



# FLORE

# Repository istituzionale dell'Università degli Studi di Firenze

# Country-wide assessment of biodiversity, naturalness and old-growth status using national forest inventory data

Questa è la Versione finale referata (Post print/Accepted manuscript) della seguente pubblicazione:

Original Citation:

Country-wide assessment of biodiversity, naturalness and old-growth status using national forest inventory data / Costanza Borghi; Saverio Francini; Ronald E. McRoberts; Francesco Parisi; Fabio Lombardi; Susanna Nocentini; Alberto Maltoni; Davide Travaglini; Gherardo Chirici. - In: EUROPEAN JOURNAL OF FOREST RESEARCH. - ISSN 1612-4677. - ELETTRONICO. - (2024), pp. 0-0. [10.1007/s10342-023-01620-6]

Availability:

This version is available at: 2158/1352706 since: 2024-03-26T15:05:02Z

Published version: DOI: 10.1007/s10342-023-01620-6

*Terms of use:* Open Access

La pubblicazione è resa disponibile sotto le norme e i termini della licenza di deposito, secondo quanto stabilito dalla Policy per l'accesso aperto dell'Università degli Studi di Firenze (https://www.sba.unifi.it/upload/policy-oa-2016-1.pdf)

Publisher copyright claim:

(Article begins on next page)

#### **ORIGINAL PAPER**



# Country-wide assessment of biodiversity, naturalness and old-growth status using national forest inventory data

Costanza Borghi<sup>1</sup> · Saverio Francini<sup>1,5</sup> · Ronald E. McRoberts<sup>3</sup> · Francesco Parisi<sup>4,5</sup> · Fabio Lombardi<sup>6</sup> · Susanna Nocentini<sup>1</sup> · Alberto Maltoni<sup>1</sup> · Davide Travaglini<sup>1</sup> · Gherardo Chirici<sup>1,2,5</sup>

Received: 19 November 2022 / Revised: 22 September 2023 / Accepted: 6 October 2023 / Published online: 4 November 2023 © The Author(s) 2023

## Abstract

Assessing forest biodiversity, naturalness and old-growth status (B-N-OG) is crucial for supporting sustainable forest planning, yet comprehensive monitoring networks specifically designed for such purposes are lacking in many countries. National Forest Inventories (NFIs) are the official source of statistics on status and trends of forests. While initially designed for wood production assessment, NFI data may be pivotal for ecological forest monitoring, thanks to their robust sampling protocolsenabling statistical inference—and regular field campaigns that ensure continuous information updates. As a consequence, in this study we explore the potential of NFIs for estimating B-N-OG indexes, aiming to establish compatible, scientifically relevant, and cost-effective indicators using existing NFI data at a European level. Based on data from the 2005 Italian NFI collected from 6563 plots, 18 indicators were selected following previous experiences and then used to estimate B-N-OG aggregated indexes. Relationships between the 18 indicators and the three indexes were investigated, along with comparisons of their relationships relative to forest type categories, management types and protected versus non-protected areas. Results confirm that NFI data offer valuable insights into specific B-N-OG indexes, especially concerning forest structure and deadwood. Moreover, the indexes contribute to developing meaningful relationships across geographic regions, forest categories and types of management. However, limitations in NFI field protocols are evident, as they are not explicitly designed for certain indicators. The study suggests the potential for NFIs to evolve into accessible, harmonized European reference networks for B-N-OG assessment for better supporting sustainable forest management, planning and conservation decisions related to forest ecosystems.

Keywords Protected areas · Microhabitats · Deadwood · Saproxylic beetles · Ecological indicators · Italian forests

Communicated by Peter Biber.

Saverio Francini saverio.francini@unifi.it

- <sup>1</sup> geoLAB-Laboratorio di Geomatica Forestale, Dipartimento di Scienze e Tecnologie Agrarie, Alimentari, Ambientali e Forestali, Università degli Studi di Firenze, Via San Bonaventura 13, 50145 Florence, Italy
- <sup>2</sup> Fondazione per il Futuro delle Città, Florence, Italy
- <sup>3</sup> Department of Forest Resources, University of Minnesota, St. Paul, Minnesota 55108, USA
- <sup>4</sup> Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise, c.da Fonte Lappone, 86090 Pesche, IS, Italy
- <sup>5</sup> NBFC, National Biodiversity Future Center, 90133 Palermo, Italy
- <sup>6</sup> Dipartimento di Agraria, Università Mediterranea di Reggio Calabria, Località Feo di Vito, 89122 Reggio Calabria, Italy

# Introduction

Forests and woodlands cover one-third of the global land surface (FAO and UNEP 2020), providing multiple benefits to society and contributing to sustaining human well-being (Kok et al. 2017; Haines-Young and Potschin 2018; Orsi et al. 2020). Despite the important benefits that forests grant, the provision of these services is threatened by climate change, over-harvesting and by the loss, degradation and fragmentation of forest landscapes and ecosystems (FAO 2015; Felipe-Lucia et al. 2020). In this context, sustainable forest management—management that concomitantly maintains forest biodiversity, productivity, regeneration capacity and vitality, as well as forests' potential to fulfill a wide range of functions and services (Ministerial Conference on the Protection of Forests in Europe 2007)—has been recognized as crucial to circumvent biodiversity loss. Indeed, forest biodiversity (CBD 2006) plays a crucial role in the variety of benefits forests can supply (Mori et al. 2017; Brockerhoff et al. 2017) thanks to the interconnection of its components, including structure (Gao et al. 2014; Bohn and Huth 2017; Ćosović et al. 2020; Toivonen et al. 2022), composition (Drever et al. 2006; Gao et al. 2015) and functions (Hilmers et al. 2018). Yet, the complex nature of ecosystems also poses challenges for biodiversity assessment (McElhinny et al. 2005; Schleicher-Tappeser 2018). In fact, an agreed definition of biodiversity still does not exist (Camia et al. 2023), but as is clear from Lyashevska & Farnsworth (2012), we can refer to forest biodiversity as a measure of the total complexity within a forest habitat considering the total variety of life forms (Wilson 1988).

In such a context, estimating biodiversity is challenging, and the scientific community has been actively engaged in trying to define the different components and dimensions of biodiversity for purposes of identifying variables that can be used for estimating and reporting spatial and temporal biodiversity trends (Pereira et al. 2013).

In this context, assessing forest biodiversity requires evaluating the extent to which forests are influenced by natural processes and free from human intervention (Reif and Walentowski 2008; Winter 2012; Côté et al. 2021), also known as naturalness. Assessing forest naturalness not only helps in accurately estimating and reporting the ecological condition of forests for biodiversity protection, but also plays a crucial role in establishing objective criteria for identifying natural, old-growth forests (Buchwald 2005). In fact, old-growth forests, which exhibit structural attributes and successional processes resulting from minimal human management and disturbances, play an essential role in biodiversity conservation (Paillet et al. 2010). Additionally, their complex structures support the abundance of microhabitats (Kozák et al. 2018; Parisi et al. 2021). Identifying the characteristics of old-growth forests-here referred to as old-growth status—is crucial for searching for potential gaps in the network of protected areas (European environment agency 2014; Côté et al. 2019), particularly in Europe where human impact has historically been substantial (Potapov et al. 2017). Therefore, gaps in monitoring can lead to the ineffective implementation of protection policies (Ette et al. 2023). This may explain why, despite international conventions such as the United Nations Strategic Plan for Forests 2030 (United Nations 2019) and the EU Biodiversity Strategy for 2030 (European Commission 2020), current rates of biodiversity loss remain large (Waldron et al. 2017; Ette and Geburek 2021). Indeed, to effectively achieve forest ecosystem conservation goals, it is crucial to have technically sound and economically viable methods that include welldefined criteria and indicators to support sustainable forest management and planning at multiple levels: local, regional and national (Heink and Kowarik 2010; Maes et al. 2018; FAO 2020; Lier et al. 2022).

In this context, NFIs may play a crucial role in evaluating and estimating indicators related to forest biodiversity, naturalness and old-growth status (B-N-OG) (Corona et al. 2011; Storch et al. 2018), given the extensive data routinely collected from numerous sample plots (Heym et al. 2021). The number of studies that have assessed the utility of NFI data for monitoring biodiversity, naturalness or old-growth status is relatively small, and none has compared estimates of B-N-OG simultaneously using data for an entire countrylevel NFI (Winter 2008; Corona et al. 2011; Pignatti et al. 2012; Chirici et al. 2012; Storch et al. 2018; Heym et al. 2021).

It is important to underline that in this study we inherited the definitions used in quantitative social sciences (e.g., Stockemer et al. 2018): The term "indicator" is used when its calculation is based only on one variable measured or estimated, while the term "index" is used when its calculation is based on multiple indicators. So, for example, the total volume of deadwood is an indicator that can be aggregated with others to estimate a biodiversity index. The objective of this study was to test a set of indicators satisfying three criteria: (i) they must be able to estimate aggregated indexes of B-N-OG, (ii) they should be supported by substantial scientific evidence, and (iii) they can be estimated using existing NFI datasets, thereby ensuring their compatibility with available data sources (Saint-André and Hervé 2015). After a comprehensive literature review, we selected 18 indicators that were then used to estimate B-N-OG indexes using raw data from 6563 plots visited in the field in the framework of the 2005 Italian NFI (Gasparini and Tabacchi 2011). To evaluate the potential usefulness of these indicators, we estimated pairwise correlations among them and the three aggregated B-N-OG indexes, their spatial distribution and relationships between the indicators and the indexes separately for protected areas and individual forest type categories. Finally, we used the results of our analysis to propose integration of new NFI variables to facilitate and optimize B-N-OG assessments.

# Materials

#### Study area

Our study is conducted over the entirety of Italy which is divided into 20 Administrative Regions and 107 provinces. Forests in Italy cover nearly 11 million ha—more than one-third of the total Italian territory (INFC 2007a, b)—and are mainly found in mountainous, hilly and interior regions. Italian forests are composed mostly of deciduous species (68%), mainly oaks (*Quercus. cerris* L., *Q. pubescens* W., *Q. ilex* L.,

*Q. petraea* (M.) L., *Q. robur* L.), European beech (*Fagus sylvatica* L.) and chestnut (*Castanea sativa* M.). While dominant conifers are Norway spruce (*Picea abies* K.) and pines, the latter are mostly located in mountainous (e.g., *Pinus sylvestris* L. and *P. nigra* A.) and coastal areas (e.g., *P. pinea* L., *P. pinaster* A. and *P. halepensis* Mill.). Overall, due to its latitudinal and altitudinal variability, Italy is a very biodiverse country, hosting half of the European forest types (Barbati et al. 2014).

## Italian national forest inventory

The Italian NFI was designed to satisfy the reporting requirements set by the United Nations Framework Convention on Climate Change. NFI estimates play a crucial role in various national and international reporting processes, including Italy's national forest report, Kyoto Protocol, national natural capital report, European report on sustainable forest management and the FAO's global Forest Resource Assessment. The 2005 Italian NFI has three phases and is based on an unaligned systematic sampling design (Fattorini et al. 2006) featuring a field plot randomly located in each cell of a 1 km  $\times$  1 km systematic grid (INFC 2007a, b). In the first phase, 301,000 sample points are photo-interpreted to identify their land use/land cover classes consistent with the first level of the CORINE Land Cover nomenclature system (Bossard et al. 2000) and with the FAO forest definition (Gasparini and Tabacchi 2011; FAO 2020). In the second phase, a subsample of approximately 30,000 forest and other wooded land sample points was selected from the first-phase set and visited in the field to assess forest categories and other qualitative information. Lastly, a third-phase sample of approximately 7,000 sample points was selected from among the 30,000 second-phase points. These points became the centers of 13-m radius NFI plots that were visited in the field to acquire quantitative data. The resulting database was used with statistically rigorous, unbiased design-based estimators to produce official estimates at both regional and national levels for approximately 50 qualitative and quantitative forest variables, mainly developed to estimate wood resources and the amount of carbon stocked and removed from the atmosphere.

In this study we used the data collected in the field during the third phase of the 2005 NFI cycle. After removing data for inaccessible plots and plots in temporarily unstocked areas, data for 6563 plots classified into 20 forest categories remained (Fig. 1). In Appendix, section A, Table 2 we report and explain the available raw 2005 Italian NFI data that we used.

# Copernicus high-resolution layers: imperviousness degree

To assess forest naturalness, along with other single-variable indicators, we used an indicator of hemeroby that is based on the geographical distance of an NFI plot from the nearest impervious map unit as mapped by Sentinel-2 imagery in the Copernicus High-Resolution Layer, denoted as Imperviousness Degree (HRL IMD) for the year 2006 (Congedo et al. 2016; European Environment Agency 2018), (https://land. copernicus.eu/pan-european/high-resolution-layers/imper viousness, last accessed on September 13, 2022). The HRL IMD consists of a 20-m resolution pan-European raster layer produced using a semi-automated classification, based on calibrated NDVI (Kuc and Chormański 2019). The environmental indicator mapped by HRL IMD is defined as "human-produced surfaces that are essentially impenetrable by rainfall" (Moglen and Kim 2007; Strand 2022). The HRL IMD map was reclassified into a Boolean impervious/nonimpervious mask, and the distance from the nearest impervious map unit was calculated for each NFI plot.

