



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 Garfi: data collection, analysis of results, and writing of manuscript.

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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 m² area and a canopy cover $\geq 5\%$ in case of only trees or $\geq 10\%$ 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 m² 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 m² 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.

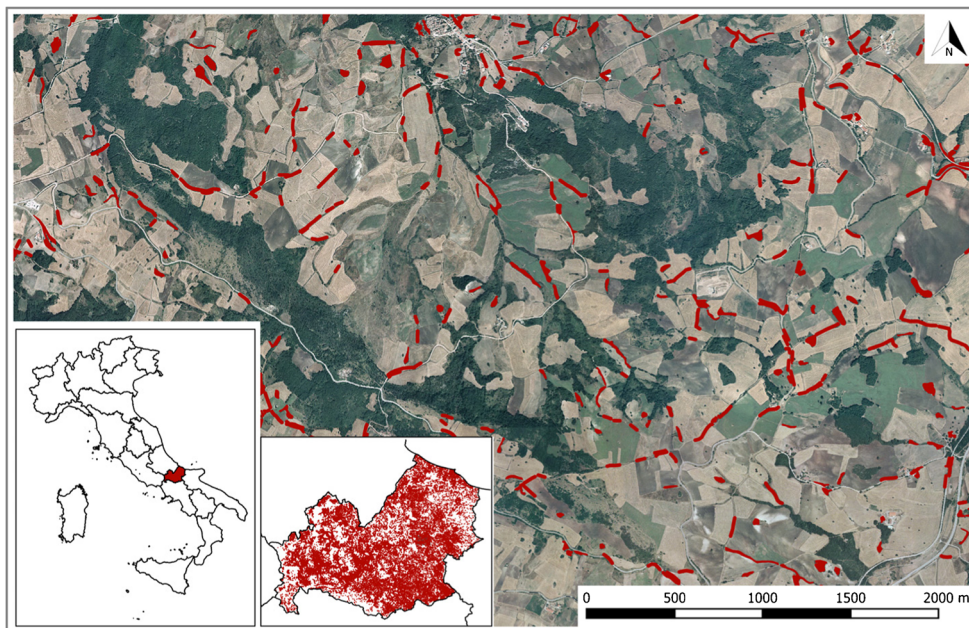
2.3 Attributes of interest and diversity measures

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 $j \in U$ 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) (m²), the volume (m³), 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

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

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 $\mathbf{T} = [T_1, \dots, T_K]^t$ 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, $p_{(1)} \leq \dots \leq p_{(K)}$, where $p_{(k)}$ is the k th 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 $k = 1, \dots, K$. 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

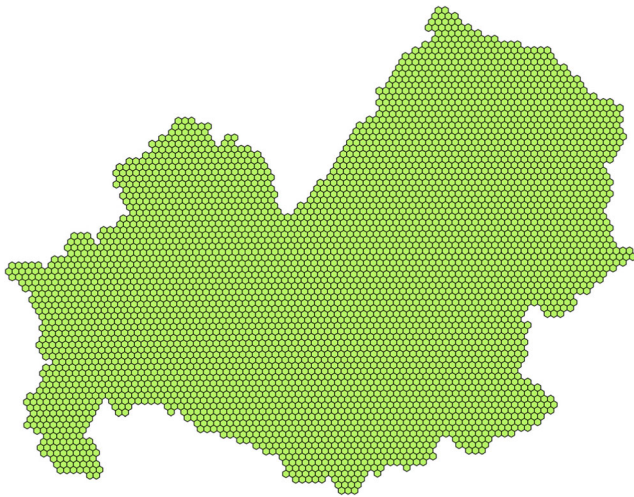


Fig. 2 The grid of 4,693 hexagons of size 1 ha adopted to cover the Molise region

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.

