{k(R)}]^t$ the K vector of the estimates of the totals of **T**. Therefore, $\widehat{\mathbf{T}}_{(R)}$ contained an unknown number of 0 s in correspondence to any lost species. In accordance with Fattorini et al. (2017, p. 198), the variance-covariance matrix of $\widehat{\mathbf{T}}_{(R)}$ was estimated by the matrix $\mathbf{V}_{(R)}$ whose element k,h was given by

$$v_{kh(R)} = \frac{1}{n(R-1)} \left[\sum_{l=1}^{n} R_l \hat{T}_{i(l)k} \hat{T}_{i(l)h} - R \hat{T}_{k(R)} \hat{T}_{h(R)} \right] , \quad k,h \in \mathrm{L} . \tag{17}$$

Once the vector **T** was estimated by $\hat{\mathbf{T}}_{(R)}$, we performed the estimation of any quantity derived from **T** by means of the plug-in criterion, as suggested by Fattorini et al. (2017, p. 4). Therefore, we estimated the overall total by

$$\hat{T}_{(R)} = \mathbf{1}^t \hat{\mathbf{T}}_{(R)}, \tag{18}$$

the proportions of attributes by species by

$$\hat{p}_{k(R)} = p_k(\hat{\mathbf{T}}_{(R)}) = \hat{T}_{k(R)} / \hat{T}_{(R)}, \quad k \in \mathrm{L}, \tag{19}$$

the Lorenz curve by plotting

$$\hat{P}_{k(R)} = P_k(\hat{\mathbf{T}}_{(R)}) = \sum_{h=1}^{k} \hat{p}_{(h)(R)} \tag{20}$$

vs $F_{0k} = k/K_0$ for $k = 1, \ldots, K_0$, the concentration index by

$$\hat{\Delta}_{L(R)} = \Delta_L(\hat{\mathbf{T}}_{(R)}) = 1 - \frac{2}{K_0 - 1} \sum_{k=1}^{K_0 - 1} \hat{P}_{k(R)}, \tag{21}$$

and the Shannon and Simpson diversity indexes respectively by

$$\hat{\Delta}_{SH(R)} = \Delta_{SH}(\hat{\mathbf{T}}_{(R)}) = \sum_{k=1}^{K} \hat{p}_{k(R)} \ln \frac{1}{\hat{p}_{k(R)}} \tag{22}$$

and

$$\hat{\Delta}_{SI(R)} = \Delta_{SI}(\hat{\mathbf{T}}_{(R)}) = 1 - \sum_{k=1}^{K} \hat{p}_{k(R)}^2. \tag{23}$$

We finally estimated the sampling variances of the plug-in estimators by exploiting the matrix $\mathbf{V}_{(R)}$ as suggested by Fattorini et al. (2017, p. 4), i.e. the variance estimate of $\hat{T}_{(R)}$ was simply $v^2_{(R)} = \mathbf{1}^t \mathbf{V}_{(R)} \mathbf{1}$ while for the remaining nonlinear functions of $\hat{T}_{(R)}$, the variance estimates were

$$v_{(R)}^2 = \hat{\mathbf{d}}^t \mathbf{V}_{(R)} \hat{\mathbf{d}} , \qquad (24)$$

where the vector $\hat{\mathbf{d}}$ was the gradient of the functions p_k, P_k, Δ_L, Δ_{SH} and Δ_{SI} at $\hat{\mathbf{T}}_{(R)}$. Once the variance estimates were achieved, we estimated standard errors by square roots of the variance estimates and the relative standard errors (RSE) by square roots divided by the resulting estimates. The 95% confidence intervals were achieved presuming approximately normal distributions of the estimators, i.e., by the estimates plus and minus two times the standard error estimates. While the estimation of p_k, Δ_{SH}, and Δ_{SI} did not necessitate the knowledge of the species richness K, the inference on Lorenz curve and concentration index necessitated the knowledge of K which was substituted by the number of detected species K_0. While the gradient of p_k, Δ_{SH}, and Δ_{SI} always existed, the gradients of P_k and Δ_L necessitated that the T_ks were all distinct (Fattorini & Marcheselli, 1999), a conditions very likely to occur in real cases.

2.2.5. Results and discussion

A total of K_0 = 60 tree species were detected (see Annex II, Table 1). Downy oak (*Quercus pubescens* Willd.) is the tree species with the greatest abundance (1,067,453 individuals; proportion 21%; Table 6), basal area (33,431 m^2; proportion 30%), wood volume (198,790 m^3; proportion 34%; Table 7), and above-ground C stock estimates (82,482 t; proportion 37%; Table 8). Turkey oak (*Quercus cerris* L.) is ranked as second with respect to all the considered attributes, with an abundance estimate of 694,949 individuals (proportion 14%), basal area of 12,958 m^2 (proportion 12%), volume estimate of 65,772 m^3 (proportion 11%), and C stock estimate of 26,749 t (proportion 12%). The species ranked third is field elm (*Ulmus minor* Mill.), in terms of tree abundance, and white willow (*Salix alba* L.) in terms of basal area, wood volume and above-ground C stock. The TOF community shows a list of 40 species out to 60 detected tree species with relative abundance estimates smaller than 1% and 21 species with relative abundance estimates smaller than 0.1%. Similar results are achieved in terms of basal area, volume, and C stocks.

Table 6 Estimates of abundances and their percentages and of the relative standard errors for the tree species detected in the TOF of the Molise Region. Species are listed in decreasing order of abundance. We have reported exclusively the estimates of the first 5 species for abundance; for more details, see Table 3 in Annex II

SPECIES	ABUNDANCE	RSE%	% ABUNDANCE	RSE%
Downy oak	1067453.40	29.27	20.83	25.07
Turkey oak	694949.41	51.75	13.56	41.65
Field elm	683408.13	27.66	13.34	24.59
Field maple	434156.46	35.55	8.47	26.68
White willow	320897.67	43.84	6.26	37.71
Other 55 species	-	-	37.54	-

Table 7 Estimates of wood volumes and their percentages and of the relative standard errors for the tree species detected in the TOF of the Molise Region. Species are listed in decreasing order of abundance. We have reported exclusively the estimates of the first 5 species for abundance; for more details, see Table 4 in Annex II

SPECIES	VOLUME (m^3)	RSE%	% VOLUME	RSE%
Downy oak	198790.43	29.74	33.74	23.77
Turkey oak	65772.34	43.57	11.16	40.16
White willow	59571.70	59.43	10.11	51.80
Black poplar	41596.48	53.57	7.06	47.17
English oak	37848.90	99.98	6.42	95.42
Other 55 species	-	-	31.51	-

Table 8 Estimates of above-ground C stocks and their percentages and of the relative standard errors for the tree species detected in the TOF of the Molise Region. Species are listed in decreasing order of abundance. We have reported exclusively the estimates of the first 5 species for abundance; for more details, see Table 4 in Annex II

SPECIES	C STOCK (t)	RSE%	% C STOCK	RSE%
Downy oak	82481.75	29.26	37.31	21.36
Turkey oak	26749.09	43.61	12.10	38.91
White willow	17789.77	56.52	8.05	51.43
English oak	15287.41	99.98	6.92	94.78
Black poplar	10628.84	52.71	4.81	48.76
Other 55 species	-	-	30.81	-

The tree abundance provided by the TOF units throughout the whole Molise region is estimated to consist of 5,123,478 individuals (RSE = 20%) with a density of 662.5 trees ha^{-1}; the total wood volume is estimated to be 589,261 m^3 (RSE = 20%) with an average wood volume of 76.2 m^3 ha^{-1}, and the total amount of C is estimated to be 221,047 t (RSE = 19%) with an average C stock of 28.6 t ha^{-1} (Table 9).

Table 9 Total estimates of tree abundance, basal area, wood volume and above-ground C stock and of the relative standard error for the TOF of the Molise region

ATTRIBUTE	TOTAL ESTIMATE	PER HECTARE	RSE%
Abundance (n° of Trees)	5,123,478.1	662.5	19.76
Basal area (m^2)	112,154.7	14.5	18.54
Volume (m^3)	589,260.9	76.2	19.92
C stock (t)	221,046.8	28.6	19.34

In terms of abundance, the 90% (54 of 60 tree species) of the least abundant tree species shares the 35% of the individuals, the remaining 65% of individuals being shared by the 10% (6 of 60 tree species) of the most abundant species (Table 10). A more marked concentration is evidenced in terms of the other considered attributes. The fraction of wood volume due to the bottom 90% of species is estimated to be 26%, while the fraction in terms of C stock is estimated to be 27%.

Table 10 Estimates of the Lorenz curve ordinates related to tree abundance, wood volume and above-ground C stocks corresponding to percentages of bottom species ranging from 10 to 90% and estimates of the relative standard errors of TOF in Molise region. The same curves are plotted in Figures 4, 5, and 6 of Annex II, together with the corresponding confidence intervals

PERCENTAGE OF SPECIES	**ABUNDANCE**		**VOLUME**		**C STOCK**	
	%	**RSE%**	**%**	**RSE%**	**%**	**RSE%**
10%	0.11%	48.74%	0.01%	44.27%	0.02%	47.12%
20%	0.31%	35.76%	0.06%	40.95%	0.07%	38.15%
30%	0.62%	32.81%	0.21%	30.01%	0.24%	29.49%
40%	1.20%	29.90%	0.52%	27.61%	0.60%	25.74%
50%	2.54%	27.46%	1.10%	26.22%	1.19%	24.28%
60%	5.57%	22.49%	2.71%	27.13%	3.08%	26.99%
70%	11.43%	20.14%	5.83%	22.34%	6.53%	20.57%
80%	20.99%	19.07%	11.77%	20.50%	13.03%	21.01%
90%	34.69%	13.39%	25.72%	18.13%	26.69%	20.27%
100%	100.00%	0.00%	100.00%	0.00%	100.00%	0.00%

Table 11 reports the estimates of the diversity indexes. The concentration index estimate is 0.78 for tree abundance (RSE = 3%) and increases to 0.85 for both wood volume and C stock (RSE = 2% and 3%, respectively). The Shannon index estimate is 2.86 for tree abundance (RSE = 5%) and decreases to 2.50 and 2.46 for wood volume and C stock (RSE = 6% and 7%, respectively). The Simpson index estimate is 0.90 for tree abundance (RSE = 2%) and decreases to 0.85 and 0.83 for wood volume and C stock (RSE = 5% and 6%, respectively). The RSE estimates are in general higher than 20% for all the estimates with the exception of the overall total estimates that show RSE values slightly below 20% and the diversity index estimates that show RSE values invariably below 10%.

Table 11 Estimates of the concentration index and of the Shannon and Simpson diversity indexes related to tree abundance, wood volume and above-ground C stocks and estimates of the relative standard errors for the TOF of the Molise region

ATTRIBUTE	CONCENTRATION INDEX	RSE (%)	SHANNON INDEX	RSE (%)	SIMPSON INDEX	RSE (%)
Abundance	0.78	2.96	2.86	4.50	0.90	1.98
Volume	0.85	1.86	2.50	6.26	0.85	5.04
C Stock	0.85	1.64	2.46	7.35	0.83	6.01

Our findings highlight a relevant concentration of all the four considered TOF attributes in few dominant tree species. The Lorenz curve estimates highly deviate from the equal-apportionment line and the concentration index estimates are near to one. Concentration is more marked in terms of wood volume and above-ground C stock with respect to tree abundance and basal area. However, the presence of dominant species, that should entail a poor ecological diversity, should be mitigated by the presence of many rare species that, in accordance with Patil & Taillie (1982), tend to increase diversity. This fact should be revealed by the Shannon and Simpson diversity index estimates. However, these index estimates have poor sense if not compared with their maxima achieved in the most diverse situation. In order to have a clear indexing of the ecological diversity, the standardized version of these indexes should be considered by dividing the index estimates by their maxima. Unfortunately, in both cases, the knowledge of maxima entails the knowledge of the species richness K, which is an unknown quantity. However, it is important to note that 60 tree species is a very significant figure. In fact, Italian forests are primarily made by 20 tree species out of a total number of the 45 species that represent more of the 90% of the total biomass (INFC, 2005). Moreover, the vascular flora native to Italy consists of about 7000 species, and trees are only few units, including several “tree like” flora elements. In fact, 188 species and intraspecific taxa have been recognized (Raimondo, 2013). This total number is highly diversified and enriched by woody polistemmed or shrubby species that, growing in special conditions, could reach a tree-like size. Genetic expressions of classic tree-like species, variously treated from the taxonomical point of view, have also been added. Therefore, the surveyed number here taken into account reveals the high amount of dendroflora diversity in the TOF in the Molise region.

Dividing the Shannon and Simpson diversity index estimates by ln 60 and 59/60, respectively, the estimate of the standardized Shannon index results of 0.70 for tree abundance, decreases to 0.66 for basal area and to 0.61 and 0.60 for wood volume and above-ground C stock, while the estimate of the Simpson index results of 0.92 for tree abundance, decreases to 0.88 for basal area and to 0.86 and 0.84 for wood volume and above-ground C stock. Almost nothing will change if the tree species richness is cautiously presumed to be 70. In this case, the standardized Shannon index estimates range from 0.67 to 0.58, while the standardized Simpson index estimates remain practically unchanged. The insensitive behavior of these indexes - especially the Simpson indexes - to the variation of species richness can be explained by the fact that, as apparent from the Lorenz curves, the species abundance distribution seems quite close to the Fisher log series model. In this case, when the number of species is greater than 10, the Simpson index is insensitive to increases in species richness (e.g. Magurran, 2003). Besides this fact, the Simpson index evidences a high level of ecological diversity, while the Shannon index ranges the TOF population as a community of quite intermediate diversity. This is not surprising because it is well known that different diversity indexes may provide different rankings for the same communities (Hurlbert, 1971). Results are also consistent with those achieved by the Lorenz curves, i.e., diversity is more marked (and dominance less marked), in terms of tree abundance, while it decreases if measured in term of basal area, volume, and above-ground C stock.

Regarding the latter figure, TOF contribution to C stock is not negligible, amounting to 28.6 t ha^{-1}, more than half the average of forests at national level (47.2 t ha^{-1}; INFC, 2005). This result is even more relevant if considering a regional perspective. Indeed, TOF in Molise region contribute with a stock equal to 67.6% of the C sequestered by regional forests (i.e., 42.3 t ha^{-1}; INFC, 2005).

2.3. Aesthetic contribution of Trees Outside Forests to Mediterranean landscapes

2.3.1. Land use interpretation

Considering research gaps previously discussed (see Paragraph 1.2), the last part of the doctoral period is focused on the understanding and assessment of social values (i.e., cultural ES) of TOF at landscape scale. Specifically, this work represents an attempt to assess TOF aesthetic contribution to landscape quality by combining a visual choice experiment and a GIS-based analysis. We place three main research hypotheses, in order to evaluate TOF contribution to landscape aesthetics as function of i. dissimilar landscape contexts, ii. contrasting levels of landscape heterogeneity and iii. different degrees of TOF abundance. The study was carried out in the Molise region. In order to produce a landscape photo-sequence covering the whole urban-rural-natural gradient, a land use interpretation was carried out.

We took a sample of 15 oblique photographs, five for each urban, rural, and natural landscape pattern, along an altitudinal gradient and from representative overlooks in the Molise region. Photos were taken during September 2018, on sunny days. Using a 25-m Digital Elevation Model (DEM), and knowing camera position, orientation, and field of view, we assigned real-world locations to each of the photographs pixels, producing 15 viewsheds, of which we interpreted land use types and in scenic viewpoints of different landscape types domains (i.e., urban, rural and natural). Obtained viewsheds were on-screen interpreted using digital aerial images. Five land use types have been distinguished: urban, crop, meadow and pasture, shrub and forest. We calculated the patch density (PD), land use class density (CD) and Shannon's diversity index (SDI) (see McGarigal, 2014 for further details on these metrics) of each viewshed, later reduced to a 0-1 interval by the min-max method of ranging (Sneath & Sokal, 1973) and verified that they were not correlated (Spearman $\rho < |0.8|$). The metrics were chosen because of their proved correlation with aesthetic service (Uuemaa et al., 2009) as well as their ability to describe landscape structure irrespective of the area extent (Plexida et al., 2014). The average of the normalised values was assumed as an index of landscape heterogeneity ($H\ Index_V$) (see Table A3 in the supplementary materials of Annex III). Finally, we selected six viewsheds and the related photographs corresponding to the lowest and the highest $H\ Index_V$ value within each landscape pattern (Figure 6). The photo-sequence has been then recreated as follows:

L1 - homogeneous urban landscape, the landscape with the lowest heterogeneity level among those with the main land use represented by urban areas;

L2 - heterogeneous urban landscape, the landscape with the highest heterogeneity level among those with the main land use represented by urban areas;

L3 - homogeneous rural landscape, the landscape with the lowest heterogeneity level among those with the main land use represented by croplands;

L4 - heterogeneous rural landscape, the landscape with the highest heterogeneity level among those with the main land use represented by croplands;

L5 - heterogeneous forest landscape, the landscape with the highest heterogeneity level among those with the main land use represented by forests;

L6 - homogeneous forest landscape, the landscape with the lowest heterogeneity level among those with the main land use represented by forests.

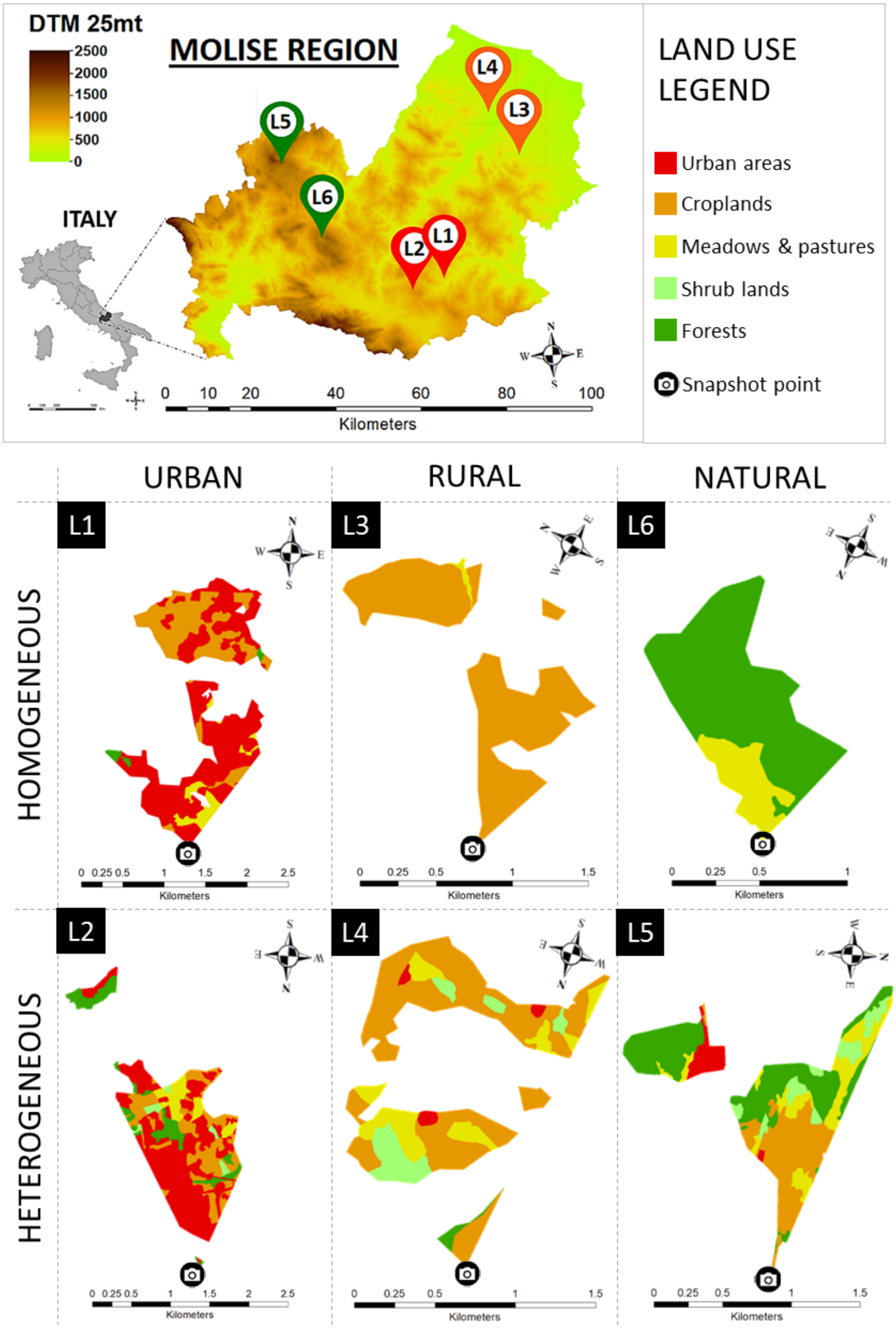

Figure 6 The six selected viewsheds representative of the urban-nature gradient and their geographical location in the study area

2.3.2. Visual choice experiment

The selected photos were then modified using a raster graphic editor. First editing aimed to (i) remove all TOF present in original photos, (ii) harmonize exposure and saturation values, and (iii) eliminate clouds as plausible misleading stimuli on observer perception (Kaplan & Kaplan, 1989). Accordingly, first photo of each triplet related to the absence of TOF (No TOF). In the second photo of each triplet, TOF has been added until 1.7%: the average density of TOF (Med TOF) in the Molise region (according Annex II). Finally, the third photo of each triplet was modified by adding TOF elements until reaching a relatively high TOF abundance of 3.4% (High TOF), twice the average density. TOF were added from 0 to 1.5 km from the snapshot point, equal to the maximum visual threshold for clearly discerning individual elements such as trees (Schirpke et al., 2013) (Figure 7).

The adoption of visual approaches is particularly useful for analyzing landscape preferences. In particular, graphic experiments with "stated" choices allow an accurate analysis of people perception regard to visual stimuli because pictures and all related randomness that could occur are contained (Häfner et al., 2018). Furthermore, almost all of the people who were intercepted accepted to participate in the visual choice experiment, showing a high appeal for the chosen approach. Edited photos have been exposed in a visual choice experiment to 360 respondents, equally distributed by age, (i.e., young, adults and elderly, respectively under 35, between 36 and 55, and over 55 years), gender, place of origin (i.e., inhabitants or visitors) and residential site (i.e., in town or out of town). An equal distribution of the survey sample among several social groups aims to represent and compare the perception of the whole community regard to belonging in different groups (Lothian, 1999). Respondents were randomly intercepted in public locations of Molise region between December 2018 and March 2019, gradually rejecting people who fall into already completed groups. First part of interviews included individual data sheets, gathering further information about profession, educational level and marital status. Then, each respondent was asked to rank the photos contained in each triplet according to their individual aesthetic preference. The three photos were simultaneously shown on A2 sheets in order to grant an optimal observation of the portrayed landscapes, facilitating their comparison. Hence, the three photos of each triplet were ranked from 1 to 3 following an increasing aesthetic appreciation (i.e., 1 for the less preferred, 2 for the intermediate and 3 for the most preferred photo). At the end of the visual choice experiment, respondents were also asked to rank the six original unmodified photographs from 1 to 6 according to their aesthetic appreciation. A mean preference score for each of the 18 photos was calculated as the product of the preference value of each photo within the triplet by the preference value of the original unmodified photo.