## Italian network of protected areas

To study the potential relationship between the selected B-N-OG indexes and ecological and management conditions, we included the Italian protected areas in our analysis. We considered both the official dataset of protected areas from the Italian Ministry of Environment (EUAP—*Elenco Ufficiale delle Aree Protette*) and the Natura 2000 network.

The EUAP includes 24 National Parks, 144 State Natural Reserves, 134 Regional National Parks, 365 Regional Natural Reserves and 171 Other National Protected Areas (Fig. 2, *panel a*) for a total of 2,878,963 ha, in total approximately 11% of national territory (Boitani et al. 2003). The Natura 2000 consists of 2,314 sites (Fig. 2, *panel b*) established based on the "Habitats" and "Birds" European Directives (Council Directive 92/43/EEC and Directive 2009/147/EC, respectively), covering 5,844,915 ha, or approximately 19% of the national territory (Ministry of Environment and Energy Security 2022).

The two networks have substantial overlap. Almost 40% of the protected areas were included in both the EUAP and Natura 2000 areas. For this reason, we considered only the classification protected versus non-protected areas, independently of whether a plot was in EUAP or in Natura2000 area. Of the 6,563 NFI plots, 67% were outside protected areas, while the remaining 33% were included in EUAP or Natura 2000 areas.

Fig.1 Spatial distribution and relative frequency of Italian NFI (INFC 2007a, b) forest type categories



# **Methods**

Based on a comprehensive literature search of scientific publications and reports, we defined 18 indicators (Sect. "Plotlevel indicators used to assess B-N-OG"), each of which was further classified as relevant or not relevant for the three biodiversity indexes, B, N and OG. The indicators were then calculated for each of the 6,563 NFI plots (Sect. "Statistical analysis"). To facilitate aggregation for estimating the indexes, we normalized the indicators to the range 0–1 by applying a min–max normalization, the same approach used by Storch et al. (2018). The three B-N-OG aggregated indexes were then estimated for each plot as the average of the selected indicators. Finally, the resulting database was analyzed to investigate multiple relationships: i) pairwise correlations among the different indicators, ii) spatial distributions to highlight geographical trends, iii) distributions for individual forest type categories and management types to better understand different levels of forest biodiversity, naturalness and oldgrowth status in distinct ecosystems and iv) the effects of the network of protected areas.

# Plot-level indicators used to assess B-N-OG

In the following sections we describe the indicators selected and their relevance for B-N-OG assessment. We classified the indicators into five categories: (i) composition, (ii) Fig. 2 Italian network of protected areas. Panel a (left) reports the Italian protected areas according to the EUAP; on panel b (right) different colors represent the Natura 2000 network in relation to the year of institution. On the background, the Copernicus High-Resolution Layer "Tree cover density" (ESA, 2018)



structure, (iii) regeneration, (iv) deadwood and (v) hemeroby (Table 1).

(i) Composition

First, we calculated the number of tree species, a very straightforward and frequently used indicator of biodiversity (Van Den Meersschaut and Vandekerkhove 2000; Sullivan et al. 2001; Crist et al. 2003).

The distribution of tree species was then characterized using the Shannon and the Evenness indexes; both calculated based on the basal area. The Shannon index, commonly used in ecological studies, served as a direct measure of compositional diversity (Varga et al. 2005; Lexerød and Eid 2006; Ozdemir et al. 2008; Arekhi et al. 2017). The Evenness index, which describes the strength of interactions within communities and functional trait diversity, was calculated as the ratio of the observed Evenness index to its maximum value with the same number of species (Pielou 1969).

(ii) Structure

For structural diversity we first considered growing stock volume (GSV) as reported by the NFI (Tabacchi et al., 2011). Then we considered the variability of tree height as estimated by the standard deviation of height as a measure of vertical forest layering (Zenner 2000). In addition, Stand Density Index (SDI) (Reineke 1933) was used to describe the density of living trees on each NFI plot. SDI is characterized in terms of quadratic mean diameter and number of trees per hectare by calculating the number of stems per hectare in these stands related to 25 cm mean diameter. SDI is independent of site conditions and tree age (Zeide 2005), the latter not commonly recorded during NFI field measurements.

The presence of large trees is often considered a relevant indicator for B-N-OG assessment (Basile et al. 2020; Asbeck et al. 2022; Marziliano et al. 2021; Larrieu et al. 2021, 2022; Santopuoli et al. 2022). Tree dimensions can be considered a proxy for the age of the trees, and the presence of old trees is a direct measure of OG. Large trees are also more frequently habitat trees, and the tree-related microhabitats they host are of primary concern for forest biodiversity because they can harbor many endangered specialized species of flora and fauna. To estimate tree size, we considered both maximum tree height and maximum DBH for all living trees. We also considered a frequency index at the plot level which determines the occurrence of living trees with DBH≥40 cm. While the threshold for identifying large trees could be differ by country (Gilhen-Baker et al. 2022), the Italian Environment Ministry proposed a 40-cm threshold for living trees in the Mediterranean area; we used this threshold for current study (Blasi et al. 2010).

Lastly, the Gini coefficient, widely used in forestry, was used to analyze diversity in the distribution of tree sizes (Valbuena et al. 2016; Meyer et al. 2021; Motta et al. 2022; Hirschmugl et al. 2023)

#### (iii) Forest regeneration

Forest regeneration has been recognized as an indicator of forest biodiversity within the guidelines of sustainable forestry issued through the Ministerial Conferences on the Protection of Forests in Europe and the Montréal Process (Ministerial Conference on the Protection of Forests in Europe 2007; Montréal Process 2009). For this study, regeneration was estimated using three indicators based on the methods and definitions used in the Italian NFI. The first indicator of

| Indicator (abbreviation)                                | Component    | B-N-OG relevance | Main references  |
|---|--------------|------------------|--|
| Growing Stock Volume<br>(GSV)                           | Structure    | B-OG             | Chirici et al. (2012)<br>Liang et al. (2016)   |
| Variability of tree height<br>(v_H)                     |              | В                | Zenner (2000)<br>Heym et al. (2021)  |
| Stand Density Index<br>(SDI)                            |              | В                | Reineke (1933)   |
| Max DBH<br>(max_DBH)                                    |              | B-OG             | Ziegler (2000)<br>McElhinny et al. (2005)  |
| Max height<br>(max_H)                                   |              | B-OG             | Spies (1998)<br>McElhinny et al. (2005)  |
| Large living trees<br>(L_trees)                         |              | B-OG             | Blasi et al. (2010)<br>Ćosović et al. (2020)   |
| Gini coefficient<br>(GINI)                              |              | В                | Cordonnier and Kunstler (2015)<br>Valbuena et al. (2016)                             |
| Number of species (n_SP)                                | Composition  | В                | Crist et al. (2003)<br>Zhang et al. (2012)   |
| Shannon index<br>(S)                                    |              | В                | Shannon (1948)   |
| Evenness<br>(E)   |              | В                | Hill (1973)<br>Stirling and Wilsey (2001)  |
| Deadwood volume (DWD)                                   | Deadwood     | B-N-OG           | Chirici et al. (2012)  |
| Dead-to-living volume ratio (DLR)                       |              | B-N-OG           | Hahn and Christensen (2005)<br>Wirth et al. (2009a, b)                               |
| Stump decay class ratio<br>(DWD_stump_ratio)            |              | B-OG             | Bertini et al. (2010),<br>Badalamenti and Cairone (2017)<br>Parisi et al. (2020a, b) |
| Standing dead trees decay class ratio (DWD_stand_ratio) |              | B-OG             | Vuidot et al. (2011)<br>Parisi et al. (2016, 2019)                                   |
| Regeneration class I<br>(REG_1)                         | Regeneration | В                | Chirici et al. (2012)  |
| Regeneration class II<br>(REG_2)                        |              | В                |  |
| Regeneration class III<br>(REG_3)                       |              | В                |  |
| Distance from anthropogenic disturbance (HEM)           | Hemeroby     | Ν                | Jalas (1955)<br>Winter et al. (2010)<br>McRoberts et al. (2012)                      |

 Table 1
 Single-variable indicators and how they were combined to create biodiversity, naturalness and old-growth status (B-N-OG indexes), with main references

regeneration refers to the number of small trees with heights between 50 and 130 cm; the second indicator is for small trees taller than 130 cm but with maximum DBH of 2.4 cm, and finally the third indicator was similar to the second but with a maximum DBH of 4.4 cm.

(iv) Deadwood

The amount of deadwood volume plays a crucial role for assessing B-N-OG because it influences the presence of bryophytes, lichens and saproxylic beetles and is also used for assessing N and OG (DeWalt et al. 2003; Lassauce et al. 2011; Parisi et al. 2016, 2019, 2020a; Czerepko et al. 2021). In this study we also considered the ratio of dead-to-living biomass because it contributes to understanding ecosystem dynamics (Olson 1963; Harmon et al. 2001; Hahn and Christensen 2005; Wirth et al. 2009a, b). The assessment of deadwood volume includes use of a classification into five classes (Maser et al. 1979) that offer valuable information for assessing the development stage of forest stands (Bertini et al. 2010; Parisi et al. 2019, 2020a). In addition, it is associated with the presence of diverse organisms that utilize trees at different decay stages (Franklin 1981; Gibbons and Lindenmayer 2002; DeWalt et al. 2003; Vuidot et al. 2011), because it is useful for assessing the impact of deadwood on soil carbon storage (Błońska et al. 2023). For these reasons, we included two indicators, one for stumps and one for standing dead trees, each calculated as a ratio between the volume in more decayed classes divided by the volume in the less decayed classes.

#### (v) Hemeroby

Hemeroby can be considered as the opposite of naturalness and is used to measure the impact of humans on the ecosystems (Chirici et al. 2012). As an indicator of hemeroby for this study, we calculated the distance of each NFI plot from the nearest impervious map unit (urban areas, artificial surfaces) as mapped by the European Earth Observation Copernicus program. Firstly, we constructed a Boolean impervious/non-impervious map reclassifying the Copernicus High-Resolution Layer—Imperviousness Density map (European Environment Agency 2018) for the year 2006 at 20 m resolution. Then, we constructed a map of the distance from the artificial surface class of the Boolean map using a maximum distance of 10 km and extracted a distance for each NFI plot. The values of the indicator were standardized on the basis of a threshold of 10 km.

#### **Statistical analysis**

The values of the 18 standardized indicators were estimated for each of the 6,535 NFI plots and then averaged at national, provincial and regional levels, as well as for protected areas and for each of the 20 forest type categories outlined in the Italian NFI. The distribution of the 18 selected indicators is reported in Fig. 3.

The indicators were averaged for the five categories (composition, structure, regeneration, deadwood, hemeroby) and on the basis of the three B-N-OG indexes. Multiple statistical analyses were conducted using the database. First, we estimated correlations for all pairs of the 18 indicators from Table 1 (Wei et al. 2017). Second, we conducted a principal component analysis (PCA), a multivariate technique that reduces the data's dimensionality while preserving their covariances. When applied to our data (18 indicators for 6535 observations), PCA finds the eigenvalues and eigenvectors of the covariance matrix of each indicator. The purpose of the PCA was to better understand the relationships among the indicators.

Combining the correlation analysis and the PCA, we estimated the pairwise correlations between the indicators to assess their interrelationships (highlighting overlaps and gaps) and to ensure a rigorous quantitative approach for analyzing their redundancy when the indicators are aggregated to estimate the B-N-OG indexes. The pairwise correlations (r) among B-N-OG indexes were then analyzed using the Pearson correlation method. Analyzing the correlation between B-N-OG indexes serves the purpose of understanding underlying ecological processes and dynamics within forest ecosystems. For instance, positive correlations between B-N-OG may suggest shared ecological traits or processes that led the indexes to increase, while negative correlations may indicate trade-offs between indexes. The same approach was also used to analyze the relationships between the five different categories (composition, structure, regeneration, deadwood and hemeroby).

Finally, a one-way analysis of variance (ANOVA) was conducted to analyze the relationship between B-N-OG



**Fig. 3** Distribution of the 18 selected indicators



**Fig.4** Correlation matrix among Italian NFI's derived indicators. Statistically insignificant correlations (p < 0.01) are left blank

indexes and the classes of specific variables available in external datasets. Specifically, the one-way ANOVA was used to assess statistically significant differences among the means of B-N-OG indexes (i) between areas inside and outside the boundaries of protected areas (considering both EUAP and Natura 2000 networks) and (ii) between different forest type categories. To better understand the relationships between the three aggregated B-N-OG indexes and the forest type categories we performed a ranking analysis. All the analyses were performed using R software (Chambers 2008; Wei et al. 2017).