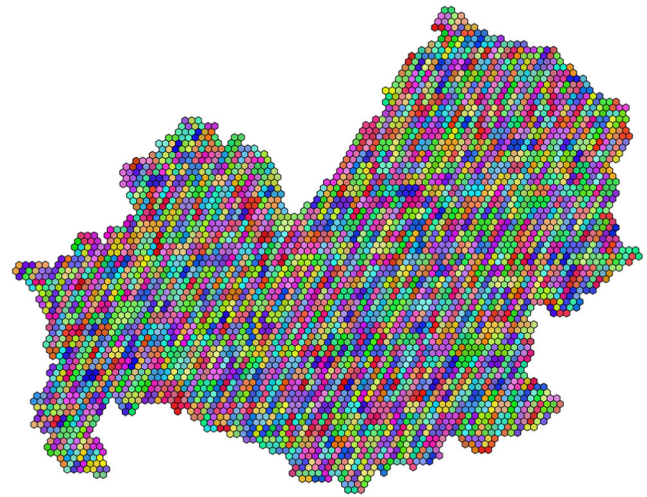


Fig. 3 The stratification of the grid covering the Molise region into blocks of two contiguous hexagons performed to achieve a second-phase sampling rate of 50%

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 $k \in L_0$, 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 $\hat{\mathbf{T}}_{(R)} = [\hat{T}_{1(R)}, \dots, \hat{T}_{K(R)}]^t$ 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 (<i>Prunus cerasus</i> L. var. <i>marasca</i> (Host.) Viv.); sweet chestnut (<i>Castanea sativa</i> Mill.); sweet cherry (<i>Prunus avium</i> L.); common fig (<i>Ficus carica</i> L.); white mulberry (<i>Morus alba</i> L.); kiwi (<i>Actinidia deliciosa</i> (A. Chev.) C.F. Liang & A.R. Ferguson); almond (<i>Prunus dulcis</i> (Mill.) D.A. Webb); apple tree (<i>Malus</i> spp.); common hazel (<i>Corylus avellana</i> L.); olive (<i>Olea europea</i> L.); common pear (<i>Pyrus communis</i> L.); peach (<i>Prunus persica</i> (L.) Batsch); stone pine (<i>Pinus pinea</i> L.); service tree (<i>Sorbus domestica</i> L.); plum (<i>Prunus domestica</i> L.); black elderberry (<i>Sambucus nigra</i> L.); Morello cherry (<i>Prunus cerasus</i> L. var. <i>austere</i> L.)
2 - Nature conservation	Field maple (<i>Acer campestre</i> L.); common holly (<i>Ilex aquifolium</i> L.); common hawthorn (<i>Crataegus monogyna</i> Jacq.); dogwood (<i>Cornus mas</i> L.); european spindle (<i>Euonymus europaeus</i> L.); mastic tree (<i>Pistacia lentiscus</i> L.); common laburnum (<i>Laburnum anagyroides</i> Medik.); Christ's thorn (<i>Paliurus spina-christi</i> Mill.); crab apple (<i>Malus sylvestris</i> Mill.); rosebay (<i>Nerium oleander</i> L.); wild pear (<i>Pyrus pyraster</i> (L.) Burgsd.); eurasian aspen (<i>Populus tremula</i> L.); blackthorn (<i>Prunus spinosa</i> L.); purple willow (<i>Salix purpurea</i> L.); goat willow (<i>Salix caprea</i> L.); laurustinus (<i>Viburnum tinus</i> L.)
3 - Wood production	Nettle tree (<i>Celtis australis</i> L.); oriental hornbeam (<i>Carpinus orientalis</i> Mill.); common hornbeam (<i>Carpinus betulus</i> L.); Turkey oak (<i>Quercus cerris</i> L.); european beech (<i>Fagus sylvatica</i> L.); holm oak (<i>Quercus ilex</i> L.); field elm (<i>Ulmus minor</i> Mill.); black alder (<i>Alnus glutinosa</i> (L.) Gaertn.); manna ash (<i>Fraxinus ornus</i> L.); Aleppo pine (<i>Pinus halepensis</i> Mill.); maritime pine (<i>Pinus pinaster</i> Aiton); white poplar (<i>Populus alba</i> L.); black poplar (<i>Populus nigra</i> L.); oriental plane (<i>Platanus orientalis</i> L.); black locust (<i>Robinia pseudoacacia</i> L.); Arizona cypress (<i>Cupressus arizonica</i> Greene); tree of heaven (<i>Ailanthus altissima</i> (Mill.) Swingle); arborvitae (<i>Thuja</i> spp.); downy oak (<i>Quercus pubescens</i> Willd.); white willow (<i>Salix alba</i> L.)
4 - Valuable timber production	Sycamore maple (<i>Acer pseudoplatanus</i> L.); Italian maple (<i>Acer opalus</i> Mill.); English oak (<i>Quercus robur</i> L.); common ash (<i>Fraxinus excelsior</i> L.); wild service tree (<i>Sorbus torminalis</i> L.); narrow-leaved ash (<i>Fraxinus angustifolia</i> Vahl); common walnut (<i>Juglans regia</i> L.)