The responses were analysed both on the overall sample and for each individual group of respondents. In order to check the significant differences in preference from different groups of respondents, a $\chi 2$ test was then performed.

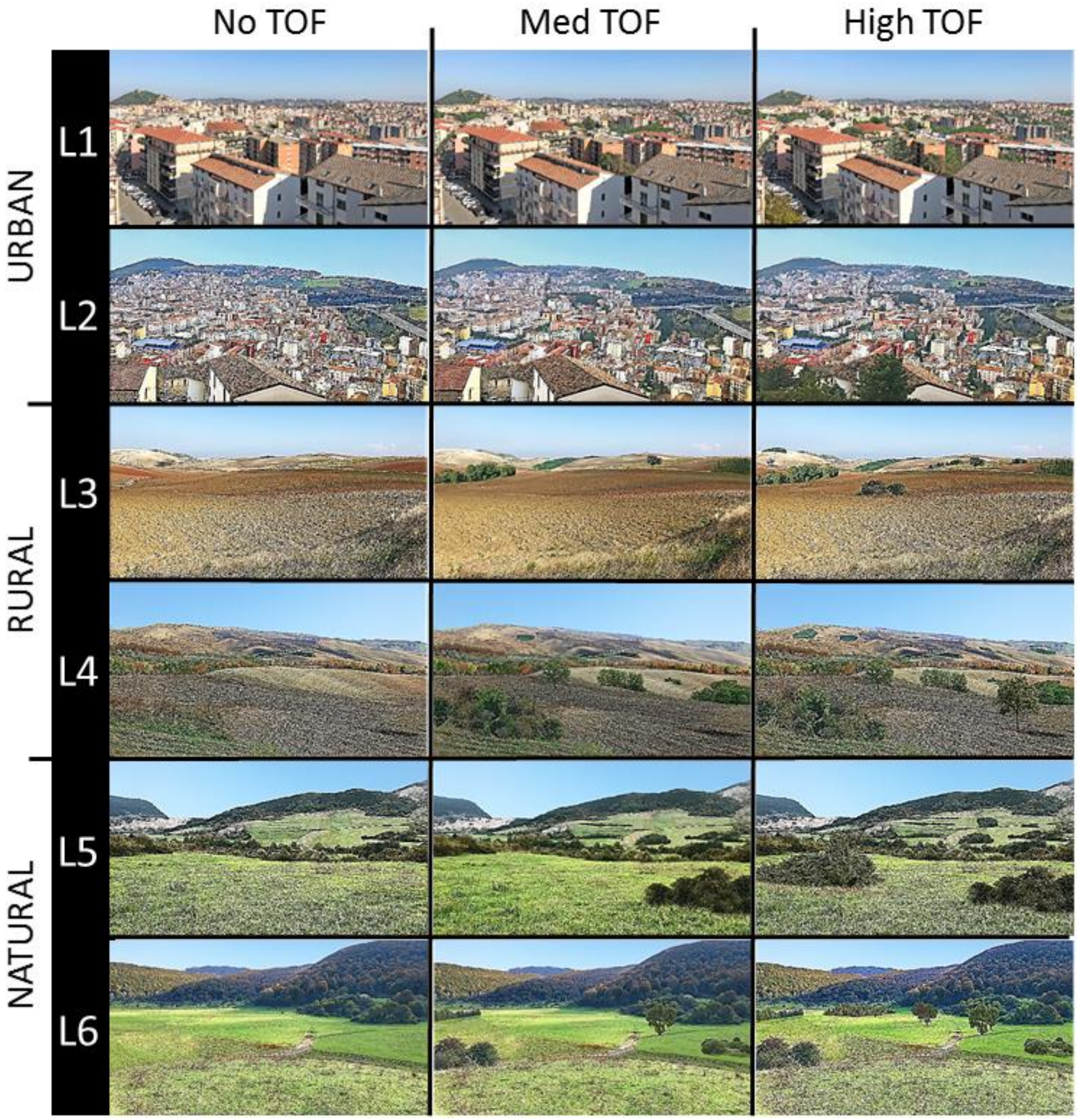

Figure 7 The six triplets of photos edited in Adobe Photoshop® CS6 software, showing 6 different landscape types of the urban-nature gradient (from the bottom to the top) and 3 different degrees of TOF abundance (No TOF, Med TOF and High TOF)

2.3.3. Landscape and statistical analysis

Correspondingly to the photo editing, land use maps of the six photos have been edited in a GIS environment, thus reproducing six triplets of viewsheds. TOF patches edited in photos were indeed replicated in the corresponding viewsheds, faithfully reflecting their spatial configuration, both for distribution (i.e., azimuth and distance from the observer) and for geometry (i.e., shape and area). Then, a landscape analysis of each viewshed was carried out, computing sixteen landscape metrics currently used to describe landscape fragmentation, complexity and diversity (see Table A4 in the supplementary materials of Annex III). Only seven metrics showing a Spearman $\rho < |0.8|$ between each other were retained and ranged to 0-1 interval using the min-max method (Sneath & Sokal, 1973). The metrics were used to calculate three landscape indices: fragmentation, given by the mean of mean patch size (MPS), patch size coefficient of variation (PSCoV) and total edge (TE); complexity, given by the mean of area weighted mean shape index (AWMSI) and mean patch fractal dimension (MPFD); diversity, given by the mean of landscape complexity (CMP), class density (CD) and Shannon's diversity index (SDI). Indeed, the use of these seven metrics allowed characterizing and comparing the six different landscapes in relation to the three TOF abundance degrees. Lastly, correlations between preference scores and the three landscape indices for each triplet were assessed through Pearson's r correlation test. Finally, the statistical significance of *R* values at 0.01 level was tested.

2.3.4. Results and discussion

The educational level of respondents involved in the visual choice experiment has a normal distribution. About half of the sample (47.8%) obtained a higher secondary school certificate and the remaining part is divided evenly between lower (i.e., primary and lower secondary school) and advances (e.g. degree, master, PhD) levels. The main part (i.e., 86.7%) of tourists/visitors intercepted by the survey indicated as place of residence a city belonging to a region bordering Molise, especially Puglia (32.2%) and Campania (27.2%) regions. As for marital status, sample distribution is fairly uniform between separated (i.e., unmarried, widowers and divorced) and coupled (i.e., cohabiting and married). Only 42.5% of respondents are employed/self-employed, while 57.5% of respondents does not work (unemployed, retired or housewife). In general, frequency of preference scores was relatively more similar between different TOF densities in the rural and natural landscapes then in the urban (Figure 8). Main results reveal that urban and rural landscapes without TOF are less aesthetically preferred by most of respondents. Conversely, in natural landscapes, most of respondents indicate as less aesthetically preferred those having the highest TOF abundance. Moreover, most of respondents consider as aesthetically preferred urban and rural landscapes with the highest degree of TOF abundance. Otherwise, preferred natural landscapes by most of respondents are heterogeneous with a mean TOF density and homogeneous without TOF. Poor statistically significant differences appear respect to the preferences expressed by the different groups of respondents (as displayed in Figure A5 in supplementary materials of Annex III, for between groups' distributions of preferences, results are almost the same of the overall sample).

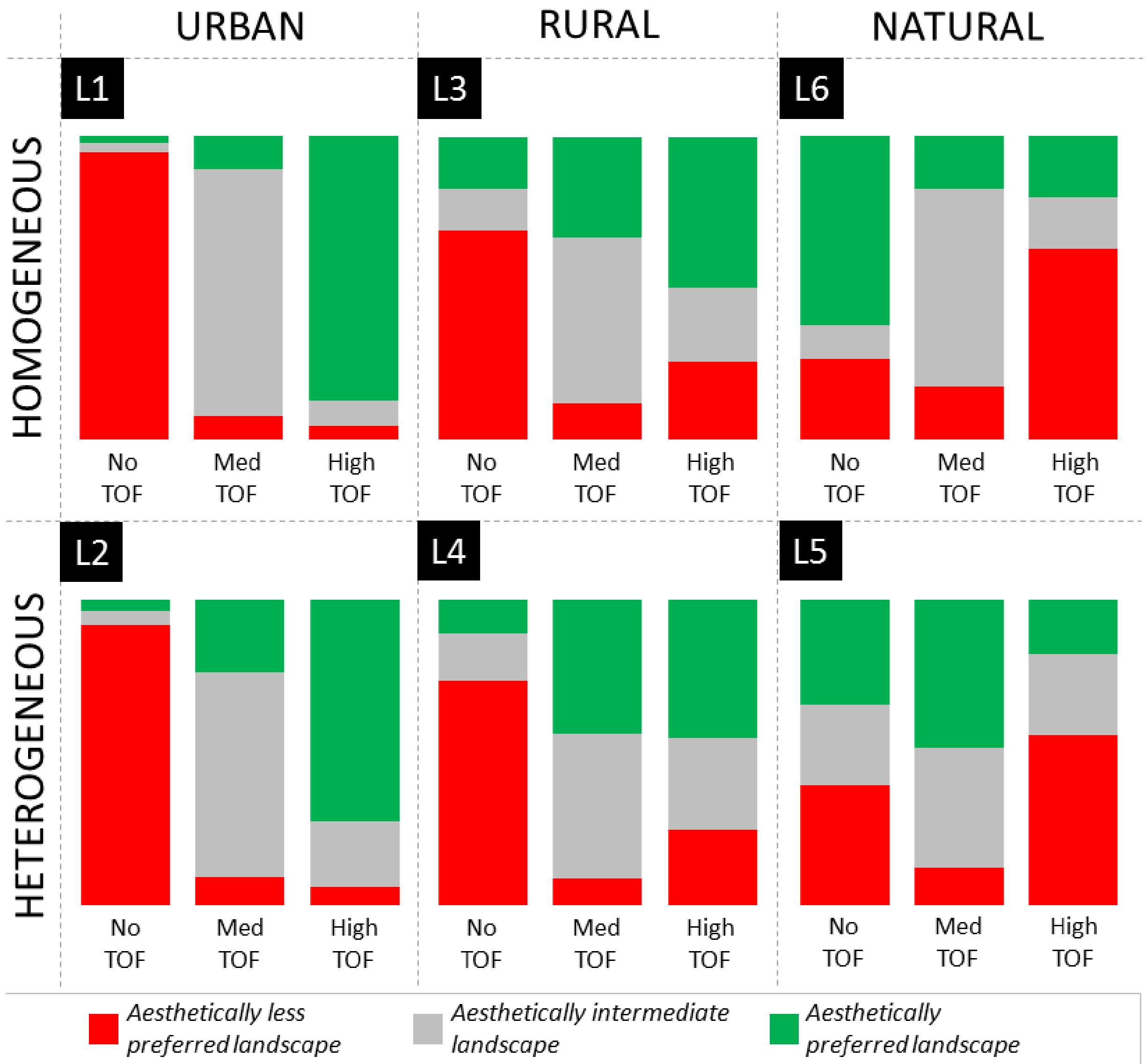

Figure 8 Preference distributions of the overall sample of respondents recorded in the choice experiment

Looking at Figure 9, metric values of landscapes with high TOF abundance (green line) are always higher respect to the same metrics in case of average TOF abundance (grey line) and TOF absence (red line). Accordingly, these metrics' trends show that a higher TOF abundance is directly correlated with a higher level of fragmentation, complexity and diversity of the landscape mosaics. Moreover, differences related to TOF abundance are more emphasized in homogeneous than heterogeneous landscapes. In these landscapes (i.e., L1, L3 and L6), MPS, PSCoV and TE show the widest absolute variations in relation to changing TOF abundance. In homogeneous urban landscape (L1), MPS, PSCoV and TE respectively increase by 33%, 22% and 13% for High TOF and decrease by 50%, 20% and 13% for No TOF, respect to Med TOF. In homogeneous rural landscape (L3), MPS PSCoV and TE respectively increase by 38%, 33% and 19% for High TOF and decrease by 100%, 41% and 16% for No TOF, respect to Med TOF. Last, in homogeneous natural landscape (L6), MPS, PSCoV and TE respectively increase by 40%, 37% and 7% for High TOF and decrease by 100%, 65% and 10% for No TOF, respect to Med TOF. In these homogeneous landscapes, we also found that AWMSI and MPFD are less sensitive to changes in TOF abundance.

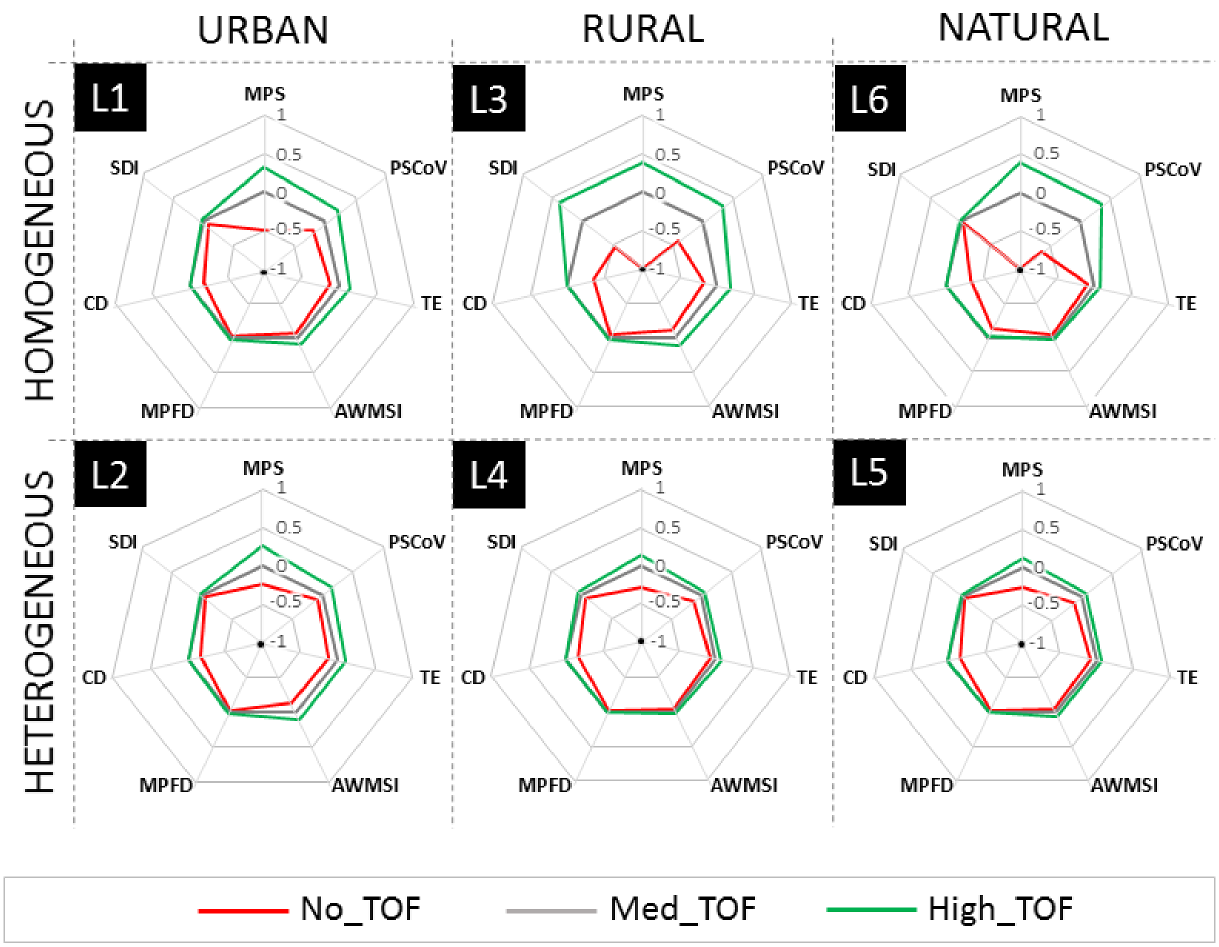

Figure 9 Radar chart of representing the seven normalized landscape metrics for the 18 viewsheds. For a graphic convenience, variation of MPS was reversed (from 1 to 0 instead 0 to 1)

Mean preference scores of the 18 photos show an increasing trend moving along the urban-natural gradient (Table 12). Furthermore, in general terms the increase of the mean preference scores in urban and rural landscape triplets matches the increase of TOF abundance Mean preference scores for L1 and L2 without TOF increase respectively by 85% and 83% passing to Med TOF and by 146% and 128% passing to High TOF. Similar but less emphasized are trends related to rural landscape triplets (L3 and L4). Indeed, in these cases results reveal that the highest mean preference scores correspond to Med TOF instead High TOF degree. In fact, in L3 and L4 mean preference scores respectively increase by 142% and 173% passing to the Med TOF while 3% and 7% of decrease respectively appear passing from Med TOF to High TOF. Med TOF achieves the highest mean preference score even in the heterogeneous natural landscape (L5) with the lowest value found in High TOF degree. For the natural homogeneous landscape (L6), No TOF show the highest mean preference score. In fact, in this case results display that trend in mean preference scores is opposite to the increase of TOF abundance. In detail, mean preference scores of L6 decrease by 16% from No TOF to Med TOF and by 23% from Med TOF to High TOF. With regard to the trends of landscape indices, a direct correlation with the increase in TOF abundance was found for all landscape types. This common trend is particularly emphasized in homogeneous rural and natural landscapes (L3 and L6) where, for example, DIV index triplicates passing from No TOF to High TOF in L3 and FRG index raises from 0 to 0.49 passing from No TOF to High TOF in L6.

Table 12 Mean preference scores and landscape indices of the six landscape types investigated in relation to three different degrees of TOF abundance. FRG index is the Fragmentation index, CMP index is the Complexity index and DIV index is the Diversity index

DOMAIN	LANDSCAPE ID	TOF ABUNDANCE DEGREE	MEAN PREFERENCE SCORE	FRG INDEX	CMP INDEX	DIV INDEX
URBAN	*L1*	*No TOF*	2.1	0.62	0.55	0.28
		Med TOF	3.9	0.75	0.71	0.35
		High TOF	5.1	0.87	0.86	0.36
	L2	*No TOF*	2.5	0.83	0.46	0.47
		Med TOF	4.6	0.91	0.64	0.55
		High TOF	5.7	1.00	0.80	0.56
RURAL	*L3*	*No TOF*	4.9	0.21	0.15	0.10
		Med TOF	6.9	0.39	0.33	0.28
		High TOF	6.7	0.50	0.48	0.30
	L4	*No TOF*	5.1	0.52	0.26	0.70
		Med TOF	8.8	0.56	0.36	0.83
		High TOF	8.2	0.59	0.40	0.86
NATURAL	*L5*	*No TOF*	9.6	0.53	0.37	0.86
		Med TOF	11.6	0.58	0.48	0.99
		High TOF	7.9	0.61	0.55	1.00
	L6	*No TOF*	12.5	0.00	0.00	0.27
		Med TOF	10.4	0.37	0.51	0.43
		High TOF	8.1	0.49	0.47	0.44

Main results from correlation analysis (Table 13) show that relationships between trends in mean preference scores and trends in fragmentation, complexity and diversity indices have greater positive intensity in urban (L1 and L2) than rural landscapes (L3 and L2). These correlations are inverted, thus becoming negative, passing to natural landscapes (L5 and L6). Homogeneous urban landscape (L1) displays the strongest positive correlations between trends in mean preference scores and trends in landscape indices, which tend to smoothly decrease passing to heterogeneous urban landscape (L2). Inversely, positive correlations are stronger in heterogeneous than homogenous landscapes in rural patterns (L4 and L3, respectively). Heterogeneous natural landscape (L5) displays very weak correlations, almost null in the case of the DIV index. Finally, in homogeneous natural landscape (L6) weak negative correlations between mean preference scores and CMP index and DIV index, which tend to be slightly higher in the case of FRG index.

Table 13 Correlation matrix between trends in preference scores and trends in landscape indices (FRG index is the Fragmentation index, CMP index is the Complexity index and DIV index is the Diversity index.). We found statistical significance at 0.001 level for all Pearson's product moment correlation coefficient R

	LANDSCAPE PREFERENCE SCORES					
	URBAN		**RURAL**		**NATURAL**	
	L1	**L2**	**L3**	**L4**	**L5**	**L6**
Fragmentation index	0.62	0.53	0.35	0.43	-0.15	-0.42
Complexity index	0.62	0.54	0.33	0.46	-0.14	-0.34
Diversity index	0.57	0.55	0.38	0.49	-0.03	-0.37

Primary consideration from results concerns that aesthetic appreciation usually increases when human-shaped landscapes abound in TOF and other natural features. Emotional response to nature amenity is particularly evident in urban domains, where the high occurrence of TOF and natural features is in contrast with the common idea of a townscape. Indeed, as observed by Hagerhall (2001), archetypal landscapes generate an immediate judgment by people, which in the specific case of a townscape rich in natural features (e.g. TOF) is reflected in a strong positive consensus. In this sense, our results are in agreement with the theory that landscape appreciation is commonly inspired by nature (Kaplan & Kaplan 1989; Kellert & Wilson, 1995). Accordingly, TOF contribution to landscape aesthetics depends on the level of naturalness of landscapes along the urban-nature gradient, resulting very high in urban domains where TOF represent the last legacy of nature (Willis & Petrokofsky, 2017). Results of the visual choice experiment thus also confirm the hypothesis that aesthetical preferences in general are considerably affected by nature exposure (i.e., the amount of contact of people with nature), that is enhanced by the presence of TOF in urban contexts (Bratman et al., 2019). Our findings are in line with other similar studies, highlighting how people commonly prefer urban landscapes plentiful of TOF elements (Camacho-Cervantes et al., 2014; Giergiczny & Kronenberg, 2014;

Vesely, 2007). Differently, preference analysis in rural landscapes show a more balanced distribution ratio, albeit confirming the general aesthetical preference for landscape with high TOF abundance. Considering rural landscapes as transitional between extremely anthropized and natural landscapes (Colgan et al., 2014), natural features such as TOF are already present thus lowering their overall aesthetic impact compared to urban domains. Indeed, TOF influence on preferences appear slightly greater in homogeneous rural landscapes characterized by high agricultural intensification respect to heterogeneous and extensively cultivated ones. As exposed by van Zanten et al. (2016), trees and small woods in arable plots represent the most appreciated visual landscape attributes. Furthermore, results are consistent with those obtained by Beza (2010), showing how aesthetics of natural landscapes includes not only large bio-physical features (i.e., mountains and forests more than TOF) but also conceptual (e.g., wildness) and emotional (e.g., excitement) aspects. Moreover, Ode et al. (2009) proved how in natural landscapes the abundance of small and scattered forest patches is interpreted as a reduction in naturalness negatively influencing landscape perception.