# Results

# Analysis of single-variable indicators

The pairwise correlations between the 18 indicators are presented in Fig. 4, while the results of the PCA are shown in Fig. 5. Further details are available in Appendix, section A, Table 3 and 4.



**Fig. 5** Results of the PCA showing the first two components. The plots in the main graph are colored based on the 20 forest categories (same colors and codes of the map in Fig. 1). In the smaller graph the

same plot is instead colored on the basis of the belonging to a protected area (green) or not (red). (Color figure online)

For a large proportion of the cases, the relationships between the indicators were statistically meaningful even though the correlations were quite variable. Considered in terms of absolute values, the max\_H, GSV and the L\_trees had the largest average correlations, r=0.27 and r=0.23, respectively. The PCA confirmed the same results with GSV, v\_H, SDI, max\_DBH and max\_H having the largest eigenvalues with the first two principal components together explaining only the 38% of the total variability.

On the opposite side, HEM (as the distance from artificial surfaces) was less correlated with the other indicators (average r=0.06), with greatest (positive) correlation with the GSV. Small correlations were also found for the three regeneration indicators with average r ranging between 0.08 and 0.1. Once again, PCA confirmed these results with HEM, REG\_1, REG\_2 and REG\_3 having the smallest eigenvalues.

The largest correlation was between GSV and max\_H (r=0.79) and max\_DBH (r=0.77).

In general, the average agreement between the seven indicators belonging to the "structure" category is large (r=0.48) and always positive. The relationship between the three indicators belonging to the "composition" category is even greater in absolute values (0.74) because the relationships between E and the other two indicators, n SP and S, were r = -0.52 and r = -0.85, respectively. A different behavior is shown by the deadwood category indicators with only small agreement among them with average absolute value of only r = 0.08. The main indicator of this category (DWD) is positively related to GSV (r=0.35), and consequently also with the max\_H (r=0.31) and max\_ DBH (r=0.24), as well as with L trees (r=0.22) and SDI (r=0.19). The average correlation for the three regeneration category indicators is always positive (r=0.32), although correlations with indicators external to this category were small. Correlations between GSV and the B-N-OG indexes were small, ranging from r = 0.12 to r = 0.16. Finally, HEM had only small correlations with all the other indicators with the greatest values for GSV (r=0.10) and n\_SP (r = -0.125). The correlations and the statistical significances among indexes for the five categories is reported in Fig. 6. More details are available in Appendix, section A, Table 5 and 6.

The results confirm a positive and consistent agreement of structure with deadwood and composition (r=0.2 and r=0.14, respectively), while the relationship between composition and deadwood is weaker (r=0.1). Regeneration has weak negative relationships with structure and deadwood and no meaningful relationship with composition. Finally, hemeroby shows a weak positive relationship with structure, and negative relationship with the other categories of indicators.



Fig. 6 Correlations and statistical significances among B-N-OG indexes components. Statistically insignificant correlations (p < 0.01) are left blank

#### Analysis of aggregated B-N-OG indexes

Following are the results of aggregating the indicators to estimate the indexes. Plot-level B estimates ranged between 0.031 and 0.357 with mean of 0.149 and standard deviation (sd) of 0.042; N estimates ranged between 0 and 0.435 with mean of 0.060 and sd of 0.048, while OG estimates ranged between 0 and 0.441 with mean of 0.088 and sd of 0.054) (Fig. 7). More details on B-N-OG estimates at plot-level are available in Appendix, section B.

The correlations between the three aggregated B-N-OG indicators are also reported in Fig. 7. The data demonstrated a stronger relationship between plot-level B and OG (r=0.81), than between B and N (r=0.15) or between N and OG (r=0.25).

Mean estimates of the three aggregated B-N-OG indexes demonstrated relevant diversity across Italy. Greatest B and OG means were in the northern regions, i.e., Trentino Alto Adige, Veneto and Friuli Venezia Giulia (B 0.178, 0.169, 0.166 and OG 0.140, 0.110, 0.109, respectively) (Fig. 8). On the other hand, the southern regions, such as Calabria, Puglia and Sicilia, had the greatest N mean estimates (i.e., 0.089, 0.084 and 0.082, respectively).

Further detail of B-N-OG at national and regional levels is available in Appendix, section B.

Figure 9 shows the relationships between regional forest area—as reported in official NFI statistics for 2005 (INFC 2007a, b)—and the relative mean B-N-OG estimates.

Fig. 7 Histogram distributions and correlations between the biodiversity, naturalness and old-growth status (B-N-OG) indexes







Fig. 9 B-N-OG mean estimates in Italian regions and forest area (INFC 2007a)

As reported in Fig. 10, the greatest estimates of the mean for the three indexes were for the mountainous coniferous forest type categories (dominated by fir, spruce, stone pine and larch), while the smallest mean estimates were for broadleaved artificial plantations including poplar plantations, especially regarding N.

Forest area NFI 2005 [ha]



Fig. 10 Biodiversity, naturalness and old-growth status (B-N-OG) mean estimates (with standard deviation bars) over plots in the Italian NFI plots among the 20 Italian NFI forest categories. The Italian NFI forest categories are sorted by the overall B-N-OG mean, in descending order

The ANOVA suggested that the main effect of species groups, conifers or broadleaves, on B-N-OG means was statistically significant (p < 0.001). Further information on ANOVA results is reported in Appendix, section D.

After ranking the forest type categories on the basis of the mean estimates of the three indexes, we found a strong relationship not just between B and OG (r=0.929) but also between N and B (r=0.693) and N and OG (r=0.665). The greatest rank order was always obtained for beech, fir, spruce and larch forests (Fig. 11).

#### Relationship with protected areas

More than one-third of the plots are located inside protected areas (2154 plots, 32.8% of the total). Specifically, the Natura 2000 network comprises 1924 plots, while EUAP comprises 1062 plots with 832 plots located in both



Fig. 11 B-N-OG pairwise ranking in forest categories

European Journal of Forest Research (2024) 143:271-303

EUAP and Natura 2000 protected areas. Considering that each Natura 2000 site could host more than one habitat, most NFI plots were located in habitats "Quercus ilex and Quercus rotundifolia forests" (9340) and "Apennine beech forests with Taxus and Ilex" (type 9210) with 925 and 830 plots, respectively (Biondi et al. 2010; Commissione Europea 2013). Further information and habitat descriptions are available in Appendix, section C.

Mean B estimates for inside and outside protected areas were not statistically significantly different (p=0.483). On the other hand, the differences between mean N and OG inside and outside EUAP protected areas were statistically significant (p < 0.001 and p=0.005, respectively). Hence, mean N and OG over plots inside protected areas were larger than outside protected areas (N 0.077 vs. 0.052, OG 0.091 vs. 0.087).

Figure 12 shows the distribution of B, N and OG inside (blue) and outside (red) protected areas.

Among Natura 2000 habitat macroclasses (Biondi et al. 2010), temperate mountains coniferous forests registered the greatest B-N-OG estimates (0.170, 0.101, and 0.132,

respectively), while deciduous Mediterranean forests and sclerophyllous Mediterranean forests registered the smallest estimates for all the three indexes (Fig. 13). Moreover, mean B estimates for inside and outside protected areas were not statistically different (p=0.280). Conversely, the differences between mean N estimates and between mean OG estimates inside and outside protected areas were statistically significant (p < 0.001 and p = 0.006, respectively).

# Discussion

Threats to forest habitats are likely to increase, mostly due to human-related activities such as climate change, urbanization and habitat loss and degradation (Seto et al. 2012; Aronson et al. 2014; Curtis et al. 2018; Kondratyeva et al. 2020). In this scenario, multiple international processes (Montréal Process 2009; Maes et al. 2018; Convention on Biological Diversity 2019; Forest Europe 2020; FISE 2021) require consistent tools to assess and report on B-N-OG.



Fig.12 Biodiversity, naturalness and old-growth status (B-N-OG) distribution inside and outside protected area



Fig. 13 Biodiversity, naturalness and old-growth status (B-N-OG) mean estimates over plots, per 'Natura 2000 habitats' macroclasses. The classes are sorted by the overall B-N-OG mean per habitat, in descending order

These requirements could be fulfilled by implementation of a sound, multipurpose, forest monitoring system based on data acquired from multiple sources (Chirici et al. 2011, 2012; Rondeux et al. 2012; Reise et al. 2019). In such a context, a relevant question is whether data routinely acquired by NFIs can contribute to such monitoring systems. For this study, we tested a set of indicators for assessing forest B-N-OG indexes using data acquired by the Italian 2005 NFI.

#### Single-variable indicators

When analyzed in terms of single-variable indicators, on the basis of both PCA and correlation analysis, our results confirm the relevance of the GSV variable but at a greater level than previous studies such as Storch et al. (2018). GSV is, in fact, strongly correlated with both the B index (r=0.68)and the OG index (r=0.88). This is easily explicable from an ecological perspective view, at least in forest conditions typical of Italy where the accumulation of GSV is typical of less disturbed forest ecosystems that can accumulate a greater level of biodiversity and can evolve to conditions that have greater OG. This is confirmed by the finding that forest type categories with greater estimates of the aggregated B-N-OG indexes (beech, spruce, silver fir, larch and stone pine forests) are those dominating mountain areas in Italy. These areas are less disturbed by forest logging and by fires, while deciduous broadleaved forests dominated by oaks (mainly Q. cerris and Q. pubescens) together with Mediterranean forests are more disturbed by forest loggings of the coppice system and by fires.

Further, deadwood volume showed a strong, positive correlation with the presence of large trees, GSV and structural indicators in general. While data on deadwood are extremely relevant for assessing B-N-OG indexes from an ecological perspective, the Italian dataset was strongly characterized by the dominance of forests with very small deadwood values (Fig. 3). For this reason, more advanced indicators based on the analysis of just one component of deadwood volume were only weakly related to the overall aggregated indexes. Because we cannot generalize these results, these indicators should be reconsidered when analyzing regions characterized by greater values of deadwood volume.

Results for regeneration are similar to the results for deadwood, because only very limited regeneration was found for the plots (Fig. 3). Nevertheless, these indicators showed a general negative correlation with structure indicators—especially GSV, max DBH and height, and the presence of large trees—suggesting that greater forest structures could hinder certain stages of regeneration (class III, above all).

As expected, forest structure (i.e., variability of tree height and Gini coefficient) and composition indicators (i.e., Evenness) showed an overall negative pattern of correlation, apart from the number of species which was positively correlated with SDI and variability of tree height. As underlined in several other studies (Chirici et al. 2011; Galluzzi et al. 2019), the composition indicators estimated using NFI data consider only tree species, a very small component of the overall  $\alpha$ -biodiversity. Therefore, the results of this study should be interpreted with caution.

Additionally, the hemeroby indicator (i.e., calculated on the basis of the distance from anthropic disturbance) displayed small correlations with other indicators. Nevertheless, the correlations are still meaningful; for example, GSV is greater when the distance from urban areas increases because such areas are probably more difficult to access and thus less easily exploitable for forest operations.

Importantly, when we analyzed the PCA results (Fig. 5), we found an interesting possibility for clustering into subpopulations among plots on the basis of their forest type categories. A comprehensive quantitative cluster analysis is beyond the scopes of this study, but we tried to characterize the subpopulations using three ellipses in Fig. 5 that we labeled on the basis of the European forest type categories from Barbati et al. (2014). Mountain forests are thus dominated by Alpine and Appennine forests with beech, spruce, silver fir and larch, Mediterranean forests are those with holm and cork oaks together with Mediterranean pines, and finally thermophilus forests are instead dominated by deciduous broadleaved (mainly downy and Turkey oaks).

#### **Aggregated B-N-OG indexes**

When compared in an aggregated way, the B and OG indexes demonstrated strong correlation, while naturalness was mostly uncorrelated with either of them. This is, of course, easily explained because of the selection of the input indicators. However, when geographical regions and forest type categories are ranked based on the three indexes, interesting differences emerged between B and OG, too. The indexes have consistent estimates when compared across the different types of management types. High forests have the greatest estimates followed by uneven-aged systems then by even-aged forests and finally by coppice forests. An example for the B index is reported in Fig. 14.

From a geographical perspective, our results showed that the northern part of Italy, particularly Trentino Alto Adige, Veneto and Friuli Venezia Giulia, exhibited the greatest B-OG estimates, most probably for three reasons: (i) mountainous topography, (ii) dominant forest type categories with greater B-OG estimates and (iii) large amounts of deadwood and GSV (Giannetti et al. 2022; Vangi et al. 2021). Smaller levels of anthropogenic disturbance (Riitano et al. 2016), compared to northern regions, are related to the largest mean N estimates obtained in southern regions such as Calabria, Puglia and Sicilia. Forest fragments with large N estimates were mainly found in protected areas or remote mountainous regions which experienced fewer human disturbances



compared to forests nearby to population centers (e.g., Lombardi et al. 2012; Motta et al. 2006). Moreover, previous studies confirmed that habitat quality increases where human population become sparser (Newbold et al. 2015), such as from lowland to mountainous areas. The combined presence of protected areas in mountainous areas (Sallustio et al. 2015, 2017) and different forest management approaches used in the different forest type categories can indeed explain this trend in Italy.