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

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

$$\hat{T}_{(R)} = \mathbf{1}' \hat{\mathbf{T}}_{(R)}$$

the proportions of attributes by species by

$$\hat{P}_{k(R)} = P_k(\hat{\mathbf{T}}_{(R)}) = \hat{T}_{k(R)} / \hat{T}_{(R)}, \quad k \in L$$

the Lorenz curve by plotting

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

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

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

and the Shannon and Simpson diversity indexes by

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

and

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

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 $v_{(R)}^2 = \mathbf{1}' \mathbf{V}_{(R)} \mathbf{1}$ while for the remaining non linear functions of $\hat{\mathbf{T}}_{(R)}$, the variance estimates were

$$v_{(R)}^2 = \hat{\mathbf{d}}' \mathbf{V}_{(R)} \hat{\mathbf{d}}$$

where the vector $\hat{\mathbf{d}}$ was the gradient of the functions $p_k, P_k, \Delta_L, \Delta_{SH}$, 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_k s 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 m²; proportion 30%), wood volume (198,790 m³; 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 m² (proportion 12%), volume estimate of 65,772 m³ (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 m³ (RSE = 20%) with an average wood volume of 76.2 m³ 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 (m³)

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

Table 3 (continued)

Species	Volume	RSE %	Volume %	RSE %
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

Table 4 (continued)

Species	Carbon	RSE %	Carbon %	RSE %
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.

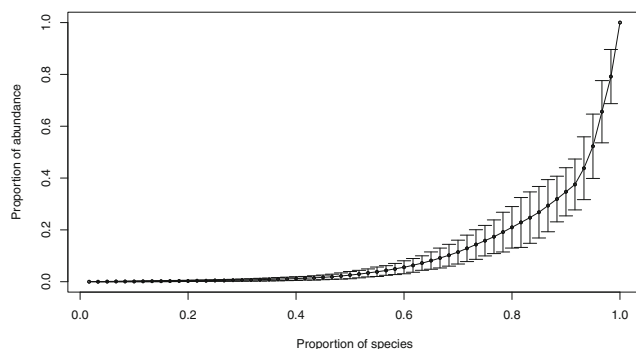


Fig. 4 Plot of the Lorenz curve estimated from tree abundances and of the 95% confidence band for the TOF of the Molise region

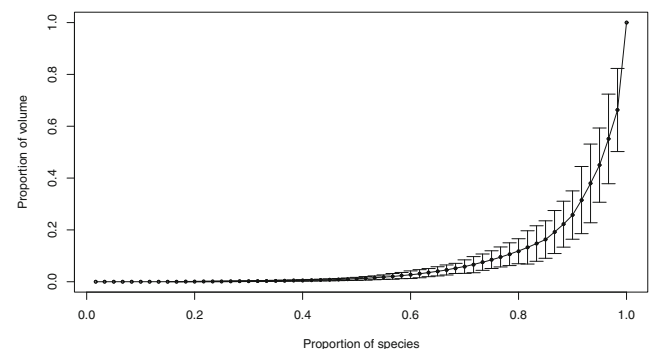


Fig. 5 Plot of the Lorenz curve estimated from wood volumes and of the 95% confidence band for the TOF of the Molise region

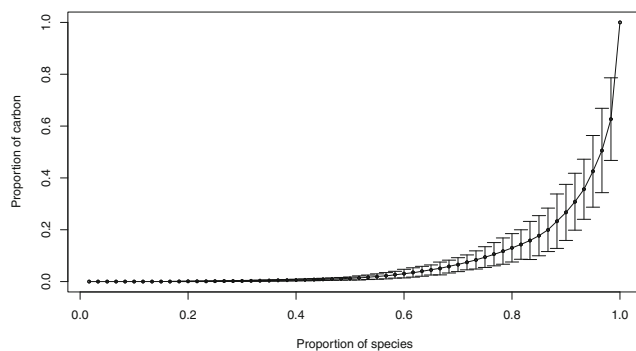


Fig. 6 Plot of the Lorenz curve estimated from above-ground carbon stocks and of the 95% confidence band for the TOF of the Molise region

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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