Effects of an increase/decrease in TOF abundance are mostly evident in landscapes with lowest levels of heterogeneity, where TOF and small patches in general represent the main elements of diversification (see Annex I). Conversely, the ongoing processes of urbanization, agricultural intensification and abandonment of marginal lands in Italy and other countries (above all in Mediterranean area), are often taking place at the expense of TOF with subsequent landscape homogenization (Plieninger, 2012). More specifically, landscape analysis proves how changes in TOF abundance in homogeneous landscapes mainly affect patch size and edge metrics. Confirming this result, a spatial simulation exercise by Rossi et al. (2016) demonstrated that TOF precisely affect these variety of metrics, achieving an exponential improvement of the ecological connectivity. Besides, TOF abundance strongly affects diversity metrics in homogeneous rural landscapes where they represent the only permanent features of structural and biological diversity (Sitzia et al., 2013). Indeed, agricultural intensification process mainly implies the removal of TOF patches to facilitate mechanization, thus favoring the consolidation of small land holdings in single huge proprieties that radically simplify the landscape mosaic (Eichhorn et al., 2006).

Our results confirm the positive correlations between landscape preferences and indices in relation to the increasing TOF abundance in landscapes largely modified by humans (i.e., urban and rural). Pearson's coefficients tend to decrease with the decreasing human-induced landscape alteration in rural compared to urban landscapes. Moreover, the diversity index is less correlated to preference scores than the complexity and fragmentation indices. As previously mentioned, agricultural lands, currently accounting for almost half of the EU surface (FAO 2015), have undergone important structural changes after the post-war period, led to the extreme simplification of landscape mosaics (Eichhorn et al., 2006). This simplification has also negative impacts on the perceived aesthetic value due to the homogenization of the landscape mosaic which is mainly dominated by few and large similar land patches (Svobodova et al., 2015). Moving towards more natural landscapes, human impacts on landscape structure tend to decrease as well as TOF contribution to scenic beauty. Although TOF abundance continue to implicate a general upgrading in heterogeneity, their increase in natural landscapes is in fact generally perceived as a reduction of naturalness. Since TOF influence on landscape structure is less marked in heterogeneous natural landscapes compared to homogeneous ones, correlations between trends in preferences and indices are negligible in the former and weak or medium negative in the latter. In detail, FRG index shows the highest negative correlation with preference scores in homogeneous natural landscapes (L6), thus confirming fragmentation as a negative indicator for aesthetic perception (Ode et al., 2009).

This study affords further evidences on the key role of TOF in social terms, providing communities with values that are a significant part of the cultural capital (Tabbush, 2010). The important contribution of TOF to aesthetics upholds the importance of developing green infrastructures to strengthen the human-nature relationship (Soga & Gaston, 2016) as well as the links between urban and rural areas through recovering habitat connection in such anthropized domains (Benedict & McMahon, 2002). These findings thus confirm the positive role of TOF from both ecological, i.e. ecological connectivity, and cultural, i.e. aesthetic perception, terms in rural and urban domains. Conversely, this positive role of TOF in natural landscapes is lower in terms of ecological connectivity, especially in ones that are more homogeneous, while negative for aesthetics. Accordingly, this general finding highlights the crucial role of planning activities in balancing the TOF-related trade-offs among different services. One of the main reasons at the basis of these trade-offs is related to the fact that ecological and cultural services act at different scales. In fact, natural processes take place on a wide scale ranging from microscopic to global. Otherwise, human perception derives from cognitive processes that are restricted at the specific scale on which human experience can directly interact with the surrounding environment (i.e., the so-called "perceptible realm"; Gobster et al., 2007). This scale mismatch can lead to the implementation of conservation measures not perfectly fitting with the aim of maximizing the different ES thus leading to win-lose situations in their provisioning along the urban-nature gradient (Herrero-Jáuregui et al., 2019).

This work offers a more complete understanding of TOF-related cultural services provisioning, encouraging their inclusion in future-oriented planning strategies and promoting their conservation as resources for cultural and economic development. Indeed, an in-depth knowledge of the TOF-related cultural services potential can facilitate the conversion of perceived services into concrete benefits for communities, such as economic ones linked to an increase in the houses' prices in greener towns (Song et al., 2018) and to opportunities for the growth of the eco-tourism sector in rural areas (Barbieri et al., 2016). Beyond intrinsic and instrumental values, a more complicated but extremely topical remark concerns the TOF contribution to landscapes in terms of strictly cultural implications. Specifically, we refer to the role played by TOF in landscapes through relational values, defined as preferences, principles and virtues on the relationships between humans and nature (Chan et al., 2018). It should be noted that these values stand above the mere aesthetic service of TOF, instead referring to the concept of human addiction to nature and, as a result, to the sense of identity and cohesion that link local communities to their territories. In this perspective, TOF can represent an important support to the sustainability challenges imposed by the current environmental changes, above all containing social drivers influencing landscape dynamics.

CHAPTER 3 - Conclusions and future perspectives

The aim of this thesis was to provide a deeper understanding of Trees Outside Forests (TOF), representing a further step towards their inclusion in forest resource policy and planning and monitoring systems. For this purpose, different approaches and methods were tested in order to facilitate the large-scale assessment of TOF and related ES, especially considering challenges and issues posed by the current landscape dynamics in the Mediterranean area. Main findings confirmed how TOF do not represent a negligible component of landscapes in both quantitative and qualitative terms. Rather, they are a key component of our natural and cultural capital, acting for essential elements of the "green infrastructure" network (e.g., de Foresta et al., 2013) and contributing to people well-being at local/global scales through the provision of several ecosystem goods and services.

The observed general increase in TOF abundance and coverage in recent decades in Italy can be interpreted as an encouraging evidence in contrast to the homogenization threats of rural and urban landscape mosaics. In landscapes significantly modified by human activities, besides being a structural feature, TOF are often the last natural component. Accordingly, TOF revealed the highest potential in landscape restoration in these domains, increasing biodiversity maintenance and improving habitat connections across the urban-rural interface (Benedict & McMahon, 2002). Ones again, the importance in raising policy interest in these small landscape patches, considered for too long as a supplement, but not a replacement, of large patches (Forman, 1995), is hence highlighted. Just to note that in the study area of our research (Italy), TOF are currently not managed like proper forests, with the following legal leak that allows their total removal from the territory. We argue that this issue is a matter of imperative importance given that forests and TOF represent two sides of the same resource and sustainable management cannot be recognized as integrated until it considers only the former while ignoring the latter. Furthermore, considering issues deriving from the current landscape dynamics, sustainable strategies aimed at the conservation and enhancement of TOF may reduce the negative impacts of land use change (LUC), offering an opportunity to improve the ecosystem functionality and resilience in diversified Mediterranean landscapes. Our methodology can be considered a precious milestone for the large-scale assessment of temporal and spatial dynamics of TOF and surrounding landscape patterns, being cost- and time-effective in updating processes, as well as for obtaining accurate and reliable data. Moreover, the integrated methodology (i.e., combining inventory and cartographic techniques) proposed in this thesis was particularly valuable in complying the current gaps on this topic, allowing to take advantage from both approaches. This is a further indication considering the task about the development of strategic tools for TOF assessment and, more generally, for the implementation of sustainable rules in landscape management and monitoring.

As overtly recognized, sustainability is an imperative concept in landscape policies for a half century now. Yet, a comprehensive valuation of the natural resources is increasingly required, for example in the context of Sustainable Development Goals linked to the role of forest sector (Ruijs et al., 2018). Therefore, in this thesis a large-scale assessment of the TOF-related ES potential has been proposed. As verified by results, TOF provide a high contribution to atmospheric C storage, with an above-ground C stock equal to 28.6 t ha^{-1} respect to 47.4 t ha^{-1} and 42.3 t ha^{-1} of the Italian and Molise forests, respectively (INFC, 2005). Supposing a further TOF increase in the wake of observed trends, it would represent a great prospect to achieve common targets about climate change mitigation by including C stock of TOF into the overall forest resources' accounting. Under this perspective, the estimation framework tested in Molise region should be considered a good starting basis for the definition of an inventory protocol that could be replicable in other contexts and, consequently, conventionally adopted. Indeed, two-phase inventory approach allowed a reliable large-scale estimation of ecological diversity and above-ground C stock of TOF with a very low sampling effort, facing to one of the main methodological problems respect to TOF assessment over large territories. As an approval, during the field survey 60 different species of trees were recorded. Such a high species diversity attests the multiple value of TOF linked to the variability of their uses, services, benefits and stakeholders (Bellefontaine et al., 2001). And yet, despite the very high biological diversity of this forest resource associated to the great heterogeneity of TOF systems, the resulting RSE estimates are more than satisfactory, especially those regarding the overall totals and the diversity estimators.

Further than strictly ecological aspects, findings from research on TOF-related cultural value perceived by people are particularly interesting. Taking into consideration the whole urban-nature gradient, research on TOF contribution to landscape aesthetics put emphasis on the issue about the inference of different spatial scales on the ES values (Hein et al., 2006), poorly investigated especially for cultural services (Radford & James, 2013). In detail, we found that TOF aesthetic contribution to landscape is closely linked to the degree of landscape anthropization. Although their richness positively affects all landscapes' mosaics, TOF abundance implied both positive and negative inferences on aesthetic perception. In detail, their contribution resulted highest in urban landscape, decreasing in rural domains and even becoming negative in natural ones. These upshots endorse the importance of multi-functional and multiple value frameworks in landscape planning and management, which should mediate between the ecological role, socio-cultural benefits and other TOF-related ES. Accordingly, initiatives aimed at conserving and improving TOF presence in urban and rural areas could ensure health, cultural, economic and environmental benefits for people, reiterating the opportunity to expend TOF as an additional resource for sustainable landscape development.

Just in conclusion, findings of this thesis provide clear suggestions for landscape policies, planning and future management strategies. Most of all, the need to solve the exclusion of TOF from Italian legal rules could avoid their uncontrolled removal. As well as policies aimed at maintaining TOF, a comprehensive knowledge of their ES potential would enable the implementation of actions for landscape improvement in a sustainable perspective. Moreover, a deeper understanding about the role of TOF as a key green infrastructure is increasingly required in the domain of bio-economy, especially to foster sustainability purposes in both management of forest resources in rural areas and landscape planning (e.g., Marchetti et al. 2014). Finally, it is essential to keep in mind that landscape management and conservation planning should incorporate social and ecological basis in their sustainable strategies by mediating between the ecological and social role of TOF and optimizing ES demand and supply ratio. This is particularly relevant according to the recent objectives of sustainable landscape development highlighting interactions among different material services and beneficiaries but often neglecting intangible services (Dronova, 2019).

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Annex I

forests

MDPI

Article

Evaluating the Contribution of Trees outside Forests and Small Open Areas to the Italian Landscape Diversification during the Last Decades

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Abstract: Land use by humans strongly alters the landscape mosaic, either by reducing or increasing its heterogeneity. One of the most recent and widespread land use changes in Europe has been the spontaneous reforestation of marginal agricultural lands. These primarily affected small landscape patches, such as trees outside forests (TOF) and small open areas (SOA), often represent the most diversifying features of landscape' structures. Nevertheless, only small-scale studies can be found in the literature and thus it remains a relatively unexplored issue. Integrating inventory and cartographic approaches, this work assesses changes in abundance, coverage, and average size of small patches in Italy between 1990 and 2013. Main results showed an overall increase in number and coverage of small patches during the reference period. The average patch size remains unaltered for TOF but decreases significantly for SOA, due to trees encroachment and canopy cover increasing in forests. Our findings confirm the important changes in Mediterranean land mosaics and contribute to a better understanding of current conditions and recent trends regarding TOF and SOA. The integrated approach has proven to be helpful for the large-scale assessment of small patches dynamics, representing a viable monitoring tool to encourage the inclusion of small patches in landscape policy and planning.

Keywords: land use change; land abandonment; forest expansion; small patches; inventory

1. Introduction

Natural processes and human activities might change landscape patterns over time. This will affect the configuration and distribution of the spatial elements of the land mosaic and their contribution to ecological processes [1]. The spatial elements of a land mosaic contribute to its heterogeneity and fragmentation, and have positive effects on ecosystem functionality and resilience [2,3]. Patches–relative homogeneous areas that differ from their surroundings—are among the spatial elements of the land mosaic whose geometry and spatial configuration are important for ecosystem functionality [4]. Indeed, the proportion of patch types and their spatial configuration within the land mosaic have a strong impact on ecological processes and, in turn, on the functioning of socio-economic and ecological systems [5,6].

Recently, humans have driven landscape dynamics much more than natural evolution [7,8]. Since the Industrial Revolution, intensive farming systems and urban land expansion at a global scale have increasingly altered the structures and functions of the existing landscapes at an unprecedented rate [9]. The anthropogenic influence is even more marked in landscapes characterized by higher levels of heterogeneity and built by centuries of human activities and modifications, such as those in the Mediterranean area [10–12]. During the last decades, the Mediterranean landscapes have indeed experienced a general decrease of agricultural lands, mainly due to their abandonment, followed by tree encroachment and subsequent woodland expansion [13,14], particularly in mountain and less profitable marginal lands [15–17]. Oppositely, the agricultural intensification and the expansion of urban areas, which usually follow a high scattered and fragmented spatial pattern, urban sprawl, and urban sprinkling [18,19], are occurring in lowlands and plains [20–22]. These phenomena are strictly interlinked and can alter the sustainability of such systems, especially in the medium-long term [22].

Tree encroachment can have both positive and negative implications in terms of ecosystems' functionality and their capacity to provide ecosystem services (e.g., [23–29]). The risk associated with landscape homogenization [30] is particularly relevant if combined with urban expansion, leading to the loss of fertile soils and urban green spaces [31], as well as agricultural intensification in more profitable lands [32,33]. The negative impacts of such land cover changes are particularly exacerbated when occurring at the expense of small landscape patches, due to their limited extension [27,30,32,34]. Examples of small patches are single trees, small woods, and hedgerows outside the forested matrix, collectively identified as trees outside forests (TOF) [35], and the small open areas (SOA) enclosed by forests. TOF and SOA are intended here as homogeneous areas covering between 0.05 and 0.5 ha, which is the threshold set by FAO to discriminate forestlands [36].

The relevance of TOF as landscapes' features, particularly the hedgerows, has emerged since the 70s [37]. During the last decades, the systems for their inventorying have been increasingly explored and reviewed. TOF contributes to human wellbeing at both the global and local scale [38], through the conservation of biodiversity [35] and the mitigation of climate change [39]. TOF also offers a wide range of provisioning [38], regulating [40,41], and cultural services (ecotourism, recreation, and education; [38]). Conversely, to our knowledge, poor attention has been given to the systematic inventory of SOA in forested landscapes, as demonstrated by the fact that a clear and unambiguous definition is still missing in the literature. The spatial configuration of SOA has a high variability and varies depending on the successional stage. For example, SOA in early-stage secondary forests (i.e., areas under active trees encroachment phenomena) are usually settled close to the forest edges and characterized by sparse trees in low-density stands, whereas SOA in mature stands are enclosed within forest stands and characterized by more evident and clearly defined borders [42]. These differences result in the ecological functionality of these patches, and therefore in the ecosystem services delivered [42–44].

The large-scale assessment and mapping of landscape dynamics from a socio-ecological perspective is a prerequisite for sustainable planning [8]. However, assessing the dynamics of small forest patches in diversified landscapes is limited by the currently adopted minimum thresholds for forest cover and area in many inventories [45]. Therefore, assessing the spatial configuration of small patches in fragmented landscapes and the relative influence on biodiversity and ecosystem services provision remains an open issue [46,47]. Recently, different methodological approaches and techniques for small patches monitoring were developed and implemented using both inventory and cartographic approaches [48–53]. The inventory approaches are convenient in terms of costs and are usually adopted to estimate the total coverage of small patches and additional quantitative attributes, such as trees characteristics and biodiversity. Especially thanks to the availability of very high resolution images, as well as the progresses in proximal and remote sensing techniques [52], the cartographic approach actually represents a reliable option to assess small patches. Nevertheless, current data and studies are often limited to small-scale and synchronic studies (i.e., for Italy, [53,54]), mainly due to the lack of historical data over large scales and high computational costs [51]. Accordingly, though some isolated attempts to integrate small patches within large scale monitoring systems were recently made (e.g., for TOF, [39]), further efforts should be oriented towards developing time and cost-effective approaches to analyze their consistency and characteristics (e.g., shape and average size) as well as changes over time. Furthermore, particular emphasis should be given to statistical accuracy and reliability of such information to strengthen their supporting role in decision making contexts [55].

According to these issues, the present study aims to assess coverage, abundance, and average size of small patches; i.e., TOF and SOA, in 1990 and 2013 as well as their dynamics in this time-span, using Italy as a case study. Accordingly, a design-based approach integrating inventory and cartographic data was implemented with the threefold objective to (i) reduce costs and time for monitoring activities, (ii) provide statistically-sound estimates, and (iii) increase the informative power of pure inventory approaches. In this way, the present study provides useful insights to support landscape policy and planning, and conservation strategies, and to facilitate the inclusion of small patches in existing large-scale monitoring systems.

2. Materials and Methods

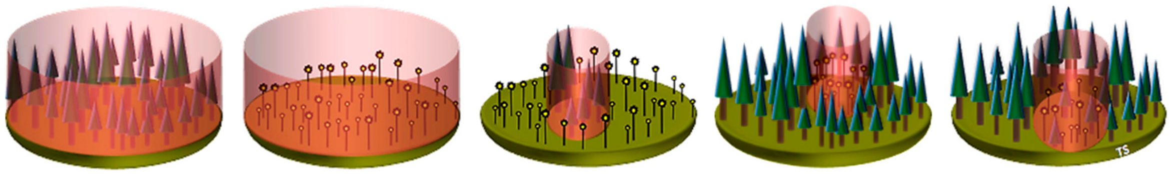
2.1. Study Area

The study area overlaps the entire national surface of Italy (about 300,000 km^2) with high ecological and socio-economic variability. The mountain chains, namely Alps and Apennines, dominate the northern and the central part of the country, respectively, have been widely characterized by outmigration, land use abandonment, and forest expansion in the last decades [56]. During the same time-span, the low hills, plains, and coastlines experienced agricultural intensification and the growth of urban areas. Currently, agricultural areas cover almost 56%, forests 32%, and settlements 7.3% of the national territory. Urban areas are mainly located along the coasts and in flat areas where the majority of population is settled [21]. As briefly introduced, changes in the socio-economic asset of the country (i.e., outmigration towards urban areas, industrialization, etc.) had strongly influenced recent land use and land cover changed dynamics nationwide [57]. Hence, on the one hand, depopulation of mountain areas resulted in the abandonment of traditional land uses, thus facilitating forest expansion [58]. On the other hand, urban growth on croplands increasingly affects low hills and plains [31].

2.2. The Classification System and Inventory Framework

The Italian Land Use Inventory (IUTI) has been adopted to implement the following methodology in order to analyze small landscape patches and their dynamics during the 1990–2013 time-span. IUTI has been promoted and implemented by The Italian Ministry of Environment and Protection of Land and Sea as a key instrument for the National Registry for forest carbon sinks [59]. According to its tessellated stratified sampling scheme, the whole Italian territory was covered by a network of 25-ha squares and one sample point was randomly located within each square [60]. For this work, a sub-sampling strategy was applied in order to further reduce cost and times for photointerpretation [60]. Accordingly, about 13,000 IUTI sampling points were classified based on high-resolution imagery in 1990 and 2013, and according to the classification system proposed by the Intergovernmental Panel on Climate Change (IPCC) [61]. Moreover, a minimum dimensional threshold of 0.5 ha was used to discriminate the land use categories [61]. The coarsest classification adopted six land use classes: forests, cropland, grassland, wetland, settlements, and other lands.

In addition to the basic land use classification, during the photointerpretation phase, sampling points falling within homogeneous patches less than 0.5 ha in size and with a land use different from the surrounding area were marked as “enclosed patches”. Particularly, we distinguished between: (i) small patches with trees within land use classes other than forests, namely TOF, and (ii) small patches without trees within forest, namely SOA. In general terms, the latter can be principally associated with: (i) human activities (i.e., clearings; [44]); (ii) natural disturbances (i.e., treefall causing tree canopy gaps [42]); (iii) the tree crown architecture typical of certain forest types due to the so-called "canopy shyness" phenomenon [52]; (iv) the traditional extensive grazing activities (e.g., the so-called "maggenghi" meadows in the Alps; [62]); (v) the canopy cover gaps due to the ongoing encroaching process in new forest stands [25]. Taking into account forest dynamics and forest ecosystem functions and related services (e.g., biodiversity conservation), in this study we divided SOA into two main sub-types, namely enclosed small open areas (encld-SOA) and encroaching small open areas (encrg-SOA). The former mainly corresponds to gaps associated with traditional grazing activities, while the latter to gaps in open recent secondary forest stands. See Figure 1 for some examples of encld-SOA and encrg-SOA. SOA due to forest harvesting or natural treefall are not considered in the present study because of their temporary nature (i.e., short-term natural evolution processes).



(**a**) (**b**) (**c**) (**d**) (**e**)

Figure 1. Schematic representation of the land cover types surveyed in this study. Forestland (**a**), non-forest semi-natural land (**b**), trees outside forest (TOF) (**c**), enclosed small open areas (encld-SOA) (**d**), encroaching small open areas (encrg-SOA) (**e**).

In order to apply the methodological approach based on the integration of inventory and cartographic data proposed by [63,64] for assessing green spaces in urban areas, each polygon surrounding a sampling point classified as TOF or SOA was drawn for both inventory occasions. This integrated approach allows to estimate not only the total coverage, but also the abundance and average size of small patches, which can offer a valuable contribution for better understanding and characterize the historical dynamics as well as their possible implications on landscape structure and functionality.

2.3. Trees outside Forests and Small Open Areas Estimation

Total coverage of small patches (A), abundance (N) and average size (a) at both inventory occasions were estimated, applying the design-based estimation approach developed by [48]. Let Q be the extent of the area covered by the n square grid cells fully overlapping the national territory under the IUTI sampling scheme, the estimate of A is given by:

$$\hat{A} = \hat{p}Q, \quad (1)$$

where:

$$\hat{p} = \frac{n_u}{n}, \quad (2)$$

where n_u is the number of sample points classified as small patches (or their sub-types). The variance of A can be estimated as:

$$\hat{\text{var}}(\hat{A}) = Q^2 \frac{n_u(n - n_u)}{n^2(n-1)}. \quad (3)$$

Let S and a_j be, respectively, the set of small patches (or their sub-types) selected by the n sampling points and the size of the j^{th} patch. Whether a_j values are negligible with respect to Q, the estimate of N is given by:

$$\hat{N} = \frac{Q}{n} \sum_{j \in S} \frac{1}{a_j}, \quad (4)$$

with estimated variance equal to:

$$\hat{\text{var}}(\hat{N}) = \frac{1}{n(n-1)}\left(Q^2\sum_{j\in S}\frac{1}{a_j^2} - n\hat{N}^2\right). \quad (5)$$

Accordingly, the estimate of a is given by A/N, i.e.,

$$\hat{\hat{a}} = \frac{n_u}{\sum_{j\in S}\frac{1}{a_j}}, \quad (6)$$

with estimated variance equal to:

$$\hat{\text{var}}(\hat{\hat{a}}) = \frac{Q^2}{\hat{N}^2 n(n-1)}\sum_{j\in S}\left(1-\frac{\hat{\hat{a}}}{a_j}\right)^2. \quad (7)$$

Considering the standard normal distribution of the variable, a statistical test was performed to assess whether a real variation occurs between estimates at 1990 and 2013. Accordingly, in the present study we considered variation as (i) extremely significant for p value < 0.01, (ii) very significant for p value < 0.05, (iii) significant for p value < 0.1, and (iv) not significant for p value > 0.1.