It is interesting to note that despite artificial broadleaved plantations (including poplar) exhibiting the smallest B-N-OG estimates among forest type categories, artificial coniferous plantations displayed a different trend (Fig. 10). Indeed, several studies in Italy (De Meo et al. 2017b, a, 2022) demonstrated that artificial coniferous plantations could host large amounts of deadwood, compared to the average deadwood volume per hectare highlighted in the Italian NFI (Pignatti et al. 2009). Similarly, coniferous forests-particularly fir forests-exhibited some of the greatest mean estimates of B and OG. This finding aligns with previous research indicating that Alpine coniferous forests, including fir forests, have large volumes of deadwood compared to other European forest types (Barbati et al. 2014; Puletti et al. 2019). Here, the effects of windthrow events caused by climatic factors are compounded by limited harvesting in high-altitude forests or less accessible areas (Pignatti et al. 2009). Moreover, multiple studies conducted in Italy (Ciancio and Nocentini 2004; Travaglini et al. 2012; Parisi et al. 2016) highlighted the complexity of fir forests, emphasizing their

potential to reach old-growth conditions, even when mixed with broadleaved species. Additionally, larch and stone pine forests recorded the largest N mean estimates over plots, closely followed by fir forests, perhaps given their capacity to reach the upper altitudinal limit of the forest (Didier 2001; Blasi C. and Biondi E. 2017). Notably, forests dominated by broadleaf species are predominantly managed using the coppice system (Fabbio 2016; Gasparini and Tabacchi 2011), such as deciduous oaks (Quercus spp., 33%), European hophornbeam (Ostrya carpinifolia Scop., 17%), beech (Fagus sylvatica L., 13%), sweet chestnut (Castanea sativa Miller, 16%), which are usually grown as pure stands, and the evergreen holly oak (Quercus ilex L., 10%) forests. This approach holds great significance in Italy, because coppices account for 35% of the overall forest area and are the main source of wood production (INFC 2007a). Thus, our results indicated that these forest type categories tend to have smaller B-N-OG estimates, most probably because of the strong negative impact of the coppice system and the easy accessibility.

These results can support future forest management strategies for coppice forests, used in Italy for fuel-wood and biomass production. Due to its consistent impact on B-N-OG, future application of the coppice system should be reconsidered. If these results are confirmed, the conversion of coppice to high forests should be preferred.

Consistently with other studies (Winter et al. 2014), no large differences in the index estimates can be found between forests within or outside protected areas. This can be explained by considering that forest management and conservation rules can be applied in very different ways within the protected areas. Once again, it is important to underline that protected areas, and more specifically large National Parks, are predominantly located in highland or mountainous regions and have a historical association with depopulation (Romano 1995; Romano et al. 2021). NFI plots within these forests, adjacent to protected areas, may exhibit specific structural traits that are directly influenced by the N and OG status of the protected areas (Barredo et al. 2021). Furthermore, the significant differences found for mean N and OG over plots in protected forest areas-compared to plots located outside protected areas-could be also related to the large amount of deadwood (Parisi et al. 2022). Moreover, creation of protected areas is relatively new in ecological timescales and thus consolidated results of their protection could not be visible yet. Finally previous studies have already underlined the strong variability of environmental conditions in national parks due to their phytogeographic, ecological and physiognomic heterogeneity (Capotorti et al. 2012).

# Conclusions

The results of our test case demonstrate a useful assessment of forest biodiversity, naturalness and old-growthstatus (B-N-OG) based on NFI data at multiple scales, from national to local levels. Moreover, the proposed set of indicators incorporated additional variables that are not related to traditional inventory purposes (Corona 2016), thus aiming toward multipurpose resource surveys. The set of the indicators we used demonstrated that PCA can identify groups of the main dominant types of forest ecosystems in Italy. We found this to be an encouraging result for future applications in larger pan-European monitoring framework.

The use of B-N-OG indexes presented here could enhance design-based assessment at the national level, enlarging the added value of NFI for supporting conservation strategies and sustainable forest management planning with trend analysis over time (Ćosović et al. 2020).

Our results also highlighted several considerations regarding the potential of NFI data in B-N-OG assessment at the European level. Firstly, NFIs should consider the future possibility of including field assessment of specific variables more directly related to biodiversity indicators: (i) the presence/absence census of all vegetation components, thus including herbs and lichens in order to be able to report a more complete assessment of  $\alpha$ -diversity and (ii) tree-related microhabitats that can more accurately complement deadwood assessment for biodiversity monitoring purposes. Secondly, more resources for the harmonization/standardization of NFIs in Europe should be invested by the European Union and by the member countries; otherwise, differences in definitions and methods will hinder implementation of a complete pan-European forest monitoring system. Thirdly, because some basic historical forest variables such as the GSV that are traditionally designed for assessing the wood production of forests, were also important for monitoring B-N-OG, a more relevant role of remote sensing for such purposes can be hypothesized, because GSV can be quite easily mapped with remotely sensed data (Camia et al. 2023). In fact modern methods in combination with large datasets of multisource remotely sensed data can be used for accurately monitoring indicators (such as GSV) and forest disturbances trends in time.

Future recommendations can be envisaged for additional progress in the studies on forest biodiversity, naturalness and old-growth status, facilitating a more robust monitoring and comparison of results in Europe.

- More investments in NFIs to improve the consistency and comparability of B-N-OG indicators across different countries.
- More objective approaches for selecting the indicators. The aggregation of the indicators to create B-N-OG indexes is still very subjective. The method used in these cases is based on the opinion of experts and the review of previous studies, but the scientific background and the ideas of scientists related to such complex and debated disciplines may strongly and adversely affect the final decision on which indicators should be considered. For this study, we introduced the use of the well-known principal component analysis that can be used to support a more objective selection and aggregation of the indicators, eventually also on a weighted basis.
- More time-trend analysis. As correctly demonstrated in Reise et al. (2019), future studies should concentrate more on the analysis of temporal trends in the indexes using the NFI data acquired at multiple dates. Unfortunately, at the date when this study was initiated, data for NFI2015 in Italy were not yet available (Burrascano et al., 2023).
- More use of stratification. We think that all the indexes proposed should be applied with caution if not stratified based on potential conditions. In fact, areas affected by strong environmental limiting conditions (a typical example is for the island of Sardinia with extreme heat and drought) may result in small B-N-OG estimates. This can be easily implemented through stratification.

# Appendix A: 2005 Italian NFI raw data

See Tables 2, 3, 4, 5 and 6.

 Table 2
 A2005
 Italian
 NFI
 raw
 data
 per
 plot
 and
 single-tree
 levels

|   |       |  |   |   |   | I |
|---|-------|--|---|---|---|---|
| Quantitative data on living trees and deadwc                            | poo   |  |   |   |   |   |
| VFI-plot number   | ×     | Dry weight of small branches of living trees, per hectare  | Volume of stumps, per hectare   | × | Dry weight of regeneration individuals class $3 (h > 130 \text{ cm} d = 2.5 - 4.4 \text{ cm})$ , per hectare                        |   |
| Latitude of the S-W node of the NFI grid,<br>WGS84 datum                |       | Dry weight of stumps of living trees, per<br>hectare   | Dry weight of stumps, per hectare   |   | Organic carbon stock of regeneration<br>individuals class 3 ( $h > 130 \text{ cm } d=2.5-$<br>4.4 cm), per hectare                  |   |
| Congitude of the S-W node of NFI grid, WGS84 datum                      |       | Dry weight of total above-ground biomass<br>of living trees, per hectare                                     | Organic carbon stock of stumps, per<br>hectare  |   | Dry weight of shrubs—class 1 $(h = 50-130 \text{ cm})$ , per hectare  |   |
| North coordinate of the S–W node of NFI<br>grid, Gauss-Boaga projection |       | Organic carbon stock of total above-<br>ground biomass of living trees, per<br>hectare                       | Volume of coarse woody debris on the ground, per hectare  | × | Organic carbon stock of shrubs—class 1 $(h = 50-130 \text{ cm})$ , per hectare  |   |
| East coordinate of the S-W node of NFI grid, Gauss-Boaga projection     |       | Number of standing dead trees, per x hectare   | Dry weight of coarse woody debris on the ground, per hectare  |   | Dry weight of shrubs—class 2<br>(h > 130 cm $d=0-2.4$ cm), per hectare  |   |
| cone (Est = East, Ovest = West), Gauss-<br>Boaga projection             |       | Basal area of standing dead trees, per x hectare   | Organic carbon stock of the coarse woody debris on the ground, per hectare                                      |   | Organic carbon stock of shrubs—class 2 $(h > 130 \text{ cm } d = 0-2.4 \text{ cm})$ , per hectare                                   |   |
| Administrative region, Italian National<br>Statistics code              |       | Volume of standing dead trees (total x above-ground), per hectare  | Number of regeneration individuals class $\rightarrow$ 1 ( $h = 50-130$ cm), per hectare                        | × | Dry weight of shrubs—class 3 ( $h$ > 130 cm $d$ = 2.5–4.4 cm), per hectare  | _ |
| Administrative region, name   |       | Dry weight of the above-ground biomass<br>of standing dead trees, per hectare                                | Dry weight of regeneration individuals class 1 ( $h = 50-130$ cm), per hectare                                  |   | Organic carbon stock of shrubs—class 3 $(h > 130 \text{ cm} d = 2.5 - 4.4 \text{ cm})$ , per hectare                                |   |
| Forest category, code   | ×     | Organic carbon stock of the total above-<br>ground biomass of standing dead trees,<br>per hectare            | Organic carbon stock of regeneration<br>individuals class 1 ( $h = 50-130$ cm), per<br>hectare                  |   | Volume of wood (stem + large branches)<br>exploited in the 12 months preceding the<br>NFI survey, per hectare                       |   |
| Number of living trees, per hectare                                     | ×     | Current annual volume increment of liv- x ing trees, per hectare   | Number of regeneration individuals class $2 (h > 130 \text{ cm d} = 0-2.4 \text{ cm})$ , per hectare            | × | Dry weight of wood (stem + large branches)<br>exploited in the 12 months preceding the<br>NFI survey, per hectare                   |   |
| 3 as al area of living trees, per hectare                               | ×     | Dry weight correspondent to the current<br>annual volume increment of living trees,<br>per hectare           | Dry weight of regeneration individuals class 2 ( $h > 130 \text{ cm} d = 0-2.4 \text{ cm}$ ), per hectare       |   | Organic carbon stock of wood (total<br>above-ground biomass) exploited in the<br>12 months preceding the NFI survey, per<br>hectare |   |
| Volume of living trees (stem + large<br>branches), per hectare          | ×     | Organic carbon stock correspondent to<br>the current annual volume increment of<br>living trees, per hectare | Organic carbon stock of regenera-<br>tion individuals class 2 ( $h$ > 130 cm $d$ = 0–2.4 cm), per hectare       |   |   |   |
| Dry weight of stem + large branches of<br>living trees, per hectare     |       | Number of stumps, per hectare x  | Number of regeneration individuals class $\rightarrow$ 3 ( <i>h</i> > 130 cm <i>d</i> =2.5-4.4 cm), per hectare | × |   |   |
| Quantitative data on litter, fine wood debris .                         | and s | oil  |   |   |   |   |
| NFI-plot number   | x     | East coordinate of the S-W node of NFI grid, Gauss-Boaga projection  | Forest category, code   | x | Organic carbon stock of organic soil layer,<br>per hectare  |   |
| Latitude of the S-W node of the NFI grid, WGS84 datum                   |       | Zone (Est=East, Ovest=West), Gauss-<br>Boaga projection  | Dry weight of fine woody debris, per<br>hectare   |   | Organic carbon stock of upper (0–10 cm) mineral soil layer, per hectare   |   |

Plot-level

| Plot-level  |         |  |                      |  |           |   |       |
|---|---------|--|----------------------|--|-----------|---|-------|
| Longitude of the S–W node of N<br>WGS84 datum               | IFI gri | id, Administrative region<br>Statistics code                 | ı, İtalian National  | Organic carbon stock of<br>debris, per hectare | fine wo   | ody Organic carbon stock of deep (10-3<br>mineral soil layer, per hectare | ) cm) |
| North coordinate of the S-W no grid, Gauss-Boaga projection | de of l | NFI Administrative region                                    | ı, name              | Organic carbon stock of                        | litter, p | er hectare  |       |
| Single-tree level   |         |  |                      |  |           |   |       |
| Living trees  |         |  |                      |  |           |   |       |
| NFI-plot number   | х       | Basal area of the living tree x                              | Diameter at breast ] | height of the living tree                      | x D       | ry weight of total above-ground biomass of the living tree                |       |
| Living tree identification numbe                            | L       | Volume of the living tree (stem + large branches)            | Total height of the  | living tree                                    | C<br>×    | urrent annual volume increment of the living tree                         |       |
| Species code  | X       | Dry weight of stem + large<br>branches of the living<br>tree | Dry weight of smal   | l branches of the living tree                  |           |   |       |
| Vitality/integrity code<br>Standing dead trees              | x       | Expansion factor to hectare                                  | Dry weight of the s  | tump of the living tree                        |           |   |       |
| NFI-plot number   | x       | Vitality/integrity code x                                    | DBH of the dead tr   | ee   | x<br>V    | olume of the dead tree (stem + large branches)                            | ×     |
| Dead tree identification number                             |         | Decay class x  | Total height of the  | dead tree                                      | x<br>D    | ry weight of the above-ground biomass of the dead tre                     |       |
| Species code  | x       | Expansion factor to hectare x                                | Basal area of the de | ad tree  | x         |   |       |
| Stumps  |         |  |                      |  |           |   |       |
| NFI-plot number   | x       | Time of the cut  | Stump volume         |  | x St      | ump height  |       |
| Stump identification number                                 |         | Decay class x  | Dry weight of the s  | tump   |           |   |       |
| Species code  | x       | Expansion factor to hectare                                  | Cut section diamete  | er of the stump                                |           |   |       |
|   |         |  | "                    | 11-11-11<br>11-11-11                           |           |   |       |

Ticks "x" indicates whether the data were used for the elaboration of indicators in "Methods" section, Table 1

Table 2 (continued)

 Table 3
 Pearson's correlation (r) between single-variables indicators

|                                       | Grow-<br>ing stock<br>volume | Variability of tree height | SDI                      | Max DBH                       | I Max heigh                          | t Large livin<br>trees | g Gini coe           | ff n° specie          | es Shannon<br>index          |
|---------------------------------------|------------------------------|----------------------------|--------------------------|-------------------------------|--------------------------------------|------------------------|----------------------|-----------------------|------------------------------|
| Growing<br>stock vol-<br>ume          | 1                            | 0.34                       | 0.528                    | 0.565                         | 0.789                                | 0.774                  | 0.133                | 0.043                 | -0.029                       |
| Variability of tree height            | 0.34                         | 1                          | 0.423                    | 0.41                          | 0.554                                | 0.345                  | 0.69                 | 0.265                 | 0.22                         |
| SBI                                   | 0.528                        | 0.423                      | 1                        | 0.344                         | 0.369                                | 0.276                  | 0.353                | 0.313                 | 0.167                        |
| Max DBH                               | 0.565                        | 0.41                       | 0.344                    | 1                             | 0.672                                | 0.638                  | 0.583                | 0.076                 | 0.002                        |
| Max height                            | 0.789                        | 0.554                      | 0.369                    | 0.672                         | 1                                    | 0.654                  | 0.309                | 0.137                 | 0.086                        |
| Large living trees                    | 0.774                        | 0.345                      | 0.276                    | 0.638                         | 0.654                                | 1                      | 0.244                | -0.044                | -0.066                       |
| Gini coeff                            | 0.133                        | 0.69                       | 0.353                    | 0.583                         | 0.309                                | 0.244                  | 1                    | 0.253                 | 0.213                        |
| n° species                            | 0.043                        | 0.265                      | 0.313                    | 0.076                         | 0.137                                | -0.044                 | 0.253                | 1                     | 0.84                         |
| Shannon<br>index                      | -0.029                       | 0.22                       | 0.167                    | 0.002                         | 0.086                                | -0.066                 | 0.213                | 0.84                  | 1                            |
| Evenness                              | 0.044                        | -0.177                     | -0.045                   | 0.026                         | -0.043                               | 0.033                  | -0.165               | -0.518                | -0.847                       |
| Dead wood<br>volume                   | 0.347                        | 0.111                      | 0.195                    | 0.238                         | 0.31                                 | 0.222                  | 0.07                 | 0.142                 | 0.096                        |
| Dead-to-<br>living ratio              | -0.068                       | -0.036                     | -0.086                   | -0.062                        | -0.062                               | -0.043                 | -0.053               | -0.027                | -0.015                       |
| Stump decay<br>class ratio            | 0.021                        | -0.036                     | -0.015                   | 0.027                         | 0.038                                | 0.024                  | -0.004               | -0.032                | -0.026                       |
| Standing<br>dead tree<br>decay ratio  | 0.075                        | 0.033                      | 0.098                    | 0.016                         | 0.061                                | 0.009                  | 0.003                | 0.071                 | 0.039                        |
| Regenera-<br>tion I                   | -0.12                        | -0.058                     | -0.053                   | -0.097                        | -0.101                               | -0.094                 | -0.031               | 0.033                 | 0.043                        |
| Regenera-<br>tion II                  | -0.165                       | -0.066                     | -0.057                   | -0.162                        | -0.149                               | -0.13                  | -0.031               | 0.023                 | 0.041                        |
| Regeneration<br>III                   | -0.151                       | -0.021                     | 0.107                    | -0.188                        | -0.179                               | -0.151                 | 0.026                | 0.07                  | 0.072                        |
| Distance<br>from<br>anthropic<br>dist | 0.101                        | 0.031                      | 0.049                    | 0.092                         | 0.044                                | 0.117                  | 0.032                | -0.125                | -0.1                         |
|                                       | Evenness                     | Deadwood<br>volume         | Dead-to-<br>living ratio | Stump<br>decay class<br>ratio | Standing<br>dead tree<br>decay ratio | Regenera-<br>tion I    | Regenera-<br>tion II | Regenera-<br>tion III | Distance from anthropic dist |
| Growing<br>stock<br>volume            | 0.044                        | 0.347                      | -0.068                   | 0.021                         | 0.075                                | -0.12                  | -0.165               | -0.151                | 0.101                        |
| Variability<br>of tree<br>height      | -0.177                       | 0.111                      | -0.036                   | 0.003                         | 0.033                                | -0.058                 | -0.066               | -0.021                | 0.031                        |
| SBI                                   | -0.045                       | 0.195                      | -0.086                   | -0.015                        | 0.098                                | -0.053                 | -0.057               | 0.107                 | 0.049                        |
| Max DBH                               | 0.026                        | 0.238                      | -0.062                   | 0.027                         | 0.016                                | -0.097                 | -0.162               | -0.188                | 0.092                        |
| Max height                            | -0.043                       | 0.31                       | -0.062                   | 0.038                         | 0.061                                | -0.101                 | -0.149               | -0.179                | 0.044                        |
| Large living<br>trees                 | 0.033                        | 0.222                      | -0.043                   | 0.024                         | 0.009                                | -0.094                 | -0.13                | -0.151                | 0.117                        |
| Gini coeff                            | -0.165                       | 0.07                       | -0.053                   | -0.004                        | 0.003                                | -0.031                 | -0.031               | 0.026                 | 0.032                        |
| n° species                            | -0.518                       | 0.142                      | -0.027                   | -0.032                        | 0.071                                | 0.033                  | 0.023                | 0.07                  | -0.125                       |
| Shannon<br>index                      | -0.847                       | 0.096                      | -0.015                   | -0.026                        | 0.039                                | 0.043                  | 0.041                | 0.072                 | -0.1                         |

## Table 3 (continued)

|                                       | Evenness | Deadwood<br>volume | Dead-to-<br>living ratio | Stump<br>decay class<br>ratio | Standing<br>dead tree<br>decay ratio | Regenera-<br>tion I | Regenera-<br>tion II | Regenera-<br>tion III | Distance from anthropic dist |
|---------------------------------------|----------|--------------------|--------------------------|-------------------------------|--------------------------------------|---------------------|----------------------|-----------------------|------------------------------|
| Evenness                              | 1        | -0.053             | 0.005                    | 0.02                          | -0.016                               | -0.045              | -0.05                | -0.058                | 0.055                        |
| Dead wood<br>volume                   | -0.053   | 1                  | 0.237                    | 0.003                         | 0.191                                | -0.024              | -0.058               | -0.097                | -0.047                       |
| Dead-to-liv-<br>ing ratio             | 0.005    | 0.237              | 1                        | 0.019                         | 0.029                                | 0.035               | 0.016                | -0.021                | -0.033                       |
| Stump decay<br>class ratio            | 0.02     | 0.003              | 0.019                    | 1                             | -0.006                               | 0.029               | 0.007                | -0.019                | -0.003                       |
| Standing<br>dead tree<br>decay ratio  | -0.016   | 0.191              | 0.029                    | -0.006                        | 1                                    | -0.008              | -0.016               | -0.028                | -0.039                       |
| Regenera-<br>tion I                   | -0.045   | -0.024             | 0.035                    | 0.029                         | -0.008                               | 1                   | 0.394                | 0.159                 | -0.038                       |
| Regenera-<br>tion II                  | -0.05    | -0.058             | 0.016                    | 0.007                         | -0.016                               | 0.394               | 1                    | 0.413                 | -0.051                       |
| Regeneration<br>III                   | -0.058   | -0.097             | -0.021                   | -0.019                        | -0.028                               | 0159                | 0.413                | 1                     | -0.026                       |
| Distance<br>from<br>anthropic<br>dist | 0.055    | -0.047             | -0.033                   | -0.003                        | -0.039                               | -0.038              | -0.051               | -0.026                | 1                            |

 Table 4 p-value between single-variables indicators

|                              | Grow-<br>ing stock<br>volume | Variability<br>of tree<br>height | SDI   | Max DBH | Max height | Large living trees | Gini coeff | n° species | Shannon index |
|------------------------------|------------------------------|----------------------------------|-------|---------|------------|--------------------|------------|------------|---------------|
| Growing<br>stock vol-<br>ume | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0.02          |
| Variability of tree height   | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0             |
| SBI                          | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0             |
| Max DBH                      | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0.869         |
| Max height                   | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0             |
| Large living trees           | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0             |
| Gini coeff                   | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0             |
| n° species                   | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0             |
| Shannon<br>index             | 0.02                         | 0                                | 0     | 0.869   | 0          | 0                  | 0          | 0          | 0             |
| Evenness                     | 0                            | 0                                | 0     | 0.033   | 0.001      | 0.008              | 0          | 0          | 0             |
| Dead wood<br>volume          | 0                            | 0                                | 0     | 0       | 0          | 0                  | 0          | 0          | 0             |
| Dead-to-<br>living ratio     | 0                            | 0.003                            | 0     | 0       | 0          | 0.001              | 0          | 0.031      | 0.239         |
| Stump decay<br>class ratio   | 0.092                        | 0.827                            | 0.217 | 0.026   | 0.002      | 0.049              | 0.766      | 0.01       | 0.033         |