3. Results

The main findings of the study reveal that the overall number and coverage of small patches, considering both TOF and SOA, increased during the 1990–2013 period. On the contrary, their average size slightly decreased, even if results in this case show different trends between TOF and SOA. Indeed, the average size of TOF essentially remained stable, while that of SOA decreased during the observed time-span (Table 1), passing from 0.16 to 0.07 ha (−56% than the average size at 1990). Even though the increase in the number of patches is higher for SOA (+181.6%) than for TOF (+17.1%), the opposite trend is visible for their total coverage (+18.0% and +27.4%, respectively). The estimates of standard errors are satisfactory for all features at both reference times, ranging from 1.3% to 12.5%.

Table 1. Number (N), coverage (A, in ha) and average size (a, in ha) of small patches (SOA and TOF) at 1990 and 2013 (±their estimated relative standard errors, in percentage). Significance levels (not significant for p value > 0.1, significant for p value ≤ 0.1, very significant for p value ≤ 0.05 and extremely significant for p value ≤ 0.01) of changes between 1990 and 2013 (Δ) are also reported in the summary tables with the relative symbol (n.s., *, **, ***, respectively).

	1990			2013			Δ		
	N	***A***	***a***	***N***	***A***	***a***	***N***	***A***	***a***
TOF	3,607,709 (±2.4%)	332,174 (±8.2%)	0.09 (±11.0%)	4,223,692 (±2.2%)	423,181 (±7.3%)	0.10 (±12.5%)	615,983 *	91,007 *	0.01 n.s.
SOA	3,246,709 (±2.5%)	505,087 (±6.6%)	0.16 (±6.7%)	9,142,196 (±1.3%)	596,094 (±6.1%)	0.07 (±8.1%)	5,895,487 ***	91,006 *	−0.09 ***

To better understand the dynamics of small patches, their changes were also compared with those of the two land matrices in which they can occur (i.e., forestlands for SOA, and non-forest lands except water and other lands without vegetation, for TOF), using data reported by [65] as a reference for land use estimates at 2013 in Italy. During the 1990–2013 period, the relative coverage of both TOF and SOA with respect to the surrounding land use matrix increased (+0.5% and +0.7%, respectively). In fact, the relative coverage of TOF passed from 1.6% to 2.1% while that of SOA passed from 5.5% to 6.2% during the observed period. However, it is worth to highlight that while forests increased by about 550,000 ha, the non-forest land uses decreased by about 580,000 ha during this time-span.

The overall increase of SOA, in terms of both abundance and coverage, is almost solely due to the dynamics of encld-SOA. In fact, as shown in Table 2, encld-SOA contribute to 93% of the overall increase in number of SOA, and even more, they are able to even compensate for the negative trend concerning encrg-SOA from 1990 to 2013.

Table 2. Number (N), coverage (A, in ha) and average size (a, in ha) of SOA (encld-SOA and encrg-SOA) at 1990 and 2013 (±their estimated relative standard errors, in percentage). Significance levels (not significant for p value > 0.1, significant for p value ≤ 0.1, very significant for p value ≤ 0.05 and extremely significant for p value ≤ 0.01) of changes between 1990 and 2013 (Δ) are also reported in the summary tables with the relative symbol (n.s., *, **, ***, respectively).

	1990			2013			Δ		
	N	*A*	*a*	*N*	*A*	*a*	*N*	*A*	*a*
ENCRG-SOA	1,189,399 (±4.3%)	177,463 (±11.3%)	0.15 (±9.9%)	1,594,233 (±3.7%)	159,262 (±12.0%)	0.10 (±9.8%)	404,834 ***	−18,201 n.s.	−0.05 ***
ENCLD-SOA	2,057,310 (±3.2%)	327,624 (±8.3%)	0.16 (±8.9%)	7,547,963 (±1.5%)	436,832 (±7.2%)	0.06 (±9.5%)	5,490,653 ***	109,208 **	−0.10 ***

Accordingly, the relative contribution of encld-SOA respect to SOA as a whole, passed from 64.8% to 74.3% in terms of coverage, and from 63.4% to 82.6% in terms of abundance, during the observed period. The average size decreased for both encld-SOA and encrg-SOA, but with major emphasis in the former, for which the 2013 value is 0.06 ha. Even in this case, estimates of standard errors are satisfactory, being in any case below 12%.

Relative transitions between the two SOA sub-types (i.e., encld-SOA and encrg-SOA) and with respect to forest and non-forest matrices (i.e., land use change occurred during the time-span towards a different land use class), were also analyzed (Table 3).

Table 3. Cross-tabulation matrix of the flows from one class to another during the 1990–2013 period, expressed in relative terms with respect to the total surface of SOA. Entries along the diagonal refer to persistence from 1990 to 2013.

		2013		
		Forests and Land Uses Other than Forests	**Encrg-SOA**	**Encld-SOA**
1990	**Forests and land uses other than forests**		10.2%	14.3%
	Encrg-SOA	3.4%	13.3%	9.9%
	Encld-SOA	7.5%	0.3%	41.2%

It is worth to highlight that values in rows refer to flows from 1990 to 2013 (loss), while values in columns to flows from 2013 to 1990 (gain). Overall, the results confirm a general increase of SOA coverage, with encld-SOA losing 7.5% mostly due to their shift toward other land uses (i.e., forests), and encrg-SOA losing about 13.3% and mainly converted into encld-SOA (74.4%). Contrarily, encld-SOA show a higher overall increase than encrg-SOA (24.2% and 10.5%, respectively). This gain predominantly occurs at the expense of other land uses for encrg-SOA, while amounts to almost 59% for encld-SOA with the remaining 41% occurring at the expense of encrg-SOA.

4. Discussion

The results reveal that the number and relative coverage of small patches generally increased across the entire Italian territory from 1990 to 2013. In particular, our results show that TOF have increasingly contributed to the diversification of semi-natural (i.e., agricultural lands) and artificial land uses. On the other hand, the decrease in average size of SOA and their strong relation with successional stages, as demonstrated by the transition from encrg-SOA to encld-SOA and from the decrease of the latter within established stands, indicate that their contribution might slightly decrease in the medium-long term due to forest expansion (landscape homogenization).

These findings extend those of several studies carried out at regional and local scales. However, the comparison with such studies is not an easy task, because of the different thresholds usually fixed to distinguish small from large patches. In addition, forests are usually aggregated, and enclosed small open patches are included in the open forest class, as a mixture of agricultural and non-agricultural lands, and thus they are difficult to distinguish from aerial photographs [66]. The same occurs at the global scale, where spontaneous reforestation led to an increase and a decrease of forest area and open patch sizes and numbers, respectively, but with some inconsistencies probably related to the lack of distinction between large and small patches [29]. Usually, the reduction of the total size of open lands is interpreted as negative for ecological connectivity in Europe, because a large part of the plant and animal biodiversity is associated with open habitats of human origin. However, species with small home ranges and a short dispersal distance are more influenced by changes at the small patch level, while only species with larger home ranges and longer dispersal distances will be affected by the loss of larger patches.

The relative coverage of TOF with respect to the national surface increased from 1.1% at 1990 to 1.4% at 2013, with an average patch size almost stable around 0.1 ha. These results are in line with those obtained by [53] in Molise Region, where TOF cover 1.7% of the regional territory, having an average patch size of 0.14 ha at 2008. Our results are slightly lower than those obtained by [54] in Central Italy, where TOF cover almost 2.3% of the territory and with an average patch size of 0.21 ha, but with large variability among the four regions considered. However, as explicitly reported by [54], the analyses were performed on four administrative regions where TOF coverage is particularly high, thus justifying these differences. If our estimates are compared with those reported by the 2017 Great Britain's National Forest Inventory [67], which used the same classification system adopted by the present study, Italy has less TOF relative coverage than GB (1.4% and 3.2%, respectively), but a larger forest area [68]. In spite of the recent debate around TOF, only few studies have been conducted so far and limited to regional scales [69]. However, if compared with those by [51] at the regional scale in the Czech Republic during the 1953–2014 period, our results show similar dynamics about the overall increase of TOF coverage. Consistently with [51]' results, we found that TOF both disappeared because it was incorporated in recently expanded forest lands, and appeared in agricultural lands. Both processes have been driven by the abandonment of agricultural practices, which in turn originated in forest expansion and TOF formation and their enlargement in other land uses other than forest. Indeed, we observed that the increase of TOF in the 1990–2013 period inversely relates with the loss of agricultural lands (+27.4% and −8.5%, respectively; [65]). This trend can be interpreted as an important extension of the green infrastructure network, through which the ecological connectivity at lower scales is further strengthened (i.e., landscape to regional) [70]. The mitigation of threats and pressures coming from the surrounding land uses and processes (e.g., urbanization and agricultural intensification) offered by TOF's network should be considered, and the TOF's functions evaluated according to different landscape patterns [54,71]. In our case, the average patch size of TOF remained almost stable, despite a general increase in already existing TOF due to the small size of newly formed TOF.

The raising relative contribution in terms of coverage for both TOF and SOA has probably different characteristics whether taking into account the opposite trends in the land use matrices in which they occur. In fact, the relative contribution of TOF mainly increases because of the decrease of the land use matrix during the same period, while the increase in the relative contribution of SOA is exclusively due to the their own coverage increase. Moreover, results show that non-forested landscape are becoming more diverse thanks to the increase of small patches, while the decrease in average size of SOA and their coverage increase mostly related to encld-SOA, thus mostly coming from trees encroachment processes, could led to a progressive homogenization and simplification of forested landscapes in the medium-long term period.

Results show a reduction in average patch size of SOA, particularly regarding encld-SOA; (−62% with respect to the average patch size at 1990). This trend indicates the closure of these patches due to forest expansion and tree densification as a consequence of the progressive abandonment of extensive grazing and forest management practices [72]. We observed a rate of reduction similar to what has been detected at local scales [30]. Similarly, other authors have detected larger differences in the response of metrics over time at smaller spatial extents, and a stronger reduction in small patch size in completely abandoned forestlands, rather than in low-intensively managed watersheds [28].

This is confirmed by the in-depth analysis of the IUTI sampling points classified as SOA in 1990 and 2013, showing that 45.5% of them experienced a change in the reference period (i.e., new SOA, disappearing or shifting from one sub-type to another). This is also consistent with the evident dynamics in Mediterranean forests, triggered by land use and climate change, especially regarding the modifications of species composition and spatial structure [73]. Considering the key role played by forest structure on productivity [74], biodiversity [75], and the resistance/resilience [76] of forest ecosystems, these dynamics deserve particular attention from forest managers. At a broader scale (i.e., landscape), forest management and planning should valorize the role of small forest patches as contributing to ecological connectivity (in terms of e.g., species corridors, refugia, seed dispersers, and pollinators; [77,78]).

Looking at our results, the low increase in the number of patches of encrg-SOA compared to encld-SOA, and their relatively unchanged coverage overtime, might be related to the progressive slowdown of forest expansion processes in Italy during the most recent years [65]. Considering the origin of encrg-SOA (usually associated with recent secondary forests; [79]), future active forest management should be considered as a valuable option towards the long-term maintenance of their functionality and stability [80]. Results also suggest that recently formed encld-SOA are mainly represented by residual canopy gaps in the successional phases. Therefore, if a further decrease in forest harvesting and extensive grazing coupled with a progressive decrease in forest expansion in the future is hypothesized, a general negative trend in SOA in the medium to long term will be expected, as well as negative implications on their ecological roles. This is particularly true if considering that these small patches are prone to the rapid invasion of fast growing and light demanding species [80]. Furthermore, it is worth noting that only 41.2% of SOA belongs to permanent encld-SOA, probably having the highest ecological value if it is considered that they effectively contribute to the heterogeneity of mature stands [42]. Accordingly, from a management perspective, management activities oriented towards their maintenance should be set as a conservation priority. With this regard, a future scenario of increase of the harvesting rate could be also possible, consistently with the sustainable mobilization of wood [81]. In this case, competent authorities should resist the temptation to develop a bimodal forest landscape pattern (frequent timber harvest, including clearcut, and no timber harvest) and to simplify the forest plan requirements, because this will result in the loss of small patches [82].

5. Conclusions

In the present work, we demonstrated that small patches do not represent a negligible component, at least in quantitative terms, of heterogeneous landscapes. TOF represent essential elements of the "green infrastructure" network (e.g., [83]), and SOA contribute to forest heterogeneity, biodiversity conservation, and ecosystem services' provision. The observed results underline that the management of secondary forests may reverse the impact of land use change (LUC), and give an opportunity to maintain ecosystem functionality and resilience in diversified landscapes.

Open patches play also a key role for the conservation of EU habitats [77]. To bridge the gap between forest planning and habitat conservation, enclosed patches may be included in the ordinary silvicultural plans, and the (larger) open patches may be a focus of rural farming plans. A support is therefore needed for those restoration actions aiming at levelling out habitat gains and losses through the conservation of small patches. The current scenario of wood accumulation might conduct the forest landscape of Italy to a bifurcated model of intensive logging against total conservation, undermining the historical land mosaic patterns, namely of small patches, which are a key-habitat feature of small home-range species, as well as non-matching with stakeholders' expectations (e.g., in Switzerland; [66]).

From a methodological perspective, the integrated approach (i.e., coupling inventory and cartographic data) we propose can be considered particularly valuable for large-scale assessment of small landscape patches and related temporal and spatial dynamics. Moreover, the proposed approach seems to be cost- and time-effective in updating processes, as well as for obtaining accurate and reliable data. In addition, it enables a cross-comparison between small patches dynamics and surrounding landscape patterns. Considering the ecological and economic relevance of small forest patches, a deeper understanding of their spatial arrangement may increase their "edge-effect", and enhance the ecosystem services' flow, thus counterbalancing the disservices coming from the agricultural intensification [84]. Further work should deal with the inventory of temporal and spatial changes in other patch metrics like shape, which might be equally important than size and density in assessing habitat quality and landscape ecosystem services. In conclusion, sustainable land management and conservation planning should (i) incorporate small forest patches and associated dynamics, into current intervention plans; (ii) balance biological conservation with other landscape services (e.g., small vs. large heaths; [85]); (iii) include effective landscape restoration actions [25]; and (iv) consider local knowledge, in combination with remote-sensing techniques, when assessing and mapping the historical landscape changes (e.g., participatory mapping; [45]). As at the basis of sustainability, the consideration of small elements in landscape planning indeed contributes to further understand the impacts of landscape complexity and the related slow processes of change for local wellbeing, otherwise neglected when looking at broader scales.

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Annex II

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ORIGINAL PAPER

Inference on forest attributes and ecological diversity of trees outside forest by a two-phase inventory

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Abstract

• ***Key message*** **Trees outside forests (TOF) have crucial ecological and social-economic roles in rural and urban contexts around the world. We demonstrate that a large-scale estimation strategy, based on a two-phase inventory approach, effectively supports the assessment of TOF's diversity and related climate change mitigation potential.**

• ***Context*** Although trees outside forest (TOF) affect the ecological quality and contribute to increase the social and economic developments at various scales, lack of data and difficulties to harmonize the known information currently limit their integration into national and global forest inventories.

• ***Aims*** This study aims to develop and test a large-scale estimation framework to assess ecological diversity and above-ground carbon stock of TOF.

• ***Methods*** This study adopts a two-phase inventory approach.

• ***Results*** In the surveyed territory (Molise region, Central Italy), all the attributes considered (tree abundance, basal area, wood volume, above-ground carbon stock) are concentrated in a few dominant species. Furthermore, carbon stock in TOF above-ground biomass is non-negligible (on average: 28.6 t ha^{-1}). Compared with the low field sampling effort (0.08% out of 52,796 TOF elements), resulting uncertainty of the estimators are more than satisfactory, especially those regarding the diversity index estimators (relative standard errors < 10%).

• ***Conclusion*** The proposed approach can be suitably applied on vast territories to support landscape planning and maximize ecosystem services balance from TOF.

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Contribution of the co-authors Marco Marchetti: research idea, revision of literature, and review of manuscript.
Vittorio Garfì: data collection, analysis of results, and writing of manuscript.
Caterina Pisani: methodological development and data analysis.
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Marzia Marcheselli: methodological development and data analysis.
Piermaria Corona: revision of literature and review of manuscript.
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Marco di Cristofaro: data collection and writing of manuscript.
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Keywords Diversity estimation · Tree inventory · Sampling · Field survey · Carbon stock · Molise region (Italy)

1 Introduction

Trees are the largest component of above-ground biomass in forest ecosystems. Although tree resources are mainly associated with the forest area, there is an extensive tree wealth outside continuous forested areas. In recent decades, the attention of trees outside forest (TOF) has risen. In general, TOF refer to trees growing on agricultural land, along road, railways, canals, orchards, parks, gardens, and homestead. According to FAO (2004), a TOF unit is a small group of trees not classified as forest, such as (i) groves with less than 5,000 m^2 area and a canopy cover ≥ 5% in case of only trees or ≥ 10% if trees are mixed with shrubs; (ii) "linear tree formations" (trees in roadside, shelterbelts, and riparian buffers) of less than 20-m width and minimum length equal to 25 m; and, also, (iii) scattered trees.

TOF are considered important landscape elements, as they provide fundamental ecosystem goods and services (hereinafter ecosystem services (ES)), and largely contribute to improve the well-being of local communities (de Foresta et al. 2013; Plieninger et al. 2012; Sadio and Negreros-Castillo 2006). They represent valuable sources of timber and non-timber products in rural areas. Furthermore, they contribute to climate change mitigation (carbon sequestration potential (CSP); Guo et al. 2014; Nair 2012; Nowak et al. 2013; Plieninger 2011; Schnell et al. 2015a; Singh and Chand 2012), absorb air pollutants in urban areas (Bottalico et al. 2017; Vos et al. 2013), improve water resources quality, protect against soil erosion (Lee et al. 2010; Ruhl et al. 2007; Ryszkowski and Kedziora 2007), and also dramatically improve biological diversity (Corona et al. 2011a). In developing countries, TOF represent important sources of wood available for local people, especially in those places where they are considered the primary wood resource (Ahmed 2008; Bellefontaine et al. 2002). In 2007, Smeets and Faaij estimated that two thirds of the wood fuel consumption in developing regions is supplied by TOF. The contribution to national woody biomass stock was highest for countries with a comparably low forest cover (Schnell et al. 2015b). For example, Schnell et al. (2015b), based on forest inventories conducted in 11 countries, reported that the national above-ground biomass ranges between 72.8% in Bangladesh and 3.3% in Zambia, where the total forest area covers about 8% and 64%, respectively, with average TOF biomass stocks of less than 10 t ha^{-1}.

Although they provide fundamental ES across the landscape, TOF have been and are being ignored for a long time by land management policies (de Foresta et al. 2013). The importance of TOF-associated functions was primarily and formally recognized in 1996, during the "FAO Expert Consultation on Global Forest Resources Assessment," held in Finland (Nyyssönen and Ahti 1996). During this event, the importance of collecting information on TOF, in order to evaluate their effective contribution to local and global well-being and to include them in the landscape planning, was strongly emphasized. Four years later, TOF were more precisely defined, and the scientific discussion about the inventory aspects to assess TOF was introduced (Sadio et al. 2001).

Over time, TOF were progressively included in several national forest monitoring systems (Schnell et al. 2015b), such as, e.g., national forest inventories (NFIs), especially to assess their CSP. Therefore, only in few cases (e.g., those inventories using the guidelines from FAO national forest monitoring and assessment (NFMA) program and the Indian NFI) the TOF-related characteristics are considered (Schnell et al. 2015b). The inclusion of TOF in national forest monitoring systems is important also with regards to the land use, land use change and forestry good practice guidance (LULUCF-GPG) of the Kyoto protocol (Schnell et al. 2015b). In particular, improving CSP of TOF in cultivated/arable lands may be a key planning priority (e.g., Mbow et al. 2014), especially considering the contribution of TOF in developing countries refers to approximately 70% of the total C storage for the agricultural sector (Smith and Wollenberg 2011). Moreover, many studies in developed countries (e.g., USA, Europe, Canada) highlighted that CSP from TOF in urban areas cannot be ignored, since they contribute to green infrastructures development (Calfapietra et al. 2015). Nevertheless, the contribution of TOF to climate change mitigation through C storage is not obvious mainly because of limited information regarding their extent and inadequate methods for biomass quantification (Kuyah et al. 2014). The very large population size makes any complete investigation prohibitive. Thus, the study of trees in "non-forest areas" through an inventory approach is very useful to quantify their ES provision, and in turn, to improve the integrated land management (Corona et al. 2009).

During the last two decades, most of the research on TOF focused on developing and implementing various inventory approaches. On the other hand, few TOF inventories have used the same methodology so far, using a variety of methodological approaches and data sources (Corona 2016; de Foresta et al. 2013; Kleinn 2000). Examples of large-scale TOF surveys performed by means of probabilistic sampling are Kenya (Holmgren et al. 1994), India (Tewari et al. 2013), Sweden (Fridman et al. 2014), France (Bélouard and Coulon 2002), and Switzerland (Price et al. 2017). Most surveys adopt classical two-phase sampling schemes, with aerial photos used in the first phase and field measurements in the second;

alternatively, Corona and Fattorini (2006) proposed a two-stage scheme for surveying tree rows. Interesting recent attempts to achieve well-behaved estimators of TOF attributes in the framework of multipurpose large-scale forest inventories are provided by Lister et al. (2009), Saket et al. (2010), and Baffetta et al. (2011).

The aim of this study was the development and testing of a large-area estimation framework, utilizing a two-phase inventory approach. Of prime interest was the assessment of ecological diversity and above-ground carbon stock. The proposed strategy is based on (i) a first-phase tessellation of the study area into regular polygons of equal size and the random allocation of one point per polygons, usually referred to as the tessellation stratified sampling (TSS); and (ii) a second-phase selection of the first-phase points by means of a stratified scheme usually referred to as one-per-stratum stratified sampling (OPSS) with the subsequent selection of those TOFs spotted by the second-phase points (point sampling). The strategy is not new and is quoted from some contributions of inventory literature. The statistical properties of TSS and their superiority with respect to other scheme for allocating first-phase points onto the study area have been investigated by Barabesi and Franceschi (2011) and Barabesi et al. (2012), while the second-phase strategy has been proposed and investigated by Fattorini et al. (2016, 2017). The study was conducted in the Molise region, an administrative district of 443,800 ha in central Italy. The relevance of the study is that the exploited estimation approach can be readily embedded in the two-phase sampling schemes adopted by most large-area forest surveys (e.g., national forest inventories), so that it can represent a suitable and practical tool to support landscape planning and maximize the ecosystem services balance from TOF over large scales.