# Table 4 (continued)

|                                       | Grow-<br>ing stock<br>volume | Variability<br>of tree<br>height | SDI                         | Max DBH                       | Max height                           | Large living trees  | Gini coeff           | n° species          | Shannon index                |
|---------------------------------------|------------------------------|----------------------------------|-----------------------------|-------------------------------|--------------------------------------|---------------------|----------------------|---------------------|------------------------------|
| Standing<br>dead tree<br>decay ratio  | 0                            | 0.008                            | 0                           | 0.191                         | 0                                    | 0.485               | 0.828                | 0                   | 0.001                        |
| Regenera-<br>tion I                   | 0                            | 0                                | 0                           | 0                             | 0                                    | 0                   | 0.012                | 0.008               | 0                            |
| Regenera-<br>tion II                  | 0                            | 0                                | 0                           | 0                             | 0                                    | 0                   | 0.012                | 0.06                | 0.001                        |
| Regeneration<br>III                   | 0                            | 0.096                            | 0                           | 0                             | 0                                    | 0                   | 0.035                | 0                   | 0                            |
| Distance<br>from<br>anthropic<br>dist | 0                            | 0.012                            | 0                           | 0                             | 0                                    | 0                   | 0.01                 | 0                   | 0                            |
|                                       | Evenness                     | Deadwood<br>volume               | Dead-<br>to-living<br>ratio | Stump<br>decay class<br>ratio | Standing<br>dead tree<br>decay ratio | Regenera-<br>tion I | Regenera-<br>tion II | Regeneration<br>III | Distance from anthropic dist |
| Growing<br>stock vol-<br>ume          | 0                            | 0                                | 0                           | 0.092                         | 0                                    | 0                   | 0                    | 0                   | 0                            |
| Variability of tree height            | 0                            | 0                                | 0.003                       | 0.827                         | 0.008                                | 0                   | 0                    | 0.096               | 0.012                        |
| SBI                                   | 0                            | 0                                | 0                           | 0.217                         | 0                                    | 0                   | 0                    | 0                   | 0                            |
| Max DBH                               | 0.033                        | 0                                | 0                           | 0.026                         | 0.191                                | 0                   | 0                    | 0                   | 0                            |
| Max height                            | 0.001                        | 0                                | 0                           | 0.002                         | 0                                    | 0                   | 0                    | 0                   | 0                            |
| Large living trees                    | 0.008                        | 0                                | 0.001                       | 0.049                         | 0.485                                | 0                   | 0                    | 0                   | 0                            |
| Gini coeff                            | 0                            | 0                                | 0                           | 0.766                         | 0.828                                | 0.012               | 0.012                | 0.035               | 0.01                         |
| n° species                            | 0                            | 0                                | 0.031                       | 0.01                          | 0                                    | 0.008               | 0.06                 | 0                   | 0                            |
| Shannon<br>index                      | 0                            | 0                                | 0.239                       | 0.033                         | 0.001                                | 0                   | 0.001                | 0                   | 0                            |
| Evenness                              | 0                            | 0                                | 0.672                       | 0.103                         | 0.201                                | 0                   | 0                    | 0                   | 0                            |
| Dead wood<br>volume                   | 0                            | 0                                | 0                           | 0.837                         | 0                                    | 0.053               | 0                    | 0                   | 0                            |
| Dead-to-<br>living ratio              | 0.672                        | 0                                | 0                           | 0.133                         | 0.019                                | 0.005               | 0.184                | 0.083               | 0.007                        |
| Stump decay<br>class ratio            | 0.103                        | 0.837                            | 0.133                       | 0                             | 0.619                                | 0.019               | 0.562                | 0.119               | 0.816                        |
| Standing<br>dead tree<br>decay ratio  | 0.201                        | 0                                | 0.019                       | 0.619                         | 0                                    | 0.511               | 0.2                  | 0.025               | 0.001                        |
| Regenera-<br>tion I                   | 0                            | 0.053                            | 0.005                       | 0.019                         | 0.511                                | 0                   | 0                    | 0                   | 0.002                        |
| Regenera-<br>tion II                  | 0                            | 0                                | 0.184                       | 0.562                         | 0.2                                  | 0                   | 0                    | 0                   | 0                            |
| Regeneration<br>III                   | 0                            | 0                                | 0.083                       | 0.119                         | 0.025                                | 0                   | 0                    | 0                   | 0.033                        |
| Distance<br>from<br>anthropic<br>dist | 0                            | 0                                | 0.007                       | 0.816                         | 0.001                                | 0.002               | 0                    | 0.033               | 0                            |

| Table 5  | Pearson's correlation |
|----------|-----------------------|
| (r) betw | een B-N-OG            |
| compon   | ents                  |

|              | Structure | Composition | Deadwood | Regeneration | Hemeroby |
|--------------|-----------|-------------|----------|--------------|----------|
| Structure    | 1         | 0.137       | 0.203    | -0.161       | 0.085    |
| Composition  | 0.137     | 1           | 0.082    | 0.01         | -0.094   |
| Deadwood     | 0.203     | 0.082       | 1        | -0.067       | -0.057   |
| Regeneration | -0.161    | 0.01        | -0.067   | 1            | -0.051   |
| Hemeroby     | 0.085     | -0.094      | -0.057   | -0.051       | 1        |

# Table 6*p*-value betweenB-N-OG components

|              | Structure | Composition | Deadwood | Regeneration | Hemeroby |
|--------------|-----------|-------------|----------|--------------|----------|
| Structure    | 0         | 0           | 0        | 0            | 0        |
| Composition  | 0         | 0           | 0        | 0.433        | 0        |
| Deadwood     | 0         | 0           | 0        | 0            | 0        |
| Regeneration | 0         | 0.433       | 0        | 0            | 0        |
| Hemeroby     | 0         | 0           | 0        | 0            | 0        |

# Appendix B: B-N-OG at national, regional, provincial and plot levels

See Tables 7 and 8.

**Table 7**B-N-OG results at theregional level in Italy

| Region                | n plots | Mean B | Max B | Mean N | Max N | Mean OG | Max OG |
|-----------------------|---------|--------|-------|--------|-------|---------|--------|
| Abruzzo               | 295     | 0.144  | 0.289 | 0.052  | 0.194 | 0.077   | 0.236  |
| Basilicata            | 218     | 0.136  | 0.259 | 0.074  | 0.227 | 0.073   | 0.267  |
| Calabria              | 311     | 0.152  | 0.271 | 0.089  | 0.293 | 0.107   | 0.310  |
| Campania              | 261     | 0.136  | 0.241 | 0.051  | 0.220 | 0.073   | 0.254  |
| Emilia Romagna        | 436     | 0.148  | 0.296 | 0.046  | 0.183 | 0.080   | 0.365  |
| Friuli-Venezia Giulia | 278     | 0.166  | 0.307 | 0.064  | 0.360 | 0.110   | 0.319  |
| Lazio                 | 377     | 0.141  | 0.327 | 0.051  | 0.265 | 0.074   | 0.268  |
| Liguria               | 285     | 0.152  | 0.296 | 0.069  | 0.403 | 0.089   | 0.266  |
| Lombardia             | 376     | 0.163  | 0.285 | 0.049  | 0.413 | 0.106   | 0.274  |
| Marche                | 222     | 0.140  | 0.264 | 0.052  | 0.169 | 0.063   | 0.222  |
| Molise                | 141     | 0.139  | 0.254 | 0.052  | 0.180 | 0.070   | 0.204  |
| Piemonte              | 584     | 0.155  | 0.267 | 0.063  | 0.405 | 0.099   | 0.274  |
| Puglia                | 152     | 0.134  | 0.285 | 0.084  | 0.283 | 0.070   | 0.267  |
| Sardegna              | 416     | 0.120  | 0.223 | 0.067  | 0.273 | 0.051   | 0.176  |
| Sicilia               | 235     | 0.124  | 0.230 | 0.082  | 0.300 | 0.069   | 0.234  |
| Toscana               | 681     | 0.150  | 0.327 | 0.051  | 0.320 | 0.086   | 0.422  |
| Trentino Alto Adige   | 539     | 0.178  | 0.357 | 0.068  | 0.435 | 0.141   | 0.442  |
| Umbria                | 330     | 0.141  | 0.261 | 0.058  | 0.249 | 0.062   | 0.170  |
| Valle d'Aosta         | 107     | 0.150  | 0.272 | 0.051  | 0.218 | 0.101   | 0.260  |
| Veneto                | 319     | 0.169  | 0.288 | 0.054  | 0.264 | 0.111   | 0.356  |

Table 8B-N-OG results at theregional level in Italy

| Province      | n plots | Mean B | Max B | Mean N | Max N | Mean OG | Max OG |
|---------------|---------|--------|-------|--------|-------|---------|--------|
| Agrigento     | 16      | 0.095  | 0.168 | 0.074  | 0.138 | 0.046   | 0.089  |
| Alessandria   | 104     | 0.139  | 0.259 | 0.053  | 0.192 | 0.070   | 0.186  |
| Ancona        | 23      | 0.141  | 0.261 | 0.034  | 0.086 | 0.064   | 0.145  |
| Arezzo        | 128     | 0.140  | 0.272 | 0.053  | 0.196 | 0.080   | 0.372  |
| Ascoli Piceno | 54      | 0.149  | 0.264 | 0.049  | 0.169 | 0.075   | 0.188  |
| Asti          | 25      | 0.146  | 0.218 | 0.032  | 0.136 | 0.074   | 0.167  |
| Avellino      | 51      | 0.132  | 0.203 | 0.048  | 0.164 | 0.067   | 0.205  |
| Bari          | 19      | 0.108  | 0.169 | 0.048  | 0.153 | 0.049   | 0.151  |
| Belluno       | 136     | 0.181  | 0.266 | 0.062  | 0.264 | 0.133   | 0.356  |
| Benevento     | 27      | 0.135  | 0.220 | 0.041  | 0.101 | 0.062   | 0.135  |
| Bergamo       | 58      | 0.165  | 0.264 | 0.033  | 0.103 | 0.103   | 0.257  |
| Biella        | 25      | 0.151  | 0.253 | 0.060  | 0.270 | 0.094   | 0.197  |
| Bologna       | 61      | 0.146  | 0.240 | 0.038  | 0.147 | 0.082   | 0.184  |
| Bolzano/Bozen | 253     | 0.175  | 0.303 | 0.060  | 0.435 | 0.145   | 0.308  |
| Brescia       | 92      | 0.157  | 0.246 | 0.057  | 0.182 | 0.100   | 0.274  |
| Brindisi      | 2       | 0.114  | 0.131 | 0.015  | 0.017 | 0.077   | 0.112  |
| Cagliari      | 84      | 0.113  | 0.170 | 0.083  | 0.273 | 0.042   | 0.133  |
| Caltanissetta | 7       | 0.118  | 0.148 | 0.089  | 0.157 | 0.060   | 0.099  |
| Campobasso    | 68      | 0.131  | 0.242 | 0.055  | 0.134 | 0.064   | 0.204  |
| Caserta       | 40      | 0.140  | 0.235 | 0.039  | 0.122 | 0.084   | 0.186  |
| Catania       | 43      | 0.124  | 0.211 | 0.112  | 0.300 | 0.068   | 0.234  |
| Catanzaro     | 40      | 0.152  | 0.212 | 0.083  | 0.293 | 0.114   | 0.249  |
| Chieti        | 56      | 0.145  | 0.284 | 0.040  | 0.141 | 0.077   | 0.210  |
| Como          | 34      | 0.163  | 0.254 | 0.042  | 0.112 | 0.104   | 0.246  |
| Cosenza       | 170     | 0.149  | 0.266 | 0.096  | 0.272 | 0.099   | 0.285  |
| Cremona       | 5       | 0.093  | 0.116 | 0.020  | 0.040 | 0.041   | 0.089  |
| Crotone       | 25      | 0.134  | 0.198 | 0.077  | 0.195 | 0.078   | 0.154  |
| Cuneo         | 164     | 0.157  | 0.258 | 0.077  | 0.282 | 0.103   | 0.274  |
| Enna          | 17      | 0.121  | 0.181 | 0.049  | 0.145 | 0.065   | 0.137  |
| Ferrara       | 6       | 0.142  | 0.193 | 0.047  | 0.120 | 0.092   | 0.103  |
| Firenze       | 117     | 0.159  | 0.327 | 0.054  | 0.320 | 0.099   | 0.321  |
| Foggia        | 112     | 0.142  | 0.285 | 0.103  | 0.283 | 0.078   | 0.267  |
| Forlì-Cesena  | 71      | 0.137  | 0.296 | 0.059  | 0.183 | 0.073   | 0.365  |
| Frosinone     | 84      | 0.139  | 0.252 | 0.042  | 0.151 | 0.074   | 0.212  |
| Genova        | 84      | 0.160  | 0.290 | 0.063  | 0.193 | 0.099   | 0.237  |
| Gorizia       | 11      | 0.146  | 0.206 | 0.029  | 0.078 | 0.084   | 0.204  |
| Grosseto      | 102     | 0.146  | 0.290 | 0.049  | 0.135 | 0.073   | 0.220  |
| Imperia       | 63      | 0.151  | 0.296 | 0.105  | 0.403 | 0.091   | 0.266  |
| Isernia       | 74      | 0.148  | 0.254 | 0.049  | 0.180 | 0.076   | 0.199  |
| L'Aquila      | 167     | 0.143  | 0.289 | 0.059  | 0.194 | 0.076   | 0.236  |
| La Spezia     | 48      | 0.150  | 0.227 | 0.053  | 0.133 | 0.091   | 0.198  |
| Latina        | 36      | 0.138  | 0.217 | 0.042  | 0.167 | 0.076   | 0.144  |
| Lecce         | 3       | 0.122  | 0.139 | 0.012  | 0.031 | 0.045   | 0.060  |
| Lecco         | 15      | 0.158  | 0.219 | 0.041  | 0.099 | 0.086   | 0.182  |
| Livorno       | 26      | 0.151  | 0.212 | 0.046  | 0.152 | 0.070   | 0.188  |
| Lodi          | 1       | 0.099  | 0.099 | 0.020  | 0.020 | 0.031   | 0.031  |
| Lucca         | 64      | 0.163  | 0.233 | 0.055  | 0.141 | 0.112   | 0.237  |
| Macerata      | 72      | 0.132  | 0.219 | 0.058  | 0.149 | 0.053   | 0.180  |
| Mantova       | 5       | 0.114  | 0.125 | 0.031  | 0.058 | 0.089   | 0.112  |
| Massa-Carrara | 30      | 0.147  | 0.225 | 0.054  | 0.140 | 0.092   | 0.183  |
| Matera        | 42      | 0.123  | 0.200 | 0.075  | 0.184 | 0.061   | 0.167  |
| Messina       | 77      | 0.139  | 0.230 | 0.096  | 0.280 | 0.087   | 0.184  |