2 Materials and methods

2.1 Study area

The Molise region is covered by 148,641 ha of forests and other wooded lands (33.5% of the regional surface) (www.sian.it/inventarioforestale/). The region is almost equally partitioned between mountain (55%) and hilly areas (44%) and well represents the Italian peninsula. The Adriatic coast, 40 km long, is intensively urbanized. The presence of dunes and fragile ecosystems makes the Molise coastland an important landscape, crucial for environmental resources (Foresta et al. 2016). The vast interface between forest and agricultural systems makes the area a representative example for analyzing transformations into natural and seminatural classes. The two administrative provinces (Campobasso and Isernia) have different landscape characteristics and dynamics. The province of Isernia lies partially within the Abruzzo, Lazio, and Molise National Park, including high mountainous areas such as the Matese and the Mainarde massifs. The province of Campobasso is generally hilly and located in the east, along the Adriatic Sea. It is considerably more affected by human impact, with a prevalence of intensive farming in the flattest area close to the coast and a high occurrence of natural grasslands and pastures in the inland (Sallustio et al. 2016).

2.2 Trees outside forest census

A TOF census was performed throughout the whole Molise region. The census started in 2008 and was completed in 2013. It was accomplished via GIS software and intensive visual onscreen interpretation of aerial orthophotos covering the entire study area by trained photo-interpreters, and subsequent field checks. The images were originally collected in 2000 to census agricultural crops over the entire Italian territory (IT2000 project, Compagnia Generale Riprese Aeree, Parma, Italy). Images had 1 m of geometric resolution and allowed the identification of small groups of trees. To unambiguously identify the units, a TOF unit was defined in accordance with the Italian national forest inventory (INFC 2005, available from www.sian.it/inventarioforestale/), i.e., a wooded land with an area between 500 and 5,000 m^2 or a tree row (shelterbelts, windbreaks, river galleries, and line features along property borders, roads, and railways) with no minimum width and not wider than 20 m (Baffetta et al. 2011). Each identified TOF unit was manually delineated onscreen (Fig. 1) and its size and centroid were derived. At the end of the census, a statistical population U of $N = 52{,}796$ TOF units was detected, for a total canopy cover of 7,733.2 ha, and an average size of 1,472 m^2 with coefficient of variation of 68% (Fattorini et al. 2016). In most cases, TOF units are groups of broadleaf deciduous trees within cropland and pastures or along rivers and water bodies.

2.3 Attributes of interest and diversity measures

Let L be the list of the tree species which were present in the population U and let K be the tree species richness. For each TOF unit $j \in \mathrm{U}$ and for each species $k \in \mathrm{L}$, the attributes of interest were the abundance (number of trees with diameter at breast height, 1.3 m off the ground—diameter at breast height (DBH)—greater than 5 cm), the basal area (cross-sectional area of the stem measured at breast height) (m^2), the volume (m^3), and the carbon storage (t). In the subsequent equations, these attributes are left unspecified and are generically denoted by y_{jk}. For each attribute, we focused on the totals by species

$$T_k = \sum_{j \in \mathrm{U}} y_{jk}, k \in \mathrm{L}$$

as well as on the overall total

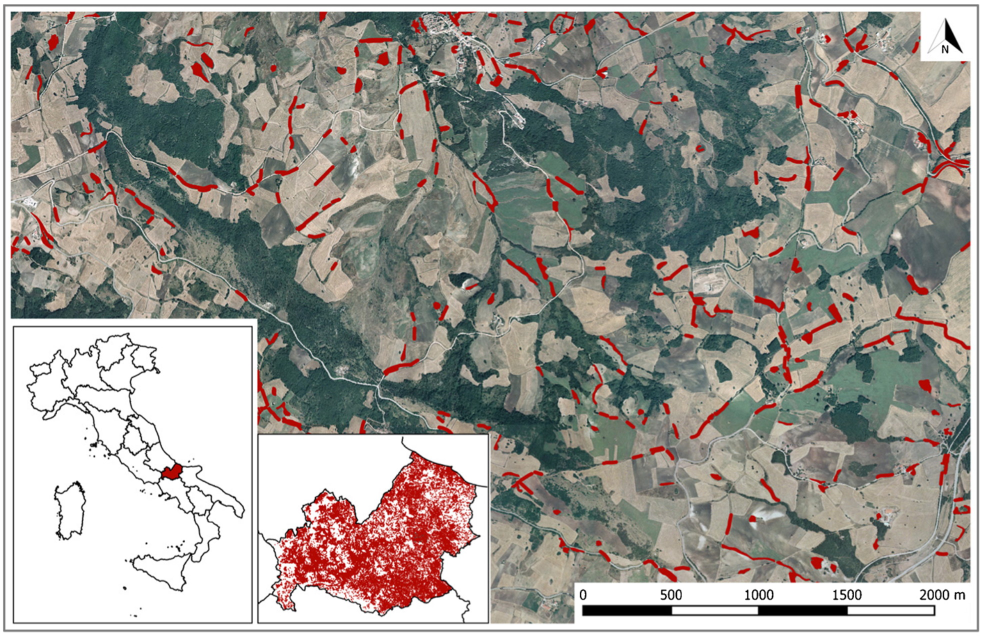

Fig. 1 An onscreen portion of the Molise region. Groups of trees classified as tree outside forest units are delineated in red. In the lower-left part, the entire collection of tree outside forest units delineated within the Molise region is reported. The position of Molise region within Italy is presented in the lower left part

$$T = \sum_{k \in L} T_k$$

To be short, it is convenient to denote by $\mathbf{T} = [T_1, \ldots, T_K]^t$ the K vector of these totals, from which $T = \mathbf{1}^t\mathbf{T}$ where $\mathbf{1}$ denotes the K vector of ones.

Any diversity measure we considered for analyzing the ecological diversity in terms of the four attributes was derived as a function of $\mathbf{T}$. We firstly considered the proportions of attributes by species

$$p_k = p_k(\mathbf{T}) = T_k/T, \quad k \in L$$

The ranking of proportions, from the smallest to the greatest, $p_{(1)} \leq \ldots \leq p_{(K)}$, where $p_{(k)}$ is the kth ranked proportion, provided a preliminary insight on the apportionment of the attribute among species. To achieve a clearer depicting of the apportionment, we considered the Lorenz curve, i.e., the plotting of

$$P_k = P_k(\mathbf{T}) = \sum_{h=1}^{k} p_{(h)}$$

vs $F_k = k/K$ for $k = 1, \ldots, K$. For each k, the Lorenz curve gave the proportion P_k of the attribute provided by the proportion F_k of the bottom species (Damgaard and Weiner 2000).

As indexes of ecological diversity, we used the concentration index, also referred to as the Gini coefficient, i.e., the proportion of the area between the Lorenz curve and the equal-apportionment line

$$\Delta_L = \Delta_L(\mathbf{T}) = 1 - \frac{2}{K-1} \sum_{k=1}^{K-1} P_k$$

The concentration index ranged from 0—in the case of an even apportionment of the attribute between species—to 1 when the attribute is provided by a sole species. We also considered the Shannon and Simpson diversity indexes (Jost 2006)

$$\Delta_{SH} = \Delta_{SH}(\mathbf{T}) = \sum_{k=1}^{K} p_k \ln \frac{1}{p_k}$$

and

$$\Delta_{SI} = \Delta_{SI}(\mathbf{T}) = 1 - \sum_{k=1}^{K} p_k^2$$

The Shannon and Simpson indexes range from 0 when the attributed is provided by a sole species, to $\ln K$ or $(K-1)/K$, respectively, in the case of an even apportionment of the attribute between species.

2.4 Sampling

A two-phase point sampling of the TOF population was devised. The sampling scheme has been chosen among those theoretically investigated by Fattorini et al. (2016). In the first phase (TSS), the Molise region was covered by a grid of $R =$ 4,693 hexagons of size 100 ha (Fig. 2), and a point was randomly selected within each hexagon. Because there is a one-to-one correspondence between points and hexagons, it is indifferent to refer to points or hexagons.

Then, to reduce the sampling effort, a sample Q of $n =$ 2,347 points/hexagons, corresponding to a sampling fraction of about 50%, was selected in a second phase by means of OPSS. The second phase was performed by partitioning the

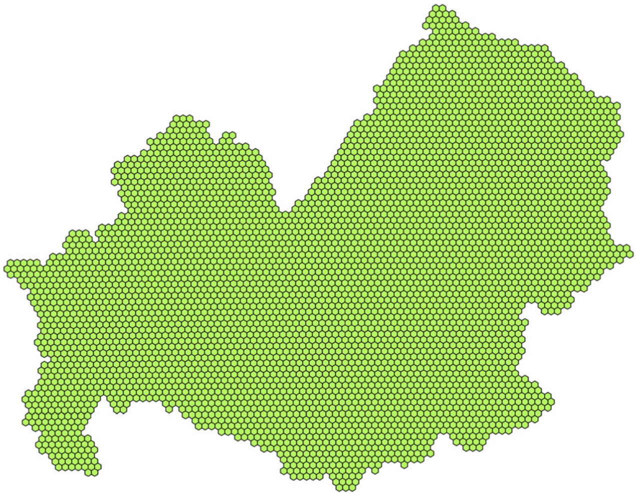

Fig. 2 The grid of 4,693 hexagons of size 1 ha adopted to cover the Molise region

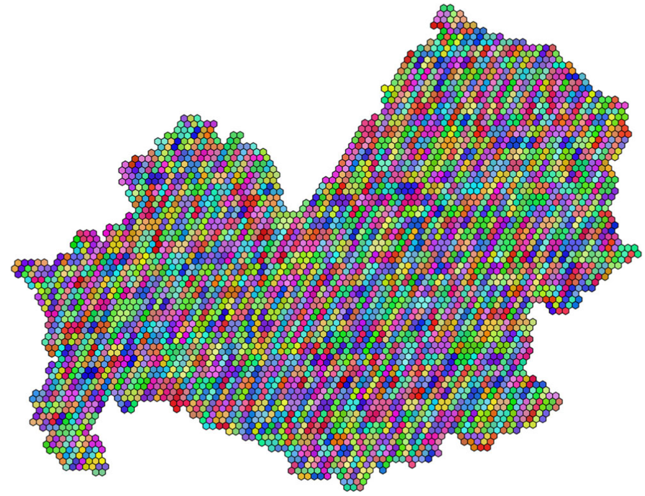

Fig. 3 The stratification of the grid covering the Molise region into blocks of two contiguous hexagons performed to achieve a second-phase sampling rate of 50%

grid into $n = 2{,}347$ blocks/strata: 2,346 blocks were formed by two contiguous hexagons, and one by only one hexagon (Fig. 3). Then, a hexagon/point was randomly selected from each block to constitute the second-phase sample Q of hexagons/points. Finally, in accordance with the point sampling protocol, all of the TOF units intercepted at least by one of these 2,347 points were sampled and visited on the ground (Fattorini et al. 2016, 2017).

Field survey was performed in 2015, from late May to middle September, by teams composed of PhDs or master students and at least one assistant researcher. For each TOF unit sampled by the second-phase points and for each species present in the units, the team recorded the number of trees, and for each tree, the stem diameter at breast height (DBH) and the stem total height were measured for determining the totals of basal area, wood volume, phytomass, and the above-ground carbon stock in the unit. Wood volume and phytomass of each tree were predicted by applying the equations from Tabacchi et al. (2011). Carbon data were obtained by multiplying the tree phytomass by the Intergovernmental Panel on Climate Change (IPCC) default carbon fraction of 0.475 (McGroddy et al. 2004).

2.5 Estimation

Under point sampling, the probability of selecting the TOF unit $j \in$ U was $\pi_j = a_j/A$ where a_j was the extent of the unit and A was the size of the sampling area onto which the point is randomly selected. In our case, the sampling area was the grid of the 4,693 hexagons covering the Molise region, so that $A = 469{,}300$ ha. Only one TOF unit can be selected by the point randomly located within the hexagon $i \in$Q. Therefore, the sample selected from the second-phase point $i \in$Q was constituted by a sole unit, say $j(i)$, or it was empty.

If the point $i \in$Q selected the TOF unit $j(i)$, we computed the Horvitz-Thompson (HT) estimate of T_k

$$\hat{T}_{kj(i)} = A\,\frac{y_{j(i)k}}{a_{j(i)}}$$

where $y_{j(i)k}$ was the amount of the ground-measured tree attribute. On the other hand, if no TOF unit was selected from the second-phase point $i \in$Q, as observed from the air photos: the point was neglected and $\hat{T}_{ki}$ was set to 0 without field work. Obviously $\hat{T}_{ki}$ was set to 0 also when a TOF unit was selected but the species k was missing in the units.

We computed the estimates $\hat{T}_{ki}$ for each $i \in$Q. Then, in accordance with Fattorini et al. (2017, Eq. 2) we computed to the two-phase estimate of T_k

$$\hat{T}_{k(R)} = \frac{1}{R}\sum_{l=1}^{n} R_l \hat{T}_{ki(l)}$$

where $i(l)$ was the label of the point/hexagon randomly selected within the block l and R_l was the number of contiguous hexagons in the block. If a species was not present in the TOF units selected by the two-phase point sampling, the species was lost and $\hat{T}_{k(R)}$ resulted to be 0. Otherwise, $\hat{T}_{k(R)}$ resulted to be a positive value for any detected species, i.e., for any $k \in \mathrm{L}_0$, where $\mathrm{L}_0 \subset \mathrm{L}$ was the set of species which was present in at least one of the TOF units intercepted by the second-phase points and $K_0 \leq K$ was the number of detected species. To be short, it is convenient to denote by $\hat{\mathbf{T}}_{(R)} = \left[\hat{T}_{1(R)}, \ldots, T_{K(R)}\right]^t$ the K vector of the estimates of the totals of $\mathbf{T}$. Therefore, $\hat{\mathbf{T}}_{(R)}$ contained an unknown number of 0 s in correspondence to any lost species.

In accordance with Fattorini et al. (2017, p. 198), the variance-covariance matrix of $\hat{\mathbf{T}}_{(R)}$ was estimated by the matrix $\mathbf{V}_{(R)}$whose element k,h was given by

Table 1 List of the 60 tree species detected in the TOF of the Molise region. The detected species are partitioned into four classes in accordance with their preeminent function

Preeminent function	Tree species
1 - Food production	Marasca sour cherry (*Prunus cerasus* L. var. *marasca* (Host.) Viv.); sweet chestnut (*Castanea sativa* Mill.); sweet cherry (*Prunus avium* L.); common fig (*Ficus carica* L.); white mulberry (*Morus alba* L.); kiwi (*Actinidia deliciosa* (A. Chev.) C.F. Liang & A.R. Ferguson); almond (*Prunus dulcis* (Mill.) D.A. Webb); apple tree (*Malus* spp.); common hazel (*Corylus avellana* L.); olive (*Olea europea* L.); common pear (*Pyrus communis* L.); peach (*Prunus persica* (L.) Batsch); stone pine (*Pinus pinea* L.); service tree (*Sorbus domestica* L.); plum (*Prunus domestica* L.); black elderberry (*Sambucus nigra* L.); Morello cherry (*Prunus cerasus* L. var. *austere* L.)
2 - Nature conservation	Field maple (*Acer campestre* L.); common holly (*Ilex aquifolium* L.); common hawthorn (*Crataegus monogyna* Jacq.); dogwood (*Cornus mas* L.); european spindle (*Euonymus europaeus* L.); mastic tree (*Pistacia lentiscus* L.); common laburnum (*Laburnum anagyroides* Medik.); Christ's thorn (*Paliurus spina-christi* Mill.); crab apple (*Malus sylvestris* Mill.); rosebay (*Nerium oleander* L.); wild pear (*Pyrus pyraster* (L.) Burgsd.); eurasian aspen (*Populus tremula* L.); blackthorn (*Prunus spinose* L.); purple willow (*Salix purpurea* L.); goat willow (*Salix caprea* L.); laurustinus (*Viburnum tinus* L.)
3 - Wood production	Nettle tree (*Celtis australis* L.); oriental hornbeam (*Carpinus orientalis* Mill.); common hornbeam (*Carpinus betulus* L.); Turkey oak (*Quercus cerris* L.); european beech (*Fagus sylvatica* L.); holm oak (*Quercus ilex* L.); field elm (*Ulmus minor* Mill.); black alder (*Alnus glutinosa* (L.) Gaertn.); manna ash (*Fraxinus ornus* L.); Aleppo pine (*Pinus halepensis* Mill.); maritime pine (*Pinus pinaster* Aiton); white poplar (*Populus alba* L.); black poplar (*Populus nigra* L.); oriental plane (*Platanus orientalis* L.); black locust (*Robinia pseudoacacia* L.); Arizona cypress (*Cupressus arizonica* Greene); tree of heaven (*Ailanthus altissima* (Mill.) Swingle); arborvitae (*Thuja* spp.); downy oak (*Quercus pubescens* Willd.); white willow (*Salix alba* L.)
4 - Valuable timber production	Sycamore maple (*Acer pseudoplatanus* L.); Italian maple (*Acer opalus* Mill.); English oak (*Quercus robur* L.); common ash (*Fraxinus excelsior* L.); wild service tree (*Sorbus torminalis* L.); narrow-leaved ash (*Fraxinus angustifolia* Vahl); common walnut (*Juglans regia* L.)

$$v_{kh(R)} = \frac{1}{n(R-1)}\left[\sum_{l=1}^{n} R_l \hat{T}_{i(l)k}\hat{T}_{i(l)h} - R\hat{T}_{k(R)}\hat{T}_{h(R)}\right], \quad k,h\in \mathrm{L}$$

Once the vector $\mathbf{T}$ was estimated by $\hat{\mathbf{T}}_{(R)}$, we performed the estimation of any quantity derived from $\mathbf{T}$ by means of the plug-in criterion, as suggested by Fattorini et al. (2017, p. 4). Therefore, we estimated the overall total by

$$\hat{T}_{(R)} = \mathbf{1}^t\hat{\mathbf{T}}_{(R)}$$

the proportions of attributes by species by

$$\hat{p}_{k(R)} = p_k\left(\hat{\mathbf{T}}_{(R)}\right) = \hat{T}_{k(R)}/\hat{T}_{(R)}, \qquad k\in L$$

the Lorenz curve by plotting

$$\hat{P}_{k(R)} = P_k\left(\hat{\mathbf{T}}_{(R)}\right) = \sum_{h=1}^{k}\hat{p}_{(h)(R)}$$

vs $F_{0k} = k/K_0$ for $k = 1, \ldots, K_0$, the concentration index by

$$\hat{\Delta}_{\mathrm{L}(R)} = \Delta_{\mathrm{L}}\left(\hat{\mathbf{T}}_{(R)}\right) = 1 - \frac{2}{K_0-1}\sum_{k=1}^{K_0-1}\hat{P}_{k(R)}$$

and the Shannon and Simpson diversity indexes by

$$\hat{\Delta}_{\mathrm{SH}(R)} = \Delta_{\mathrm{SH}}\left(\hat{\mathbf{T}}_{(R)}\right) = \sum_{k=1}^{K}\hat{p}_{k(R)}\ln\frac{1}{\hat{p}_{k(R)}}$$

and

$$\hat{\Delta}_{\mathrm{SI}(R)} = \Delta_{\mathrm{SI}}\left(\hat{\mathbf{T}}_{(R)}\right) = 1 - \sum_{k=1}^{K}\hat{p}^2_{k(R)}$$

We finally estimated the sampling variances of the plug-in estimators by exploiting the matrix $\mathbf{V}_{(R)}$ as suggested by Fattorini et al. (2017, p. 4), i.e., the variance estimate of $\hat{T}_{(R)}$ was simply $v^2_{(R)} = \mathbf{1}^t\mathbf{V}_{(R)}\mathbf{1}$ while for the remaining non linear functions of $\hat{\mathbf{T}}_{(R)}$, the variance estimates were

$$v^2_{(R)} = \hat{\mathbf{d}}^t\mathbf{V}_{(R)}\hat{\mathbf{d}}$$

where the vector $\hat{\mathbf{d}}$ was the gradient of the functions p_k, P_k, Δ_{L}, Δ_{SH}, and Δ_{SI} at $\hat{\mathbf{T}}_{(R)}$. Once the variance estimates were achieved, we estimated standard errors by square roots of the variance estimates and the relative standard errors (RSE) by square roots divided by the resulting estimates. The 95%

Table 2 Estimates of abundances and their percentages and of the relative standard errors for the tree species detected in the TOF of the Molise region. Species are listed in decreasing order of abundance

Species	Abundance	RSE %	Abundance %	RSE %
Downy oak	1,067,453.40	29.27	20.83	25.07
Turkey oak	694,949.41	51.75	13.56	41.65
Field elm	683,408.13	27.66	13.34	24.59
Field maple	434,156.46	35.55	8.47	26.68
White willow	320,897.67	43.84	6.26	37.71
Tree of heaven	145,062.88	90.57	2.83	89.61
Common hawthorn	142,854.53	59.96	2.79	59.17
Manna ash	131,603.19	72.37	2.57	63.74
Black locust	129,487.82	70.45	2.53	63.15
Olive	106,275.62	57.49	2.07	56.26
Crab apple	96,318.64	49.17	1.88	49.33
Common holly	95,684.85	99.98	1.87	98.50
Wild pear	94,738.17	49.58	1.85	42.38
Black elderberry	91,774.76	86.35	1.79	83.67
Goat willow	77,503.00	72.21	1.51	70.49
Black poplar	76,348.63	52.26	1.49	49.64
Common walnut	75,570.33	65.65	1.47	65.99
White poplar	73,840.91	65.23	1.44	65.87
Sweet cherry	62,204.58	45.56	1.21	43.66
Laurustinus	55,151.29	99.98	1.08	98.82
Plum	50,464.63	80.69	0.98	80.69
European beech	49,009.31	99.98	0.96	98.50
Common fig	45,939.74	37.02	0.90	36.94
Blackthorn	37,456.87	62.60	0.73	60.11
Mastic tree	34,214.51	99.98	0.67	100.46
Common ash	29,341.35	99.98	0.57	100.40
Almond	24,992.54	51.61	0.49	51.85
European spindle	23,208.62	84.44	0.45	78.31
Purple willow	23,169.20	72.39	0.45	69.76
Common hazel	20,312.79	52.58	0.40	50.54
English oak	17,484.09	99.98	0.34	101.58
Common hornbeam	14,879.29	90.50	0.29	89.02
Service tree	12,347.58	59.43	0.24	53.06
Wild service tree	11,101.97	99.98	0.22	93.65
Oriental plane	6,663.72	99.98	0.13	101.73
Dogwood	6,121.93	70.99	0.12	65.64
Black alder	6,086.41	99.98	0.12	101.32
Sweet chestnut	5,759.65	99.98	0.11	99.99
Nettle tree	5,735.34	99.98	0.11	100.46
Apple tree	4,217.72	58.70	0.08	58.30
Maritime pine	4,121.14	99.98	0.08	101.40
Common laburnum	3,887.42	99.98	0.08	98.05
Arborvitae	3,268.57	79.97	0.06	82.04
Eurasian aspen	2,918.74	99.98	0.06	100.85
Arizona cypress	2,577.27	72.09	0.05	70.63
Sycamore maple	2,490.29	99.98	0.05	101.05
Oriental hornbeam	2,294.14	99.98	0.04	100.46
Narrow-leaved ash	2,060.57	99.98	0.04	101.40
Morello cherry	1,945.83	99.98	0.04	100.85

Table 2 (continued)

Species	Abundance	RSE %	Abundance %	RSE %
Aleppo pine	1,943.71	99.98	0.04	98.05
Christ's thorn	1,850.48	99.98	0.04	99.73
Rosebay	1,665.93	99.98	0.03	101.73
Marasca sour cherry	1,546.98	99.98	0.03	97.26
Stone pine	1,484.66	99.98	0.03	101.64
White mulberry	1,484.66	99.98	0.03	101.64
Common pear	1,333.54	74.30	0.03	71.57
Peach	901.31	99.98	0.02	100.43
Holm oak	832.97	99.98	0.02	101.73
Italian maple	627.67	99.98	0.01	100.11
Kiwi	450.66	99.98	0.01	100.43

confidence intervals were achieved presuming approximately normal distributions of the estimators, i.e., by the estimates plus and minus two times the standard error estimates.

While the estimation of p_k, Δ_{SH}, and Δ_{SI} did not necessitate the knowledge of the species richness K, the inference on Lorenz curve and concentration index necessitated the knowledge of K which was substituted by the number of detected species K_0. While the gradient of p_k, Δ_{SH}, and Δ_{SI} always existed, the gradients of P_k and Δ_L necessitated that the T_ks were all distinct (Fattorini and Marcheselli 1999), a conditions very likely to occur in real cases.

Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

3 Results

At the end of the sampling procedure, we sampled 45 TOF units which were visited on the ground to record the target attributes. A total of $K_0 = 60$ tree species were detected (Table 1). Tables 2, 3, and 4 report the estimates of tree abundance, wood volume, and carbon stock by species listed in decreasing order.

The orderings of tree species in accordance with the four attributes are similar. Downy oak (*Quercus pubescens* Willd.) is the tree species with the greatest abundance estimate (1,067,453 individuals; proportion 21%). Downy oak is the most abundant also in terms of basal area (33,431 m^2; proportion 30%), wood volume (198,790 m^3; proportion 34%), and above-ground carbon stock estimates (82,482 t; proportion 37%). Turkey oak (*Quercus cerris* L.) is ranked as second with respect to all the considered attributes, with an abundance estimate of 694,949 individuals (proportion 14%), basal area of 12,958 m^2 (proportion 12%), volume estimate of 65,772 m^3 (proportion 11%), and carbon stock estimate of 26,749 t (proportion 12%). The species ranked third is field elm (*Ulmus minor* Mill.), in terms of tree abundance, and white willow (*Salix alba* L.) in terms of basal area, wood volume, and above-ground carbon stock. The TOF community shows a list of 40 species out to 60 detected tree species with relative abundance estimates smaller than 1% and 21 species with relative abundance estimates smaller than 0.1%. Similar results are achieved in terms of basal area, volume, and carbon stocks.

Table 5 reports the overall estimates by attributes. The tree abundance provided by the TOF units throughout the whole Molise region is estimated to consist of 5,123,478 individuals (RSE = 20%) with a density of 662.5 trees ha^{-1}, the total wood volume is estimated to be 589,261 m^3 (RSE = 20%) with an average wood volume of 76.2 m^3 ha^{-1}, and the total amount of carbon is estimated to be 221,047 t (RSE = 19%) with an average carbon stock of 28.6 t ha^{-1}.

Table 6 reports the estimates of the Lorenz curve ordinates by attributes, for fractions of detected tree species ranging from 10 to 90% by steps of 10%. The same curves are plotted in Figs. 4, 5, and 6 together with the corresponding confidence intervals. In terms of abundance, the 90% of the least abundant tree species (54) shares the 35% of the individuals, the remaining 65% of individuals being shared by the 10% of the most abundant species (6). A more marked concentration is evidenced in terms of the other considered attributes. The fraction of wood volume due to the bottom 90% of species is estimated to be 26%, while the fraction in terms of carbon stock is estimated to be 27%.

Table 7 reports the estimates of the diversity indexes. The concentration index estimate is 0.78 for tree abundance (RSE = 3%) and increases to 0.85 for both wood volume and carbon stock (RSE = 2% and 3%, respectively). The Shannon index estimate is 2.86 for tree abundance (RSE = 5%) and decreases to 2.50 and 2.46 for wood volume and carbon stock (RSE = 6% and 7%, respectively). The Simpson index estimate is 0.90 for tree abundance (RSE = 2%) and decreases

Table 3 Estimates of wood volumes and their proportions and of the relative standard errors for the tree species detected in the TOF of the Molise region. Species are listed in decreasing order of volume (m^3)

Species	Volume	RSE %	Volume %	RSE %
Downy oak	198,790.43	29.74	33.74	23.77
Turkey oak	65,772.34	43.57	11.16	40.16
White willow	59,571.70	59.43	10.11	51.80
Black poplar	41,596.48	53.57	7.06	47.17
English oak	37,848.90	99.98	6.42	95.42
Oriental plane	34,094.58	99.98	5.79	95.90
Field elm	20,725.08	31.21	3.52	28.82
Field maple	17,848.37	38.96	3.03	36.72
White poplar	17,100.62	64.10	2.90	64.70
Olive	9,058.56	62.33	1.54	63.57
Common walnut	8,806.12	53.01	1.49	54.29
European beech	8,703.96	99.98	1.48	99.53
Sweet cherry	6,745.18	54.69	1.14	54.58
Common ash	6,234.13	99.98	1.06	100.67
Tree of heaven	6,112.38	91.75	1.04	91.84
Black locust	5,753.95	61.24	0.98	58.85
Goat willow	5,679.03	78.52	0.96	70.94
Common holly	4,440.34	99.98	0.75	99.53
Stone pine	4,148.71	99.98	0.70	101.15
Manna ash	3,487.66	66.53	0.59	62.91
Crab apple	3,089.36	55.75	0.52	56.78
Almond	2,908.17	78.44	0.49	79.28
Wild pear	2,491.56	54.76	0.42	48.77
Common hawthorn	2,262.77	55.38	0.38	56.32
Plum	1,942.47	86.06	0.33	86.90
Common fig	1,899.64	43.18	0.32	45.10
Maritime pine	1,752.13	99.98	0.30	101.37
Black elderberry	1,505.23	86.58	0.26	83.90
Laurustinus	1,213.27	99.98	0.21	96.62
Holm oak	1,178.00	99.98	0.20	95.90
Eurasian aspen	842.85	99.98	0.14	101.65
Black alder	764.67	99.98	0.13	100.50
Arizona cypress	550.93	71.29	0.09	69.99
Mastic tree	528.92	99.98	0.09	101.63
Sweet chestnut	397.75	99.98	0.07	100.81
Blackthorn	368.82	60.35	0.06	60.95
Service tree	350.46	72.57	0.06	71.55
Common hornbeam	341.47	92.92	0.06	91.71
Purple willow	337.46	73.84	0.06	66.50
Common hazel	297.60	53.43	0.05	52.89
Common pear	233.89	90.64	0.04	90.56
Wild service tree	218.14	99.98	0.04	99.12
Arborvitae	212.42	94.25	0.04	90.18
European spindle	204.25	85.55	0.03	84.98
Sycamore maple	141.90	99.98	0.02	100.43
Apple tree	133.65	58.86	0.02	59.64
White mulberry	112.04	99.98	0.02	101.15
Italian maple	111.99	99.98	0.02	100.68
Nettle tree	88.60	99.98	0.02	101.15
Dogwood	74.74	77.66	0.01	76.10
Aleppo pine	45.86	99.98	0.01	100.84
Common laburnum	29.42	99.98	0.00	100.84
Narrow-leaved ash	22.23	99.98	0.00	101.37
Christ's thorn	20.75	99.98	0.00	100.72
Rosebay	18.98	99.98	0.00	95.90
Marasca sour cherry	17.58	99.98	0.00	97.24
Morello cherry	14.08	99.98	0.00	101.65
Oriental hornbeam	8.19	99.98	0.00	101.15
Peach	6.63	99.98	0.00	101.49
Kiwi	3.56	99.98	0.00	101.49

to 0.85 and 0.83 for wood volume and carbon stock (RSE = 5% and 6%, respectively).

The RSE estimates are in general higher than 20% for all the estimates with the exception of the overall total estimates that show RSE values slightly below 20% and the diversity index estimates that show RSE values invariably below 10%.

4 Discussion

From the methodological point of view, the large size of the considered TOF population makes a complete field census prohibitive. The sampling strategy here adopted has been chosen among those tested by Fattorini et al. (2016) by a large simulation study, as the one ensuring a low encounter rate of about 50 TOF units (out of more than 50,000 units) so that not more than 100 days (from late May to middle September) would be needed to complete the field survey. Alternative schemes, such as a plot sampling in which the selected field units are those intercepted by a plot of fixed radius, would have led to the practically unfeasible selection of hundreds of TOF units. Therefore, the small sampling effort of 45 TOF units—reflected in some high RSE estimates—has been an unavoidable compromise between available resources and estimation efficiency.

It is worth noting that the proposed strategy does not necessitate a complete list of the TOF units in the study region. Only the sample of second-phase points is necessary to determine the TOF units spotted by those points, to be subsequently surveyed in the field. The whole collection of TOFs in Molise region was just exploited to perform a simulation in a real large-scale situation (Fattorini et al. 2016).

Compared with the very low sampling effort of about 0.08%, the resulting RSE estimates are satisfactory, especially those regarding the overall totals of the considered attributes

Table 4 Estimates of above-ground carbon stocks and their percentages and of the relative standard errors for the tree species detected in the TOF of the Molise region. Species are listed in decreasing order of carbon stock (t)

Species	Carbon	RSE %	Carbon %	RSE %
Downy oak	82,481.75	29.26	37.31	21.36
Turkey oak	26,749.09	43.61	12.10	38.91
White willow	17,789.77	56.52	8.05	51.43
English oak	15,287.41	99.98	6.92	94.78
Black poplar	10,628.84	52.71	4.81	48.76
Field elm	9,119.41	30.74	4.13	27.19
Field maple	7,487.02	38.22	3.39	34.80
Oriental plane	7,366.14	99.98	3.33	98.21
White poplar	5,013.61	64.36	2.27	65.16
Olive	4,056.52	59.35	1.84	60.14
European beech	3,461.75	99.98	1.57	99.07
Black locust	2,801.66	62.41	1.27	59.83
Common walnut	2,795.24	51.04	1.26	52.61
Common ash	2,659.66	99.98	1.20	100.37
Sweet cherry	2,449.94	52.26	1.11	52.22
Tree of heaven	2,443.01	91.47	1.11	91.28
Common holly	2,084.24	99.98	0.94	99.07
Goat willow	1,937.74	77.00	0.88	71.77
Crab apple	1,641.76	57.21	0.74	57.75
Manna ash	1,619.43	66.81	0.73	62.26
Stone pine	1,270.78	99.98	0.57	101.13
Wild pear	1,112.72	53.10	0.50	48.75
Common hawthorn	1,004.85	56.17	0.45	56.96
Almond	983.42	69.73	0.44	70.45
Plum	940.12	84.66	0.43	85.21
Common fig	882.96	42.30	0.40	43.94
Black elderberry	699.45	87.02	0.32	85.14
Holm oak	630.29	99.98	0.29	98.21
Laurustinus	551.74	99.98	0.25	96.16
Maritime pine	476.65	99.98	0.22	101.26
Eurasian aspen	257.51	99.98	0.12	101.53
Mastic tree	252.04	99.98	0.11	101.37
Arizona cypress	223.82	71.37	0.10	70.61
Purple willow	210.84	72.14	0.10	67.00
Service tree	174.86	73.52	0.08	71.57
Black alder	166.11	99.98	0.08	100.80
Common hornbeam	165.48	92.43	0.07	90.70
Blackthorn	144.24	59.28	0.07	59.42
Sweet chestnut	134.88	99.98	0.06	100.60
Common hazel	132.31	53.57	0.06	52.82
Wild service tree	112.04	99.98	0.05	98.40
Arborvitae	105.34	90.93	0.05	89.15
Common pear	86.45	87.47	0.04	86.97
Apple tree	77.04	58.75	0.03	58.96
European spindle	73.54	86.85	0.03	85.49
Sycamore maple	57.00	99.98	0.03	100.71
White mulberry	51.56	99.98	0.02	101.13
Nettle tree	43.07	99.98	0.02	100.92
Italian maple	41.47	99.98	0.02	100.44
Dogwood	32.42	84.05	0.01	81.90
Aleppo pine	12.77	99.98	0.01	100.42
Narrow-leaved ash	11.72	99.98	0.01	101.26
Marasca sour cherry	10.01	99.98	0.00	98.04
Christ's thorn	8.92	99.98	0.00	100.43
Common laburnum	8.85	99.98	0.00	100.42
Oriental hornbeam	8.24	99.98	0.00	100.92
Rosebay	8.03	99.98	0.00	98.21
Morello cherry	5.48	99.98	0.00	101.53
Peach	2.63	99.98	0.00	101.29
Kiwi	1.12	99.98	0.00	101.29

and the diversity index estimators. This is due to the spatial balance ensured by the two-phase sampling scheme in which, in the first phase (TSS), the sample points have been evenly spread over the region, one per hexagon, and TOF are selected mostly proportional to the target variables, and in the second phase (OPSS) in which the first-phase points have been evenly sampled, one per block of contiguous hexagons. On this topic, it is worth noting that the use of polygonal grids to ensure an even layout of the sampling sites across the landscape is not only highly recommended, but is considered quite mandatory to provide statistical soundness of NFIs and REDD+ project surveys (Corona et al. 2011b).

Moreover, two-phase strategies such as that here adopted in the Molise region for surveying TOF, can benefit from the powerful machinery of national forest inventories. Indeed, TSS is becoming increasingly popular in the forest inventory scenario, and Italian and USDA forest services currently adopt TSS for their national forest inventories (Fattorini et al. 2006; Tomppo et al. 2010). Therefore, the first phase of the proposed strategy can coincide with the first phases performed in national forest inventories, differing from the traditional inventories devoted to forest resources only in the second phase.

Table 5 Total estimates of tree abundance, basal area, wood volume, and above-ground carbon stock and of the relative standard error for the TOF of the Molise region

Attribute	Total estimate	Per hectare	RSE %
Abundance (trees)	5,123,478.1	662.5	19.76
Basal area (m^2)	112,154.7	14.5	18.54
Volume (m^3)	589,260.9	76.2	19.92
Carbon (t)	221,046.8	28.6	19.34

Table 6 Estimates of the Lorenz curve ordinates related to tree abundance, wood volume, and above-ground carbon stocks corresponding to percentages of bottom species ranging from 10 to 90% and estimates of the relative standard errors for the trees outside forest in the whole Molise region surveyed in Spring 2015

Percent of species	Abundance		Volume		Carbon	
	%	RSE %	%	RSE %	%	RSE %
10	0.11	48.74	0.01	44.27	0.02	47.12
20	0.31	35.76	0.06	40.95	0.07	38.15
30	0.62	32.81	0.21	30.01	0.24	29.49
40	1.20	29.90	0.52	27.61	0.60	25.74
50	2.54	27.46	1.10	26.22	1.19	24.28
60	5.57	22.49	2.71	27.13	3.08	26.99
70	11.43	20.14	5.83	22.34	6.53	20.57
80	20.99	19.07	11.77	20.50	13.03	21.01
90	34.69	13.39	25.72	18.13	26.69	20.27
100	100.00	0.00	100.00	0.00	100.00	0.00

Finally, consistency and ease of implementation of these two-phase strategies has been recently proven by Fattorini et al. (2017) and Pagliarella et al. (2016), adding further statistical validity to these two-phase strategies: if consistency holds, the sampling distributions of the resulting estimators can be considered tightly concentrated around the true values when the spatial grain of grids is sufficiently small or the study area is sufficiently large. Owing to the considerable size of the Molise region and to the relative small grain of the hexagons here adopted we may trust on the estimates achieved by our study.

From the ecological point of view, the obtained information highlights a relevant concentration of all the four considered TOF attributes to few dominant tree species. The Lorenz curve estimates highly deviate from the equal-apportionment line and the concentration index estimates are near to one. Concentration is more marked in terms of wood volume and above-ground carbon stock with respect to tree abundance and basal area. However, the presence of dominant species, that should entail a poor ecological diversity, should be mitigated by the presence of many rare species that, in accordance with Patil and Taillie (1982), tend to increase diversity. This fact should be revealed by the Shannon and Simpson diversity index estimates. However, these index estimates have poor sense if not compared with their maxima achieved in the most diverse situation. In order to have a clear indexing of the ecological diversity, the standardized version of these indexes should be considered by dividing the index estimates by their maxima. Unfortunately, in both cases, the knowledge of maxima entails the knowledge of the species richness *K*, which is an unknown quantity. However, it is important to note that 60 tree species is a very significant figure. In fact, Italian forests are primarily made by 20 tree species out of a total number of the 45 species that represent more of the 90% of the total biomass (www.sian.it/inventarioforestale/). Moreover, the vascular flora native to Italy consists of about 7000 species, and trees are only few units, including several “tree like” flora elements. In fact, 188 species and intraspecific taxa have been recognized (Raimondo 2013). This total number is highly diversified and enriched by woody polistemmed or shrubby species that, growing in special conditions, could reach a tree-like size. Genetic expressions of classic tree-like species, variously treated from the taxonomical point of view, have also been added. Therefore, the surveyed number here taken into account reveals the high amount of dendroflora diversity in the TOF in the Molise region.

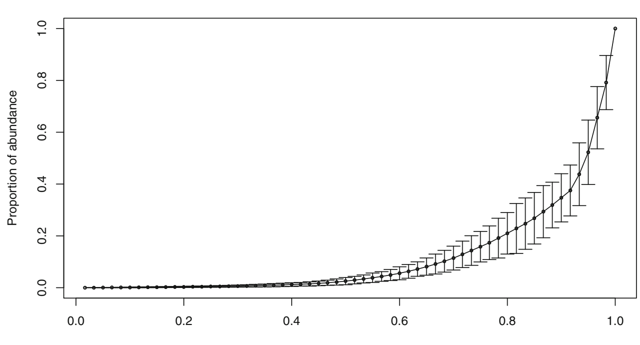

Fig. 4 Plot of the Lorenz curve estimated from tree abundances and of the 95% confidence band for the TOF of the Molise region

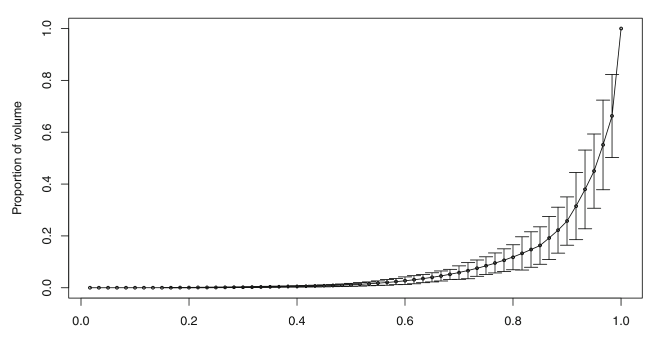

Fig. 5 Plot of the Lorenz curve estimated from wood volumes and of the 95% confidence band for the TOF of the Molise region

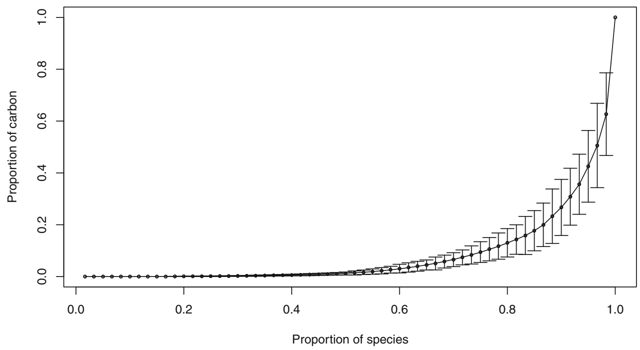

Fig. 6 Plot of the Lorenz curve estimated from above-ground carbon stocks and of the 95% confidence band for the TOF of the Molise region

Dividing the Shannon and Simpson diversity index estimates by ln 60 and 59/60, respectively, the estimate of the standardized Shannon index results of 0.70 for tree abundance, decreases to 0.66 for basal area and to 0.61 and 0.60 for wood volume and carbon stock, while the estimate of the Simpson index results of 0.92 for tree abundance, decreases to 0.88 for basal area and to 0.86 and 0.84 for wood volume and carbon stock. Almost nothing will change if the tree species richness is cautiously presumed to be 70. In this case, the standardized Shannon index estimates range from 0.67 to 0.58 while the standardized Simpson index estimates remain practically unchanged. The insensitive behavior of these indexes—especially the Simpson indexes—to the variation of species richness can be explained by the fact that, as apparent from the Lorenz curves of Figs. 4, 5, and 6, the species-abundance distribution seems quite close to the Fisher log-series model. In this case, when the number of species is greater than 10, the Simpson index is insensitive to increases in species richness (e.g., Magurran 2003). Besides this fact, the Simpson index evidences a high level of ecological diversity, while the Shannon index ranges the TOF population as a community of quite intermediate diversity. This is not surprising because it is well known that different diversity indexes may provide different rankings for the same communities (Hurlbert 1971). Results are also consistent with those achieved by the Lorenz curves, i.e., diversity is more marked (and dominance less marked), in terms of tree abundance, while it decreases if measured in term of basal area, volume, and carbon stock.

Regarding the latter figure, TOF contribution is not negligible, amounting to 28.6 t ha^{-1}, more than half the average of forests at both regional and national levels (42.3 and 47.2 t ha^{-1}, respectively: see INFC 2005, www.sian.it/inventarioforestale/).

5 Conclusion

TOF represent distinctive elements of rural and urban areas around the world, affecting the quality of landscapes and playing a multi-functional role in increasing the ecological, social and economic development at both global and local scales. However, the characteristics and dynamics of trees on farmlands are poorly known (Shvidenko et al. 2005). According to FAO (2010), one of the major reasons is the methodological problems posed by TOF assessment over large territories: a fundamental problem is the physical configuration of TOF that makes challenging to assess them with high precision; moreover, compared to forests, such tree formations have very high variability in both abundance and spatial composition.

This study, based on a two-phase inventory framework (Fattorini et al. 2016), has allowed the selection of a sample of 45 (0.08%) out of 52,796 TOF elements, in which TOF attributes were collected and analyzed. The approach provides reliable estimates of ecological diversity and above-ground carbon stock of TOF. Compared with the very low sampling effort, the resulting RSE estimates are more than satisfactory, especially those regarding the overall totals and the diversity estimators.

The results show that all the four considered attributes (tree abundance, basal area, wood volume, above-ground carbon stocks) are concentrated in few dominant tree species: downy oak, Turkey oak, field elm, and white willow. Furthermore, it was found that the carbon stock in the above-ground mass of TOF is not negligible (on average 28.6 t ha^{-1}), and the carbon stored in the TOF is going to increase in the next few years because of their further territorial expansion, arising from EU's common agricultural policy and the increasing role of the Ecological Focus Areas in the farms.

Table 7 Estimates of the concentration index and of the Shannon and Simpson diversity indexes related to tree abundance, wood volume, and above-ground carbon stocks and estimates of the relative standard errors for the TOF of the Molise region

Attribute	Concentration index	RSE %	Shannon index	RSE %	Simpson index	RSE %
Abundance	0.78	3.37	2.86	4.50	0.90	1.98
Volume	0.85	2.25	2.50	6.26	0.85	5.04
Carbon	0.85	2.53	2.46	7.35	0.83	6.01

This work allowed to assess a considerable amount of resources due to the presence of trees in the cropland and grassland of Molise region. These resources are usually neglected by forest inventories carried out over the past years in Italy, which are traditionally strictly focused on forest area. This consideration can be reliably extended to most developed countries.