## Table 8 (continued)

| Province                     | n plots | Mean B | Max B | Mean N | Max N | Mean OG | Max OG |
|------------------------------|---------|--------|-------|--------|-------|---------|--------|
| Milano                       | 6       | 0.182  | 0.270 | 0.060  | 0.117 | 0.132   | 0.207  |
| Modena                       | 59      | 0.152  | 0.272 | 0.041  | 0.108 | 0.090   | 0.293  |
| Napoli                       | 12      | 0.140  | 0.181 | 0.034  | 0.064 | 0.079   | 0.157  |
| Novara                       | 25      | 0.164  | 0.255 | 0.041  | 0.106 | 0.111   | 0.190  |
| Nuoro                        | 171     | 0.126  | 0.218 | 0.064  | 0.214 | 0.058   | 0.176  |
| Oristano                     | 37      | 0.122  | 0.193 | 0.063  | 0.141 | 0.054   | 0.138  |
| Padova                       | 8       | 0.149  | 0.220 | 0.030  | 0.073 | 0.077   | 0.132  |
| Palermo                      | 48      | 0.115  | 0.169 | 0.075  | 0.210 | 0.058   | 0.126  |
| Parma                        | 96      | 0.156  | 0.217 | 0.048  | 0.155 | 0.087   | 0.229  |
| Pavia                        | 47      | 0.155  | 0.285 | 0.037  | 0.133 | 0.087   | 0.192  |
| Perugia                      | 258     | 0.141  | 0.261 | 0.059  | 0.249 | 0.061   | 0.170  |
| Pesaro e Urbino              | 73      | 0.141  | 0.252 | 0.055  | 0.131 | 0.062   | 0.222  |
| Pescara                      | 24      | 0.139  | 0.197 | 0.043  | 0.104 | 0.076   | 0.139  |
| Piacenza                     | 56      | 0.149  | 0.227 | 0.044  | 0.119 | 0.072   | 0.200  |
| Pisa                         | 54      | 0.152  | 0.236 | 0.041  | 0.171 | 0.073   | 0.194  |
| Pistoia                      | 32      | 0.167  | 0.294 | 0.061  | 0.242 | 0.125   | 0.422  |
| Pordenone                    | 63      | 0.154  | 0.254 | 0.074  | 0.360 | 0.095   | 0.249  |
| Potenza                      | 176     | 0.139  | 0.259 | 0.074  | 0.227 | 0.076   | 0.267  |
| Prato                        | 13      | 0.167  | 0.239 | 0.058  | 0.092 | 0.109   | 0.164  |
| Ragusa                       | 7       | 0.124  | 0.182 | 0.018  | 0.029 | 0.068   | 0.107  |
| Ravenna                      | 21      | 0.135  | 0.191 | 0.050  | 0.125 | 0.069   | 0.137  |
| Reggio di Calabria           | 51      | 0.165  | 0.271 | 0.093  | 0.253 | 0.130   | 0.310  |
| Reggio nell'Emilia           | 62      | 0.149  | 0.241 | 0.039  | 0.153 | 0.078   | 0.146  |
| Rieti                        | 122     | 0.140  | 0.290 | 0.057  | 0.170 | 0.066   | 0.239  |
| Rimini                       | 4       | 0.158  | 0.183 | 0.027  | 0.061 | 0.082   | 0.115  |
| Roma                         | 84      | 0.154  | 0.327 | 0.053  | 0.183 | 0.088   | 0.245  |
| Rovigo                       | 3       | 0.116  | 0.135 | 0.019  | 0.031 | 0.086   | 0.119  |
| Salerno                      | 130     | 0.137  | 0.241 | 0.059  | 0.220 | 0.073   | 0.254  |
| Sassari                      | 124     | 0.117  | 0.223 | 0.062  | 0.226 | 0.048   | 0.119  |
| Savona                       | 90      | 0.146  | 0.214 | 0.058  | 0.265 | 0.077   | 0.189  |
| Siena                        | 115     | 0.143  | 0.247 | 0.044  | 0.142 | 0.070   | 0.181  |
| Siracusa                     | 14      | 0.109  | 0.156 | 0.035  | 0.072 | 0.052   | 0.146  |
| Sondrio                      | 73      | 0.177  | 0.258 | 0.072  | 0.413 | 0.135   | 0.268  |
| Taranto                      | 16      | 0.109  | 0.184 | 0.015  | 0.062 | 0.041   | 0.097  |
| Teramo                       | 48      | 0.149  | 0.225 | 0.048  | 0.177 | 0.084   | 0.192  |
| Terni                        | 72      | 0.141  | 0.215 | 0.056  | 0.171 | 0.064   | 0.149  |
| Torino                       | 157     | 0.159  | 0.264 | 0.061  | 0.405 | 0.101   | 0.259  |
| Trapani                      | 6       | 0.123  | 0.158 | 0.039  | 0.066 | 0.066   | 0.146  |
| Trento                       | 286     | 0.181  | 0.357 | 0.075  | 0.333 | 0.136   | 0.442  |
| Treviso                      | 41      | 0.155  | 0.288 | 0.054  | 0.185 | 0.096   | 0.282  |
| Trieste                      | 16      | 0.147  | 0.214 | 0.030  | 0.063 | 0.074   | 0.190  |
| Udine                        | 188     | 0.174  | 0.307 | 0.065  | 0.291 | 0.119   | 0.319  |
| Valle d'Aosta/Vallée d'Aoste | 107     | 0.150  | 0.272 | 0.051  | 0.218 | 0.101   | 0.260  |
| Varese                       | 40      | 0.170  | 0.254 | 0.042  | 0.156 | 0.116   | 0.216  |
| Venezia                      | 7       | 0.144  | 0.184 | 0.030  | 0.063 | 0.086   | 0.183  |
| Verbano-Cusio-Ossola         | 61      | 0.170  | 0.267 | 0.066  | 0.200 | 0.133   | 0.252  |
| Vercelli                     | 23      | 0.162  | 0.258 | 0.068  | 0.227 | 0.106   | 0.201  |
| Verona                       | 42      | 0.159  | 0.244 | 0.031  | 0.105 | 0.079   | 0.212  |
| Vibo Valentia                | 25      | 0.161  | 0.271 | 0.059  | 0.119 | 0.126   | 0.243  |
| Vicenza                      | 82      | 0.167  | 0.270 | 0.056  | 0.240 | 0.103   | 0.287  |
| Viterbo                      | 51      | 0.129  | 0.210 | 0.055  | 0.265 | 0.070   | 0.268  |
|                              |         | -      | -     |        |       | -       |        |

# Appendix C: Italian protected areas: EUAP and Natura 2000 networks

See Tables 9, 10 and 11.

| Table 9 | B-N-OG mean estimates in EUAP areas |  |
|---------|-------------------------------------|--|
| Table 9 | B-N-OG mean estimates in EUAP areas |  |

| EUAP code | Site name  | n plots | Mean B | Max B | Mean N | Max N | Mean OG | Max OG |
|-----------|--|---------|--------|-------|--------|-------|---------|--------|
| EUAP0001  | Parco nazionale dell'Abruzzo, Lazio e Molise                             | 21      | 0.183  | 0.258 | 0.096  | 0.194 | 0.126   | 0.236  |
| EUAP0002  | Parco nazionale dei Monti Sibillini                                      | 39      | 0.144  | 0.219 | 0.058  | 0.146 | 0.064   | 0.151  |
| EUAP0003  | Parco nazionale del Cilento e Vallo di Diano                             | 56      | 0.140  | 0.241 | 0.063  | 0.185 | 0.081   | 0.210  |
| EUAP0004  | Parco nazionale del Circeo   | 4       | 0.171  | 0.217 | 0.035  | 0.082 | 0.114   | 0.144  |
| EUAP0005  | Parco nazionale del Gargano  | 67      | 0.150  | 0.285 | 0.135  | 0.283 | 0.088   | 0.267  |
| EUAP0006  | Parco nazionale del Gran Paradiso  | 8       | 0.161  | 0.253 | 0.062  | 0.124 | 0.125   | 0.195  |
| EUAP0007  | Parco nazionale del Gran Sasso e Monti della Laga                        | 58      | 0.148  | 0.264 | 0.061  | 0.177 | 0.087   | 0.192  |
| EUAP0008  | Parco nazionale del Pollino  | 47      | 0.142  | 0.238 | 0.099  | 0.249 | 0.087   | 0.230  |
| EUAP0009  | Parco nazionale del Vesuvio  | 5       | 0.139  | 0.168 | 0.038  | 0.064 | 0.093   | 0.157  |
| EUAP0010  | Parco nazionale dell' Arcipelago Toscano                                 | 2       | 0.139  | 0.154 | 0.018  | 0.019 | 0.061   | 0.089  |
| EUAP0011  | Parco nazionale dell'Aspromonte  | 22      | 0.166  | 0.211 | 0.126  | 0.253 | 0.139   | 0.235  |
| EUAP0013  | Parco nazionale della Maiella  | 32      | 0.139  | 0.209 | 0.069  | 0.141 | 0.074   | 0.162  |
| EUAP0014  | Parco nazionale della Val Grande   | 1       | 0.169  | 0.169 | 0.129  | 0.129 | 0.120   | 0.120  |
| EUAP0015  | Parco Nazionale delle Dolomiti Bellunesi                                 | 6       | 0.149  | 0.211 | 0.063  | 0.161 | 0.097   | 0.192  |
| EUAP0016  | Parco nazionale delle Foreste Casentinesi, Monte Falterona e<br>Campigna | 26      | 0.170  | 0.296 | 0.071  | 0.183 | 0.139   | 0.372  |
| EUAP0017  | Parco nazionale dello Stelvio  | 25      | 0.163  | 0.271 | 0.093  | 0.235 | 0.133   | 0.295  |
| EUAP0021  | Riserva naturale Fara San Martino Palombaro                              | 1       | 0.066  | 0.066 | 0.104  | 0.104 | 0.034   | 0.034  |
| EUAP0022  | Riserva naturale Feudo Intramonti  | 1       | 0.134  | 0.134 | 0.074  | 0.074 | 0.081   | 0.081  |
| EUAP0023  | Riserva naturale Feudo Ugni  | 1       | 0.168  | 0.168 | 0.141  | 0.141 | 0.122   | 0.122  |
| EUAP0025  | Riserva naturale Monte Rotondo   | 1       | 0.065  | 0.065 | 0.049  | 0.049 | 0.015   | 0.015  |
| EUAP0026  | Riserva naturale Monte Velino  | 2       | 0.163  | 0.222 | 0.140  | 0.191 | 0.094   | 0.155  |
| EUAP0030  | Riserva naturale Quarto Santa Chiara                                     | 1       | 0.131  | 0.131 | 0.019  | 0.019 | 0.045   | 0.045  |
| EUAP0039  | Riserva naturale Rubbio  | 1       | 0.153  | 0.153 | 0.180  | 0.180 | 0.127   | 0.127  |
| EUAP0040  | Riserva naturale Coturelle Piccione                                      | 1       | 0.182  | 0.182 | 0.177  | 0.177 | 0.176   | 0.176  |
| EUAP0043  | Riserva naturale Gariglione—Pisarello                                    | 2       | 0.172  | 0.198 | 0.206  | 0.217 | 0.120   | 0.144  |
| EUAP0049  | Riserva naturale Marchesale  | 2       | 0.128  | 0.154 | 0.078  | 0.105 | 0.110   | 0.173  |
| EUAP0058  | Riserva naturale Tirone Alto Vesuvio                                     | 3       | 0.131  | 0.153 | 0.052  | 0.064 | 0.070   | 0.109  |
| EUAP0060  | Riserva naturale Bassa dei Frassini—Balanzetta                           | 1       | 0.144  | 0.144 | 0.120  | 0.120 | 0.088   | 0.088  |
| EUAP0061  | Riserva naturale Bosco della Mesola                                      | 1       | 0.161  | 0.161 | 0.027  | 0.027 | 0.101   | 0.101  |
| EUAP0062  | Riserva naturale Campigna  | 3       | 0.224  | 0.267 | 0.083  | 0.121 | 0.262   | 0.365  |
| EUAP0069  | Riserva naturale Pineta di Ravenna                                       | 1       | 0.127  | 0.127 | 0.029  | 0.029 | 0.074   | 0.074  |
| EUAP0075  | Riserva naturale Sasso Fratino   | 1       | 0.209  | 0.209 | 0.082  | 0.082 | 0.133   | 0.133  |
| EUAP0076  | Riserva naturale Badia Prataglia   | 2       | 0.259  | 0.296 | 0.152  | 0.183 | 0.301   | 0.364  |
| EUAP0079  | Riserva naturale Foresta demaniale del Circeo                            | 3       | 0.184  | 0.217 | 0.044  | 0.082 | 0.135   | 0.144  |
| EUAP0086  | Riserva naturale Litorale romano   | 3       | 0.145  | 0.162 | 0.041  | 0.082 | 0.088   | 0.116  |
| EUAP0093  | Riserva naturale Montedimezzo  | 1       | 0.254  | 0.254 | 0.038  | 0.038 | 0.147   | 0.147  |
| EUAP0094  | Riserva naturale Pesche  | 1       | 0.096  | 0.096 | 0.073  | 0.073 | 0.061   | 0.061  |
| EUAP0098  | Riserva naturale Foresta Umbra   | 1       | 0.153  | 0.153 | 0.270  | 0.270 | 0.089   | 0.089  |
| EUAP0113  | Riserva naturale Abetone   | 2       | 0.230  | 0.294 | 0.114  | 0.165 | 0.266   | 0.422  |
| EUAP0115  | Riserva naturale Belagaio  | 1       | 0.234  | 0.234 | 0.039  | 0.039 | 0.195   | 0.195  |
| EUAP0118  | Riserva naturale Camaldoli   | 1       | 0.223  | 0.223 | 0.060  | 0.060 | 0.271   | 0.271  |
| EUAP0121  | Riserva naturale Cornocchia  | 1       | 0.232  | 0.232 | 0.063  | 0.063 | 0.148   | 0.148  |