A further understanding on the role of TOF as a key green infrastructure is increasingly required in the domain of bioeconomy, especially to foster sustainability purposes in both management of forest resources rural areas, and landscape planning (e.g., Marchetti et al. 2014). The integration of forest and TOF resources allows to optimize their use and to maximize the provision of ecosystem services, as a framework for terrestrial natural renewable resource survey programs (Corona et al. 2002). In this way, a major support for sustainability planning may derive by a deeper integration of modeling tools and approaches for integrating field and remotely sensed data to spatial-explicitly assess TOF's benefits at regional scale, as suggested by other works in Italy (Vizzarri et al. 2017). Under this perspective, the approach proposed in this study could represent a good starting framework for the definition of an integrated inventory protocol including all non-fruit tree resources, and may be replicable in other contexts, where TOF play a fundamental role for local social-economic development.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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Annex III

forests

MDPI

Article

Landscape Preference for Trees Outside Forests along an Urban–Rural–Natural Gradient

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Abstract: In densely populated areas, essential sources of ecosystem services are represented by green infrastructure, which includes trees outside forests (TOF) that, regardless of their cover extension, are found on agricultural or urban land. This research aims to assess landscape preference for TOF along an urban-rural-natural gradient in relation to different levels of landscape heterogeneity. Analyses are based on the integration of a visual choice experiment (360 respondents) with a GIS-based landscape analysis at regional scale in a Mediterranean region in Central Italy. Main findings revealed that correlation between landscape preference and heterogeneity varies along the urban–rural–natural gradient and on the basis of the spatial configuration of the surrounding landscape. The additional value of TOF to landscape preference is closely and positively linked to the degree of landscape anthropization. Conversely, TOF contribution to landscape preference resulted negative in natural landscapes where they can be perceived as a disturbance of the wilderness. Considering the influence that landscape preference plays on cultural ecosystem services provisioning and, in turn, on decision making processes, our results can support landscape policy and planning in fostering or hampering TOF diffusion depending on the different territorial contexts. These findings endorse the importance of multi-functional approaches in future-oriented strategies, which should mediate between the human preference for TOF, their ecological role and the provision of other services.

Keywords: green infrastructures; visual choice experiment; landscape metrics; landscape pattern

1. Introduction

Trees outside forests (TOF) generate many benefits from environmental, social and economic perspectives, hence they have received much attention in recent years. Trees outside forests are defined as all trees and shrubs that cannot be included in the "forests" nor in the "other wooded lands" categories of the FAO forest classification. Therefore, all trees growing in agricultural, urban or natural landscapes covering less than 0.5 ha and less than 20 m in width, are considered as TOF [1]. They include several tree formations, from single trees to systematically managed trees in agroforestry systems [2]. In several land mosaics worldwide, people use them for many purposes, including food provisioning, income, and biological diversity [1], or indirectly benefit from their role in landscape connectivity [3].

A striking case is the Mediterranean region, where most natural landscapes have been replaced by cultural landscapes deriving from the reorganization of land use and cover in order to adapt to changing social needs [4]. The cultural Mediterranean landscape is, therefore, one of the most typical settings for TOF because it is shaped by a complex heterogeneous mosaic of tree formations intermixed with agricultural land and settlements. For example, in Italy, TOF substantially contribute to landscape diversification and this role has been emphasized by recent land-use change dynamics [5]. Moreover, among the TOF forming the cornerstone of the ecological network of one the most intensively cultivated and urbanized regions in Europe, the Po Plain, there are hedgerows [6], and small woodland patches [7].

The presence of TOF contributes to the landscape view, from several perspectives. It is therefore challenging and important for policy makers trying to assess whether they are drivers of landscape preference. Since TOF generally grow in the human-nature interface, as in the urban fringe, they are directly exposed to human pressures [5] and human-induced landscape dynamics [8]. Nevertheless, an incomplete understanding of potential TOF-related services still often precludes their inclusion in global and national forest resource management and monitoring systems [9]. Consequently, the effective implementation of dedicated conservation and improvement actions often remains an unresolved issue [9].

One way to study landscape preference is to perform a visual choice experiment where respondents are asked to rank different pictures. This is commonly done using photographs, modified by a computer, controlling their content and hence the evaluation by a respondent under different scenarios [10]. This perception-based experiment has proved to be able to capture landscape preferences and offer a high level of reliability [11]. Moreover, removing or replacing objects through combining a geographic information system (GIS) and photographs makes it possible to infer which are the drivers of landscape preference [12]. Crossing urban and peri-urban boundaries, landscape preference for TOF patches could be associated to their key role on landscape structure [5], often being the main antagonists to landscape homogenization and scenic monotony. Landscape metrics, such as fragmentation and shape, are known to be statistically significantly correlated with preference, even more so than the characteristics of respondents [10]. Many integrated studies have been conducted through the analysis of correlations between landscape preference and landscape metrics [13–18].

Preference for landscape features has been commonly assessed in a single type of landscape, either natural, semi-natural, agricultural or urban [19]. However, landscape-related characteristics in which they are set may also play a fundamental role in modifying the preference for single features. In particular, along an urban–rural–natural gradient of landscape types, the level of human influence will change, and this may give relatively different importance to TOF, and consequently different landscape preference [20]. Moreover, landscape preferences can vary between different groups of people based on e.g., their age and social or cultural background [21].

This study aims to assess how TOF contribute to landscape preference by combining a visual choice experiment with a GIS-based landscape analysis. Specifically, landscape preference was evaluated along an urban–rural–natural gradient in relation to the effect of varying TOF cover on landscape fragmentation, complexity and diversity. Our hypothesis is that landscape preference for TOF varies along the urban–rural–natural gradient as well as on the spatial pattern of the landscape in which they are located. Accordingly, the study sheds light on TOF as drivers of landscape preference offering a tangible support to future strategies and plans, fostering their conservation and implementation as part of the green infrastructure network.

2. Materials and Methods

2.1. Land-Use Interpretation

The study was conducted in Molise Region, Central Italy, a Mediterranean region that covers 4461 km^2 [22] between the Adriatic Sea and the Apennine mountains (Figure 1). The presence of mountains, hills, lowlands and coastal areas in this region fosters the depopulation of marginal districts due to the migration towards areas with better development opportunities. Ecological implications of this demographic and social phenomenon include forest expansion in mountain areas and agricultural intensification and urban expansion in lowlands and along the coast, mostly around the three biggest cities [23,24]. TOF cover 1.7% of the regional territory (7730 ha), having an average patch size of 0.14 ha at 2008 [25]. About 60 tree species were recorded in TOF of the Molise Region, dominated by *Quercus pubescens* and *Quercus cerris*, together covering 34% in terms of abundance, followed by *Ulmus minor* (13%), *Acer campestre* (8%) and *Salix alba* (6%). Other species individually contribute to less than 5% in terms of abundance [26].

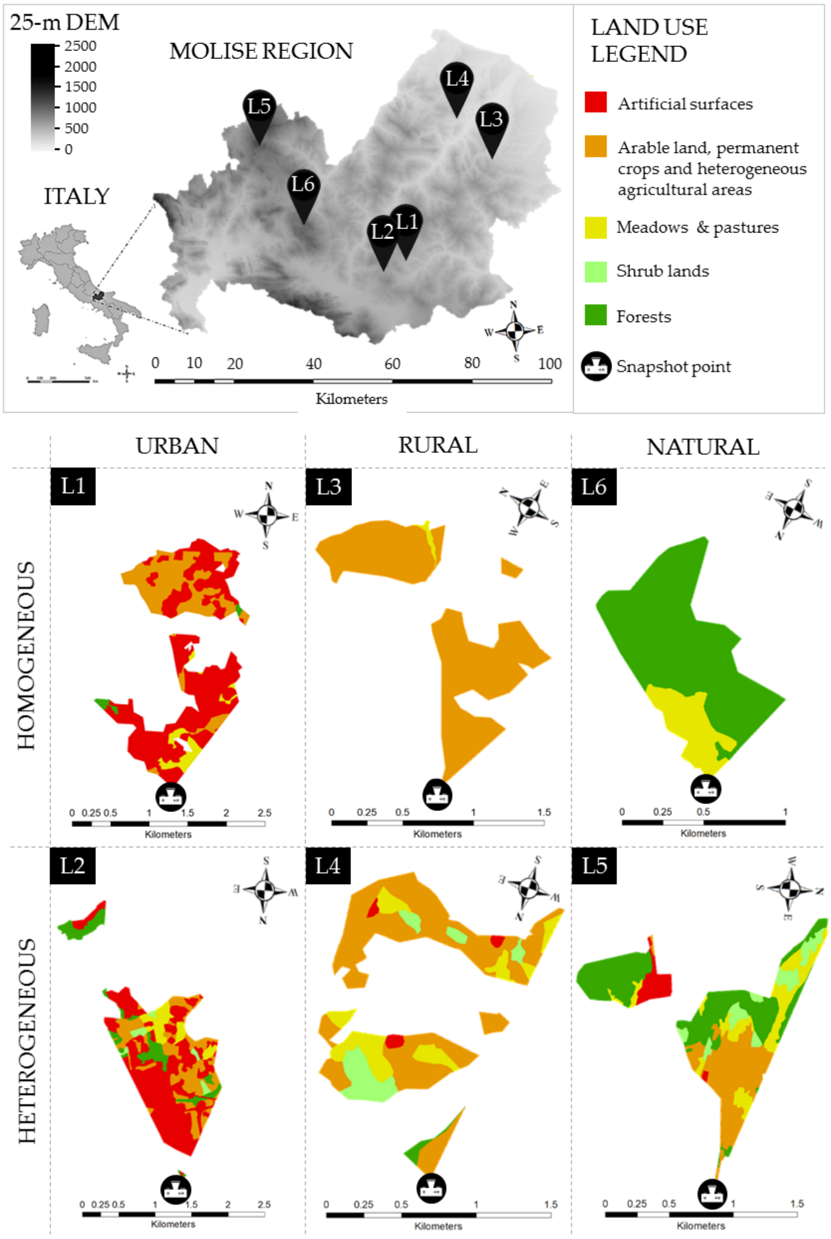

Figure 1. The six selected viewsheds representative of the urban–rural–natural landscape gradient and their geographical location in the study area.

In order to produce a landscape photo sequence covering the whole urban–rural–natural gradient, a land use interpretation was performed. A sample of 15 oblique photographs, five for each urban, rural and natural landscape domain, was taken along an altitudinal gradient and from representative viewpoints in the Molise region. Photos were taken on sunny days during September 2018. Using a 25 m digital elevation model (DEM), and knowing camera position, orientation, and field of view, we assigned real-world locations to each of the photograph pixels, producing 15 viewsheds, of which we interpreted land-use types. Through the photointerpretation of color aerial orthophotos from 2015 (nominal geometric resolution: 0.5 m), five land-use types have been distinguished and mapped with a minimum mapping unit of 500 m^2 in order to discriminate TOF: (1) artificial surfaces; (2) arable land, permanent crops and heterogeneous agricultural areas; (3) meadows and pastures; (4) forests; (5) shrublands. These maps were used to calculate three landscape metrics using the "Patch Analyst" tool in the ESRI ArcGIS® software package. Patch density (PD), land-use class density (CD) and Shannon's diversity index (SDI) (see [27] for further details on these metrics) were calculated for each viewshed, and then normalized to a 0–1 interval by the min-max method of ranging [28]. Finally, a test for checking the absence of correlation between metrics was performed (Spearman $\rho < |0.8|$). These metrics were chosen because of their proved correlation with landscape preference [29] as well as their ability to describe landscape structure irrespective of the area extent [30]. The average of these normalized metrics' values was calculated and assumed as an index of landscape heterogeneity ($H\ index_v$) (see Table A1 in Appendix A). Finally, three pairs of photographs, and their related viewsheds, were selected from those showing the lowest and highest $H\ index_v$ within each landscape domain (urban, rural and natural) (Figure 1). In this way, an urban–rural–natural landscape gradient was recreated as follows:

- L1 Homogeneous urban landscape: the landscape with the lowest heterogeneity among those with the main land use represented by artificial surfaces;
- L2 Heterogeneous urban landscape: the landscape with the highest heterogeneity among those with the main land use represented by artificial surfaces;
- L3 Homogeneous rural landscape: the landscape with the lowest heterogeneity among those with the main land use represented by arable land, permanent crops and heterogeneous agricultural areas;
- L4 Heterogeneous rural landscape: the landscape with the highest heterogeneity among those with the main land use represented by arable land, permanent crops and heterogeneous agricultural areas;
- L5 Heterogeneous forest landscape: the landscape with the highest heterogeneity among those with the main land use represented by forests;
- L6 Homogeneous forest landscape: the landscape with the lowest heterogeneity level among those with the main land use represented by forests.

2.2. Visual Choice Experiment

The six selected photos were then modified using a raster graphic editor in order to obtain six triplets of photos each with three different levels of TOF cover (Figure 2). First editing aimed to (i) remove all TOF present in original photos, (ii) harmonize exposure and saturation values, and (iii) eliminate clouds as plausible misleading stimuli on observer perception [31]. Accordingly, the first photo of each triplet referred to the absence of TOF (No TOF). In the second photo of each triplet, TOF was added until covering 1.7% of the viewshed area (Med TOF), which corresponded to the current TOF coverage in Molise region [26]. Finally, the third photo of each triplet was modified by adding TOF elements until reaching a relatively high TOF cover of 3.4% of the viewshed area (High TOF), equal to twice the average value of TOF cover in Molise region. TOF were added within 1.5 km from the snapshot point, as the maximum visual threshold for clearly discerning individual elements such as trees [17].

Edited photos were exhibited in a visual choice experiment to 360 respondents, equally distributed by age, (i.e., "young", "adults" or "elderly", respectively between 18 and 35, between 36 and 55, and over 55 years), gender, place of origin (i.e., "inhabitants" or "visitors") and residential site (i.e., "in town" if their home was within an urban or peri-urban district or "out of town" if their home was in a rural area). Respondents were randomly intercepted in public locations of the Molise Region such as town squares, holiday farms, environmental museums, archaeological sites, ski resorts etc., between December 2018 and March 2019. The first part of interviews included personal information on profession, educational level and marital status. Each respondent was then asked to rank the photos contained in each triplet according to their individual preference. The three photos were simultaneously shown on A2 sheets in order to grant an optimal observation of the landscapes portrayed, facilitating their comparison. Hence, the three photos of each triplet were ranked from 1 to 3 following an increasing aesthetic preference (i.e., 1 for the least preferred, 2 for the intermediate and 3 for the most preferred photo). At the end of the experiment, respondents were asked to rank a sequence composed of the six photos with the Med TOF cover level, assigning an increasing value from 1 to 6 according to increasing aesthetic preference. These values were finally multiplied by the preference values of each photo within the triplet in order to calculate an overall preference score for each of the 18 photos.

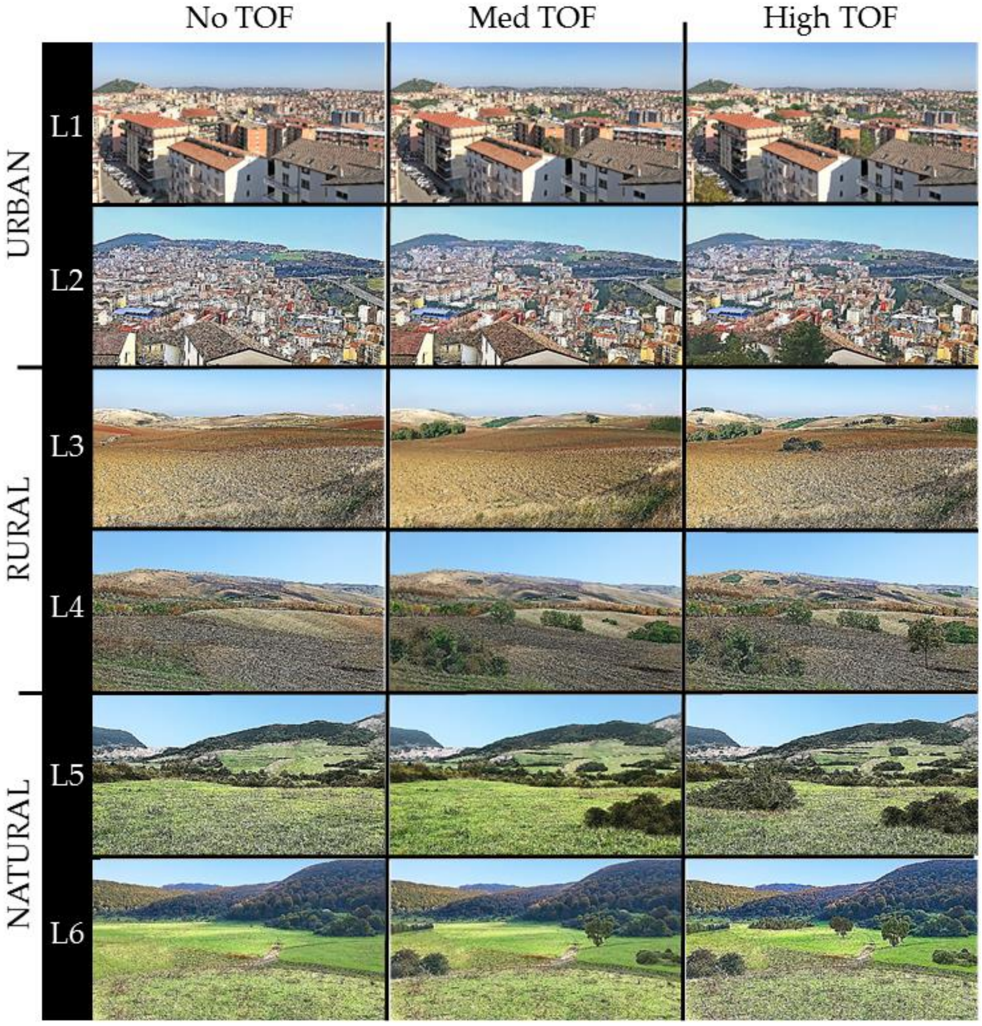

Figure 2. The six triplets of photos edited with a raster graphic editor, showing six different landscape types of the urban–rural–natural gradient (from top to bottom) and three increasing trees outside forests (TOF) covers (from left to right).

The responses were analyzed both on the overall sample and for each individual group of respondents. In order to check the significant differences in preference from different groups of respondents, a χ^2 test was then performed.

2.3. Landscape Metrics and Landscape Preference Relationships

Corresponding to the photo editing, land-use maps of the six original photos were edited in a GIS environment, thus reproducing the six triplets of viewsheds according to the three TOF cover levels.

TOF patches edited in photos were replicated in the corresponding viewsheds, faithfully reflecting their spatial configuration, both for distribution (i.e., azimuth and distance from the observer) and geometry (i.e., shape and area). A landscape analysis of each viewshed was then conducted, computing sixteen landscape metrics commonly used to describe landscape fragmentation, complexity and diversity (see Table A2 in Appendix A). Landscape metrics were calculated through the "Patch Analyst" tool in the ESRI ArcGIS® software package. Only seven metrics, showing a Spearman $\rho < |0.8|$ between one another, were retained in order to characterize and compare the six different landscapes in relation to the three TOF cover levels. These seven metrics were then normalized to 0–1 range using the min-max method [28]. Normalized metrics were used to calculate three landscape metrics: landscape fragmentation given by the average of mean patch size (MPS), patch size coefficient of variation (PSCoV) and total edge (TE); landscape complexity given by the average of area weighted mean shape index (AWMSI) and mean patch fractal dimension (MPFD); landscape diversity given by the average of class density (CD) and Shannon's diversity index (SDI). Correlations among the overall preference scores and the three related landscape metrics were then assessed through Pearson's r correlation analysis. Finally, the statistical significance of the correlations obtained was verified through the t distribution method. We found statistical significance at 0.001 level for all Pearson's product moment correlation coefficients.

3. Results

3.1. Visual Choice Experiment

The distributions of preferences were relatively more balanced between different levels of TOF cover in rural and natural landscapes than in the urban ones (Table 1). The results reveal that urban and rural landscapes without TOF are least preferred by most respondents, while those with the highest level of TOF cover are preferred. Conversely, in natural landscapes, most respondents indicate as less preferred those having the highest TOF cover. In fact, preferred natural landscapes are heterogeneous with Med TOF cover and homogeneous without TOF. Slight statistically significant differences appear with respect to the preferences expressed among the different groups of respondents (for further details, see Figure A1 in Appendix A).

Table 1. Preference distribution of the overall sample of respondents recorded in the visual choice experiment.

Domain	Landscape ID	TOF Cover	Preference Distributions (%)		
			Least Preferred Landscape	Intermediate Preferred Landscape	Most Preferred Landscape
URBAN	L1	No TOF	94.4%	3.3%	2.2%
		Med TOF	7.8%	81.4%	10.8%
		High TOF	4.7%	8.3%	86.9%
	L2	No TOF	91.9%	4.4%	3.6%
		Med TOF	9.2%	67.2%	23.6%
		High TOF	5.8%	21.4%	72.8%
RURAL	L3	No TOF	69.2%	13.6%	17.2%
		Med TOF	11.9%	55.0%	33.1%
		High TOF	25.8%	24.4%	49.7%
	L4	No TOF	73.6%	15.6%	10.8%
		Med TOF	8.6%	47.5%	43.9%
		High TOF	24.7%	30.0%	45.3%
NATURAL	L5	No TOF	39.2%	26.7%	34.2%
		Med TOF	12.2%	39.4%	48.3%
		High TOF	55.6%	26.9%	17.5%
	L6	No TOF	26.7%	10.8%	62.5%
		Med TOF	17.5%	65.3%	17.2%
		High TOF	62.8%	16.9%	20.3%

3.2. Trees Outside Forests (TOF) Influence on Landscape Structure

The values of landscape metrics with high TOF cover are always higher than medium TOF cover and TOF absence (Table 2). Accordingly, these metrics' trends show that a higher TOF cover is directly correlated with a higher level of fragmentation, complexity and diversity of the landscape mosaics. Moreover, differences related to TOF cover are more emphasized in homogeneous than heterogeneous landscapes. In these landscapes (i.e., L1, L3 and L6), MPS, PSCoV and TE show the widest absolute variations in relation to changing TOF cover. In a homogeneous urban landscape (L1), PSCoV and TE increase by 22% and 13% respectively passing from Med TOF to High TOF. At the same time, MPS decreases by 33%. Furthermore, passing from Med TOF to No TOF in L1, PSCoV and TE decrease by 20% and 13%, respectively, and MPS increases by 50%. In homogeneous rural landscape (L3), PSCoV and TE increase by 33% and 19%, respectively, and MPS decreases by 38% for High TOF. While, PSCoV and TE decrease by 41% and 16%, respectively, and MPS increases by 100% passing from Med TOF to No TOF in L3. Lastly, in the homogeneous natural landscape (L6), PSCoV and TE increase by 37% and 7%, respectively, for High TOF and MPS concurrently decreases by 40%. Conversely, passing from Med TOF to No TOF in L6, MPS increases by 200% and PSCoV and TE decrease by 65% and 10%, respectively. In these homogeneous landscapes, we also found that AWMSI and MPFD are less sensitive to changes in TOF cover.

Table 2. Values of the seven landscape metrics for the 18 analyzed viewsheds. Mean patch size (MPS), patch size coefficient of variation (PSCoV), total edge (TE), area weighted mean shape index (AWMSI), mean patch fractal dimension (MPFD), class density (CD) and Shannon's diversity index (SDI).

Domain	Landscape ID	TOF Cover	Fragmentation Metrics			Complexity Metrics		Diversity Metrics	
			MPS	PSCoV	TE	AWMSI	MPFD	CD	SDI
URBAN	L1	No TOF	9.2	218.5	44.8	2.88	1.37	0.017	0.86
		Med TOF	6.1	273.1	51.4	3.09	1.40	0.021	0.92
		High TOF	4.1	333.2	58.3	3.39	1.43	0.021	0.96
	L2	No TOF	3.7	293.6	59.1	2.51	1.37	0.022	1.24
		Med TOF	3.0	321.1	67.1	2.87	1.40	0.026	1.30
		High TOF	2.2	368.4	74.0	3.16	1.43	0.026	1.34
RURAL	L3	No TOF	19.3	98.6	9.0	1.78	1.33	0.026	0.07
		Med TOF	9.6	166.8	10.7	1.97	1.38	0.039	0.16
		High TOF	5.9	222.0	12.7	2.21	1.41	0.039	0.22
	L4	No TOF	4.6	170.4	24.9	2.19	1.33	0.050	0.98
		Med TOF	3.6	196.1	27.0	2.27	1.36	0.060	1.05
		High TOF	3.1	209.8	29.0	2.35	1.37	0.060	1.12
NATURAL	L5	No TOF	3.8	164.2	27.8	2.12	1.38	0.051	1.41
		Med TOF	3.0	189.2	30.0	2.22	1.41	0.061	1.45
		High TOF	2.6	202.4	32.0	2.36	1.42	0.061	1.48
	L6	No TOF	35.9	63.5	6.7	1.68	1.29	0.028	0.48
		Med TOF	12.0	179.0	7.5	1.73	1.48	0.042	0.49
		High TOF	7.1	244.9	8.0	1.77	1.46	0.042	0.50

3.3. Correlation between Landscape Metrics and Preferences

Mean preference scores of the 18 photos increase along the urban–rural–natural gradient (Table 3). Furthermore, the increase of the mean preference scores in urban and rural landscape triplets matches the increase of TOF cover. Mean preference scores for L1 and L2 without TOF increase by 85% and 83%, respectively, passing to Med TOF and by 146% and 128% passing to High TOF. Similar, but less emphasized, are the trends related to rural landscape triplets (L3 and L4). Indeed, in these cases, results reveal that the highest mean preference scores correspond to the Med TOF rather than High TOF cover. In fact, in L3 and L4, mean preference scores increase by 142% and 173%, respectively, passing from No TOF to Med TOF, while decrease by 3% and 7% respectively passing from Med TOF to High TOF. Med TOF achieves the highest mean preference score even in the heterogeneous natural landscape (L5) with the lowest value found for High TOF level. For natural homogeneous landscape (L6), No TOF shows the highest mean preference score. In this case, results display a trend in mean preference scores that is opposite to the increase of TOF cover. In detail, mean preference score of L6 decreases by 16% from No TOF to Med TOF and by 23% from Med TOF to High TOF. With regard to the trends of landscape metrics, a direct relation with the increase in TOF cover was found for all landscape types (Table 3). This common trend is particularly emphasized in homogeneous rural and natural landscapes (L3 and L6) where, e.g., landscape diversity triples passing from No TOF to High TOF in L3 and landscape fragmentation rises from 0 to 0.49 passing from No TOF to High TOF in L6.

Table 3. Mean preference scores and normalized landscape metrics of the six landscape types investigated in relation to three different levels of TOF cover.

Domain	Landscape ID	TOF Cover	Mean Preference Score	Landscape Fragmentation	Landscape Complexity	Landscape Diversity
URBAN	L1	No TOF	2.1	0.62	0.55	0.28
		Med TOF	3.9	0.75	0.71	0.35
		High TOF	5.1	0.87	0.86	0.36
	L2	No TOF	2.5	0.83	0.46	0.47
		Med TOF	4.6	0.91	0.64	0.55
		High TOF	5.7	1.00	0.80	0.56
RURAL	L3	No TOF	4.9	0.21	0.15	0.10
		Med TOF	6.9	0.39	0.33	0.28
		High TOF	6.7	0.50	0.48	0.30
	L4	No TOF	5.1	0.52	0.26	0.70
		Med TOF	8.8	0.56	0.36	0.83
		High TOF	8.2	0.59	0.40	0.86
NATURAL	L5	No TOF	9.6	0.53	0.37	0.86
		Med TOF	11.6	0.58	0.48	0.99
		High TOF	7.9	0.61	0.55	1.00
	L6	No TOF	12.5	0.00	0.00	0.27
		Med TOF	10.4	0.37	0.51	0.43
		High TOF	8.1	0.49	0.47	0.44

Main results from the correlation analysis (Table 4) show that relationships between trends in mean preference scores and trends in landscape fragmentation, complexity and diversity have greater positive intensity in urban (L1 and L2) than in rural landscapes (L3 and L2). These correlations are inverted, thus becoming negative, passing to natural landscapes (L5 and L6). A homogeneous urban landscape (L1) displays the strongest positive correlations between trends in mean preference scores and trends in landscape metrics, which tend to smoothly decrease passing to a heterogeneous urban landscape (L2). Inversely, positive correlations are stronger in a heterogeneous than in a homogenous rural landscapes (L4 and L3, respectively). A heterogeneous natural landscape (L5) displays very weak correlations, almost null in the case of landscape diversity. Finally, in a homogeneous natural landscape (L6) there are weak negative correlations between mean preference scores and landscape complexity and diversity.

Table 4. Mean preference scores and normalized landscape metrics of the six landscape types investigated in relation to three different levels of TOF cover.

	Landscape Preference Scores					
	URBAN		RURAL		NATURAL	
	L1	L2	L3	L4	L5	L6
Landscape fragmentation	0.62	0.53	0.35	0.43	−0.15	−0.42
Landscape complexity	0.62	0.54	0.33	0.46	−0.14	−0.34
Landscape diversity	0.57	0.55	0.38	0.49	−0.03	−0.37

4. Discussion

4.1. Preference along the Urban–Rural–Natural Gradient

Our results demonstrate that preference increases when human-shaped landscapes are rich in TOF. Emotional response to nature amenity is particularly evident in urban domains, where the abundance of natural features (i.e., TOF) are in contrast with the common idea of a townscape. Indeed, as observed by [32], archetypal landscapes generate an immediate judgment by people, which in the specific case of a townscape maximally enriched in natural features (e.g., TOF) reflect in a strong positive consensus. In this sense, our results are in agreement with the theory that landscape preference is commonly increased with exposure to nature [31,33]. Furthermore, the consensus in preferences for urban landscapes is due to the fact that judgment is not only positively conditioned by the cover of natural elements but also negatively influenced by the presence of buildings and modern factories, unanimously recognized as the least appreciated visual landscape elements [34]. The wide agreement between different groups of respondents in preferring high TOF cover in urban contexts indicates that their variations within landscapes are greater than differences in people's judgments [35]. The changes in preference for TOF depend on the level of landscape naturalness along the urban–rural–natural gradient, resulting as very high in urban domains where TOF represent the last legacy of nature [36]. Our findings are in line with other similar studies, highlighting how people commonly prefer urban landscapes with plentiful natural elements [37–39]. Instead, preference analysis in rural landscapes shows a more balanced distribution ratio, albeit confirming the general preference for landscape with high TOF cover. Considering rural landscapes as transitional between extremely anthropized and natural landscapes [40], natural features such as TOF are already present, thus lowering their overall impact compared to urban domains. Indeed, TOF influence on preferences appear slightly greater in homogeneous rural landscapes characterized by high agricultural intensification with respect to heterogeneous and extensively cultivated ones. As shown by [41], trees and small woods in arable plots represent the most appreciated visual landscape attributes. Furthermore, results are consistent with those obtained by [42], showing how preferred elements of the natural landscapes include not only large bio-physical features (i.e., mountains and forests more than TOF) but also conceptual (e.g., wilderness) and emotional (e.g., excitement) aspects. Moreover, [10] proved how in natural landscapes the cover of small and scattered forest patches is interpreted as a reduction in naturalness negatively influencing landscape perception. It is possible that this reaction also depends on the fact that fragmentation of forested landscapes is automatically linked to the spontaneous rewilding of mountain and marginal areas. Indeed, it has been observed that people prefer heterogeneous forested landscapes as long as their heterogeneity is not due to land abandonment [43].

4.2. Effects of Change in TOF Cover and Landscape Metrics

Effects of a change in TOF cover are mostly evident in landscapes with the lowest levels of heterogeneity, where TOF and small patches in general represent the main elements of diversification [5]. Conversely, the ongoing processes of urbanization, agricultural intensification and abandonment of marginal lands in Italy and other countries, are often taking place at the expense of TOF with subsequent landscape homogenization [8]. More specifically, landscape analysis proves how changes in TOF cover in homogeneous landscapes mainly affect patch size and edge metrics. Confirming this result, a spatial simulation exercise by [3] demonstrated that TOF affect this variety of metrics precisely, improving ecological connectivity. Moreover, TOF cover strongly affects diversity metrics in homogeneous rural landscapes where they represent important permanent features of structural and biological diversity [6]. Indeed, agricultural intensification mainly implies the removal of TOF patches to facilitate mechanization, thus favoring the consolidation of small landholdings into single huge proprieties that radically simplify the landscape mosaic [44].

Our results confirm the positive correlations between landscape preferences and landscape metrics in relation to the increasing TOF cover. These correlations are particularly emphasized in landscapes largely modified by humans (i.e., urban and rural). Pearson's coefficients tend to decrease with the decreasing human-induced landscape alteration in rural compared to urban landscapes. Moreover, landscape diversity is less correlated to preference scores than landscape complexity and fragmentation. As previously mentioned, agricultural lands, currently accounting for almost half of the European Union (EU) surface area [45], have undergone important structural changes in the post-war period, leading to extreme simplification of the landscape mosaics [44]. This simplification also has negative impacts on landscape preference due to the homogenization of the landscape mosaic often dominated by a few and similar large land patches [46]. Moving towards more natural landscapes, human impacts on landscape structure tend to decrease as well as TOF contribution to landscape preference. Although TOF continue to implicate a general upgrading in heterogeneity, preference scores suggest that their increase in natural landscapes is perceived as a reduction of naturalness. Since TOF influence on landscape structure is less marked in heterogeneous natural landscapes compared to homogeneous ones, correlations between trends in preferences and metrics are negligible in the former and weak or medium negative in the latter. In detail, landscape fragmentation shows the highest negative correlation with preference scores in homogeneous natural landscapes (L6), thus confirming fragmentation as a negative indicator for preference in such landscapes [10].

4.3. Methodological Remarks

Our methodology allowed landscape preference for TOF to be assessed along the whole urban–rural–natural gradient. This is particularly relevant to recent objectives of sustainable landscape planning and management highlighting interactions among different services and beneficiaries, but often neglecting the variability of landscape types [47]. In this perspective, the implementation of innovative cross-disciplinary tools able to support landscape planning is foreseeable. Huge efforts in terms of both time and costs needed to assess TOF-related cultural services at large scale through social perception approaches with an adequate level of robustness represent a barrier to their effective implementation in planning strategies [18]. Therefore, it would be more appropriate to advocate techniques that include social information in a biophysical dataset, such as predictive models able to evaluate and map TOF-related cultural services as well as their changes in relation to landscape dynamics [48]. Then again, the development of new indicators based on individual experience in natural environments could facilitate the evaluation of ecological implications on human wellbeing [49]. While these analyses are particularly important to foster in mountain areas, e.g., tourist attractiveness [48], they are becoming crucial in urban areas to promote stress relief and perceived safety linked to greenspaces planning [50]. In this perspective, our results demonstrate that an increasing cover of trees in urban domains, even if in small patches such as TOF, increases landscape preferences. Given that TOF coverage in Italy increased by approximately 27% (91,000 ha) in the last few decades with respect to 1990 [5], it is then crucial to investigate where this change occurred, e.g., natural or urban contexts, in order to understand the impact of such changes on landscape preferences. Moreover, the influence of other aspects such as patch size and shape as well as species composition of TOF elements, might be explored to better characterize their relationship with landscape preferences. These methods would represent the best compromise in order to (i) overcome the conceptual divergence between provisioning and perception of cultural services connected to their intangibility, (ii) incorporate social and ecological bases in sustainable landscape planning and management strategies by optimizing services demand and supply, and (iii) facilitate the implementation of current international recommendations and policies aimed at improving socio-cultural and economic development through green infrastructure and nature-based solutions [51].

5. Conclusions

Our results demonstrate that there is wide agreement among different groups of people in recognizing the added value of TOF to landscape preference. Increasing TOF cover positively affects landscape preferences following a landscape anthropization gradient, thus resulting as higher in urban than rural and natural ecosystems. Accordingly, our findings advocate initiatives aimed at conserving and improving the presence of TOF in urban and rural areas ensuring health, cultural, economic and environmental benefits for people [52]. The positive contribution of TOF on landscape preference in such areas demonstrate that their implementation can also ameliorate this aspect as well as those related to their ecological, regulating and supporting role [53]. In light of our results, we can conclude that increasing tree cover, either by planting or by spontaneous rewilding, even by small patches such as TOF can be considered as a positive initiative to increase landscape preference as well. Otherwise, instead of specific biophysical attributes and features, preference for natural landscapes would seem to be related to emotional reasons, including a transversal perception that originates from cognitive processes. Therefore, TOF contribution to landscape preference is null, if not negative, in extremely natural landscapes where they represent a sort of unwanted human legacy. Considering the influence that landscape preference can play on cultural ecosystem services provisioning and, in turn, on decision making processes, our results can support landscape policy and planning in fostering or hampering TOF diffusion depending on the different territorial contexts. However, given the high variability in the species as well as the spatial composition of TOF, future studies able to combine information on ecological diversity and social perception of this tree resource are suggested.

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Appendix A

Table A1. Results of the characterization of the 15 viewsheds in relation to main land-use and heterogeneity level. In bold, the six selected viewsheds. Patch density (PD), land-use class density (CD) and Shannon's diversity index (SDI) and their normalized values, and index of landscape heterogeneity (H *index*).

ID Photo	Main Land Use	Area (ha)	PD	PD Normalized Value	CD	CD Normalized Value	SDI	SDI Normalized Value	H Index
1	**Artificial surfaces**	**238.1**	**0.11**	**0.24**	**0.017**	**0.03**	**0.86**	**0.61**	**0.295**
2	Artificial surfaces	228.7	0.09	0.17	0.022	0.10	0.89	0.62	0.304
3	Artificial surfaces	99.6	0.20	0.50	0.040	0.37	0.93	0.65	0.515
4	Artificial surfaces	175.2	0.34	0.92	0.023	0.12	0.88	0.62	0.559
5	**Artificial surfaces**	**228.0**	**0.27**	**0.71**	**0.022**	**0.11**	**1.24**	**0.87**	**0.568**
6	**Agricultural areas**	**77.0**	**0.05**	**0.07**	**0.026**	**0.17**	**0.07**	**0.05**	**0.097**
7	Agricultural areas	100.1	0.06	0.09	0.030	0.22	0.20	0.14	0.155

Table A1. *Cont.*

ID Photo	Main Land Use	Area (ha)	PD	PD Normalized Value	CD	CD Normalized Value	SDI	SDI Normalized Value	H Index
8	Agricultural areas	207.8	0.07	0.13	0.014	0.00	0.75	0.53	0.220
9	Agricultural areas	12.2	0.16	0.40	0.082	1.00	0.00	0.00	0.467
10	**Agricultural areas**	**100.6**	**0.22**	**0.56**	**0.050**	**0.52**	**0.98**	**0.69**	**0.593**
11	**Forests**	**98.6**	**0.26**	**0.69**	**0.051**	**0.53**	**1.41**	**1.00**	**0.743**
12	Forests	101.0	0.19	0.47	0.040	0.37	0.88	0.62	0.489
13	Forests	297.9	0.14	0.33	0.017	0.03	1.00	0.70	0.357
14	Forests	158.0	0.06	0.10	0.025	0.16	0.97	0.68	0.316
15	**Forests**	**71.7**	**0.03**	**0.00**	**0.028**	**0.19**	**0.48**	**0.33**	**0.178**

Table A2. Overview of the 16 landscape metrics [27] originally considered for the landscape analysis of the 18 viewsheds. In bold, the seven metrics selected after the auto-correlation test and used for the landscape analysis.

	Landscape Metric	Acronym	Description
Fragmentation	Patch Density	PD	Number of patches in the viewshed, divided by total viewshed area.
	Mean Patch Size	MPS	Sum, across all patches in the viewshed, of the patch areas, divided by the total number of patches.
	Median Patch Size	MedPS	Area of the patch representing the midpoint of the rank order distribution of patch areas based on all patches in the viewshed.
	Patch Size Coefficient of Variance	PSCoV	Standard deviation of patch areas divided by the mean patch area.
	Patch Size Standard Deviation	PSSD	Square root of the sum of the squared deviations of each patch area from the mean patch area computed for all patches in the viewshed, divided by the total number of patches (i.e., the root mean squared error in the patch size).
Complexity	**Total Edge**	TE	Sum of the lengths of all edge segments in the viewshed.
	Edge Density	ED	Sum of the lengths of all edge segments in the viewshed, divided by the total viewshed.
	Mean Patch Edge	MPE	Lengths of all edge segments in the viewshed divided by the total number of patches.
	Mean Shape Index	MSI	Sum of patch perimeter divided by the square root of area of each patch in the viewshed, adjusted by a constant for a square standard, divided by the number of patches.
	Area Weighted Mean Shape Index	AWMSI	Sum, across all patches, of each patch perimeter divided by the square root of the patch area, adjusted by a constant for a square standard, multiplied by the patch area and divided by the total area of the viewshed.
	Mean Perimeter-Area Ratio	MPAR	Sum, across all patches in the landscape, of the simple ratio of patch perimeter to area, divided by the total number of patches.
	Mean Patch Fractal Dimension	MPFD	Sum of two times the logarithm of patch perimeter, divided by the logarithm of patch area for each patch in the viewshed, divided by the number of all patches.
	Area Weighted Mean Patch Fractal Dimension	AWMPFD	Sum, across all patches, of two times the logarithm of patch perimeter, divided by the logarithm of patch area multiplied by the patch area divided by the total landscape area.
Diversity	**Class Density**	CD	Total number of patch classes in the viewshed, divided by total viewshed area.
	Shannon's Diversity Index	SDI	Sum, across all patch classes, of the proportional cover of each patch class multiplied by that proportion.
	Shannon's Evenness Index	SEI	Minus the sum, across all patch classes, of the proportional cover of each patch class multiplied by that proportion, divided by the logarithm of the number of patch classes.

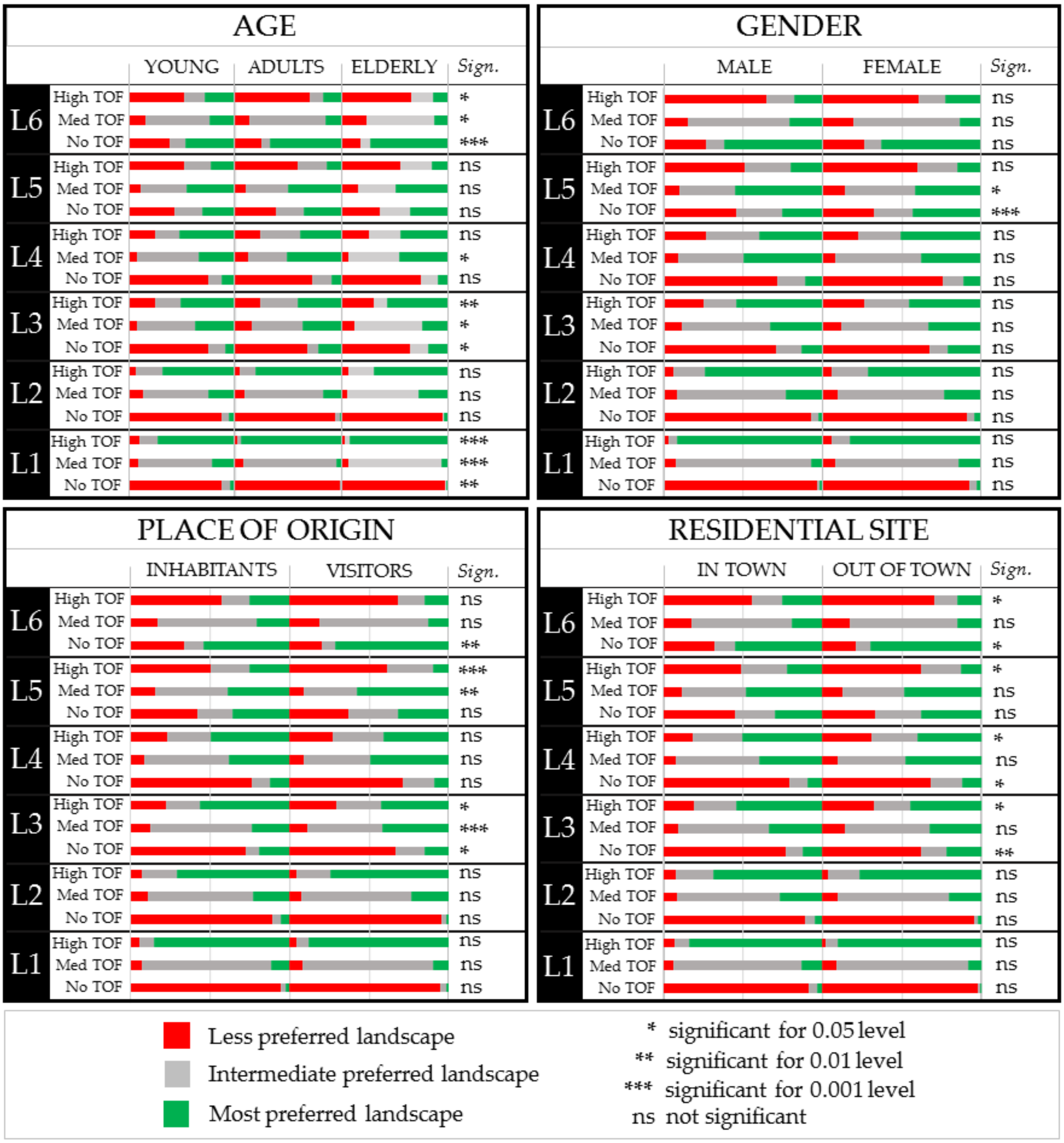

Figure A1. Between groups' preference distributions (i.e., age, gender, place of origin and residential site). For each landscape, on the right of between groups' distributions, significance level of the χ2 test is shown.

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