| EUAP code | Site name   | n plots | Mean B | Max B | Mean N | Max N | Mean OG | Max OG |
|-----------|---|---------|--------|-------|--------|-------|---------|--------|
| EUAP0128  | Riserva naturale Lamarossa                                | 1       | 0.157  | 0.157 | 0.028  | 0.028 | 0.091   | 0.091  |
| EUAP0141  | Riserva naturale Scodella                                 | 1       | 0.272  | 0.272 | 0.107  | 0.107 | 0.372   | 0.372  |
| EUAP0144  | Riserva naturale Tombolo di Cecina                        | 1       | 0.159  | 0.159 | 0.018  | 0.018 | 0.188   | 0.188  |
| EUAP0145  | Riserva naturale Vallombrosa                              | 5       | 0.242  | 0.327 | 0.098  | 0.209 | 0.234   | 0.321  |
| EUAP0148  | Riserva naturale integrale Bosco Nordio                   | 2       | 0.152  | 0.156 | 0.042  | 0.063 | 0.075   | 0.082  |
| EUAP0151  | Riserva naturale integrale Gardesana Orientale            | 1       | 0.156  | 0.156 | 0.009  | 0.009 | 0.023   | 0.023  |
| EUAP0152  | Riserva naturale integrale Lastoni Selva Pezzi            | 1       | 0.236  | 0.236 | 0.097  | 0.097 | 0.212   | 0.212  |
| EUAP0154  | Riserva naturale Monti del Sole                           | 1       | 0.108  | 0.108 | 0.068  | 0.068 | 0.049   | 0.049  |
| EUAP0173  | Parco regionale naturale del Sirente-Velino               | 21      | 0.136  | 0.217 | 0.059  | 0.124 | 0.067   | 0.155  |
| EUAP0174  | Parco regionale Monti Picentini                           | 24      | 0.153  | 0.218 | 0.094  | 0.220 | 0.102   | 0.254  |
| EUAP0176  | Parco fluviale regionale dello Stirone                    | 1       | 0.191  | 0.191 | 0.026  | 0.026 | 0.119   | 0.119  |
| EUAP0180  | Parco regionale del Corno alle Scale                      | 3       | 0.162  | 0.188 | 0.053  | 0.072 | 0.108   | 0.153  |
| EUAP0181  | Parco regionale Delta del Po (ER)                         | 3       | 0.129  | 0.140 | 0.018  | 0.047 | 0.093   | 0.096  |
| EUAP0182  | Parco regionale dell' Alto Appennino Modenese             | 9       | 0.168  | 0.272 | 0.086  | 0.108 | 0.116   | 0.293  |
| EUAP0186  | Parco naturale regionale Monti Simbruini                  | 16      | 0.145  | 0.192 | 0.056  | 0.128 | 0.087   | 0.180  |
| EUAP0187  | Parco regionale dei Castelli Romani                       | 5       | 0.146  | 0.152 | 0.035  | 0.061 | 0.091   | 0.121  |
| EUAP0190  | Parco regionale naturale dei Monti Lucretili              | 5       | 0.141  | 0.178 | 0.074  | 0.122 | 0.060   | 0.097  |
| EUAP0193  | Parco naturale dell'Alto Garda Bresciano                  | 7       | 0.141  | 0.179 | 0.074  | 0.124 | 0.048   | 0.075  |
| EUAP0195  | Parco naturale lombardo della Valle del Ticino            | 9       | 0.174  | 0.270 | 0.067  | 0.119 | 0.117   | 0.207  |
| EUAP0196  | Parco naturale del Campo dei Fiori                        | 3       | 0.173  | 0.194 | 0.100  | 0.156 | 0.129   | 0.216  |
| EUAP0199  | Parco regionale dell'Adamello                             | 2       | 0.149  | 0.162 | 0.083  | 0.086 | 0.082   | 0.099  |
| EUAP0201  | Parco naturale di Montevecchia e della Valle di Curone    | 1       | 0.176  | 0.176 | 0.004  | 0.004 | 0.090   | 0.090  |
| EUAP0203  | Parco regionale del Conero                                | 1       | 0.098  | 0.098 | 0.000  | 0.000 | 0.017   | 0.017  |
| EUAP0209  | Parco naturale del Monte Fenera                           | 1       | 0.220  | 0.220 | 0.025  | 0.025 | 0.131   | 0.131  |
| EUAP0214  | Parco naturale della Alta Valle Pesio e Tanaro            | 3       | 0.187  | 0.255 | 0.123  | 0.178 | 0.145   | 0.274  |
| EUAP0218  | Parco naturale della Valle del Ticino                     | 2       | 0.204  | 0.222 | 0.095  | 0.098 | 0.132   | 0.167  |
| EUAP0219  | Parco naturale delle Capanne di Marcarolo                 | 8       | 0.137  | 0.170 | 0.126  | 0.192 | 0.069   | 0.095  |
| EUAP0220  | Parco naturale delle Lame del Sesia                       | 1       | 0.246  | 0.246 | 0.022  | 0.022 | 0.170   | 0.170  |
| EUAP0223  | Parco naturale Orsiera-Rocciavre'                         | 2       | 0.168  | 0.191 | 0.151  | 0.151 | 0.110   | 0.143  |
| EUAP0224  | Parco regionale La Mandria                                | 1       | 0.239  | 0.239 | 0.021  | 0.021 | 0.157   | 0.157  |
| EUAP0226  | Parco dei Nebrodi   | 42      | 0.136  | 0.193 | 0.137  | 0.280 | 0.078   | 0.155  |
| EUAP0227  | Parco dell' Etna  | 28      | 0.132  | 0.211 | 0.124  | 0.300 | 0.079   | 0.234  |
| EUAP0228  | Parco delle Madonie                                       | 10      | 0.133  | 0.169 | 0.104  | 0.210 | 0.067   | 0.097  |
| EUAP0229  | Parco naturale regionale delle Alpi Apuane                | 3       | 0.151  | 0.170 | 0.057  | 0.071 | 0.098   | 0.146  |
| EUAP0230  | Parco naturale della Maremma                              | 1       | 0.173  | 0.173 | 0.061  | 0.061 | 0.096   | 0.096  |
| EUAP0231  | Parco naturale di Migliarino, San Rossore e Massaciuccoli | 3       | 0.162  | 0.173 | 0.004  | 0.006 | 0.156   | 0.194  |
| EUAP0232  | Parco naturale Paneveggio—Pale di San Martino             | 7       | 0.217  | 0.244 | 0.127  | 0.180 | 0.242   | 0.322  |
| EUAP0235  | Parco del Monte Cucco                                     | 7       | 0.145  | 0.231 | 0.041  | 0.094 | 0.078   | 0.165  |
| EUAP0236  | Parco del Monte Subasio                                   | 6       | 0.157  | 0.181 | 0.062  | 0.094 | 0.062   | 0.088  |
| EUAP0237  | Parco fluviale del Nera                                   | 1       | 0.196  | 0.196 | 0.025  | 0.025 | 0.049   | 0.049  |
| EUAP0238  | Parco fluviale del Tevere                                 | 2       | 0.136  | 0.141 | 0.023  | 0.043 | 0.045   | 0.053  |
| EUAP0240  | Parco naturale regionale del Fiume Sile                   | -       | 0.110  | 0.110 | 0.035  | 0.035 | 0.067   | 0.067  |
| EUAP0241  | Parco naturale regionale della Lessinia                   | 7       | 0.177  | 0.244 | 0.070  | 0.105 | 0.110   | 0.168  |
| EUAP0243  | Parco regionale dei Colli Euganei                         | 6       | 0 144  | 0.180 | 0.035  | 0.073 | 0.067   | 0.088  |
| EUAP0247  | Riserva naturale controllata Lago di Serranella           | 1       | 0.080  | 0.080 | 0.020  | 0.020 | 0.036   | 0.036  |
| FUAP0253  | Riserva regionale Lago Piccolo di Monticchio              | 1       | 0.173  | 0.173 | 0.077  | 0.077 | 0.118   | 0.118  |
| FUAP0267  | Riserva naturale delle Montagne della Duchessa            | 1       | 0.137  | 0.137 | 0.025  | 0.025 | 0.050   | 0.050  |
| FUAP0207  | Riserva naturale Lago di Vico                             | 1       | 0.180  | 0.197 | 0.029  | 0.038 | 0.196   | 0.196  |
| EUA D0272 | Riserva naturale Monto Novogno o Monto Correio            | 1       | 0.109  | 0.109 | 0.056  | 0.076 | 0.220   | 0.120  |
| EUAP0272  | Nisei va naturale ivionte ivavegna e ivionte Cervia       | 1       | 0.243  | 0.243 | 0.070  | 0.070 | 0.239   | 0.239  |

## Table 9 (continued)

| EUAP code  | Site name  | n plots | Mean B | Max B | Mean N | Max N | Mean OG | Max OG |
|------------|--|---------|--------|-------|--------|-------|---------|--------|
| EUAP0273   | Riserva naturale Monte Rufeno  | 3       | 0.128  | 0.137 | 0.093  | 0.139 | 0.043   | 0.052  |
| EUAP0276   | Riserva naturale parziale Selva del Lamone   | 2       | 0.150  | 0.169 | 0.082  | 0.085 | 0.068   | 0.073  |
| EUAP0318   | Riserva naturale Monte Alpe  | 1       | 0.179  | 0.179 | 0.031  | 0.031 | 0.085   | 0.085  |
| EUAP0370   | Riserva naturale speciale delle Sorgenti del Belbo                                     | 1       | 0.171  | 0.171 | 0.065  | 0.065 | 0.128   | 0.128  |
| EUAP0378   | Riserva naturale Le Montagne delle Felci e dei Porri                                   | 1       | 0.220  | 0.220 | 0.061  | 0.061 | 0.171   | 0.171  |
| EUAP0384   | Riserva naturale Alto Merse  | 4       | 0.184  | 0.219 | 0.049  | 0.092 | 0.068   | 0.105  |
| EUAP0390   | Riserva naturale Farma   | 2       | 0.200  | 0.232 | 0.054  | 0.067 | 0.147   | 0.155  |
| EUAP0403   | Riserva naturale guidata della Scanuppia   | 1       | 0.213  | 0.213 | 0.091  | 0.091 | 0.172   | 0.172  |
| EUAP0452   | Parco naturale regionale del Beigua  | 4       | 0.145  | 0.172 | 0.081  | 0.093 | 0.061   | 0.085  |
| EUAP0454   | Oasi di Bosco Casale (Casacalenda)   | 1       | 0.165  | 0.165 | 0.049  | 0.049 | 0.066   | 0.066  |
| EUAP0458   | Sistema delle aree protette della fascia fluviale del Po                               | 1       | 0.107  | 0.107 | 0.080  | 0.080 | 0.089   | 0.089  |
| EUAP0469   | Riserva di Monte Arcosu  | 1       | 0.031  | 0.031 | 0.194  | 0.194 | 0.014   | 0.014  |
| EUAP0477   | Biotopo La Rocchetta   | 1       | 0.139  | 0.139 | 0.002  | 0.002 | 0.078   | 0.078  |
| EUAP0527   | Parco regionale dei Monti Lattari  | 8       | 0.132  | 0.181 | 0.042  | 0.072 | 0.070   | 0.149  |
| EUAP0541   | Zona di salvaguardia dei Boschi e delle Rocche del Roero                               | 2       | 0.124  | 0.145 | 0.074  | 0.121 | 0.081   | 0.115  |
| EUAP0547   | Riserva naturale orientata Bosco Pantano di Policoro                                   | 2       | 0.132  | 0.160 | 0.058  | 0.100 | 0.073   | 0.093  |
| EUAP0550   | Parco nazionale della Sila   | -<br>35 | 0.176  | 0.266 | 0.152  | 0.293 | 0.146   | 0.285  |
| EUAP0660   | Parco naturale regionale Serre   | 20      | 0.174  | 0.271 | 0.065  | 0.121 | 0.129   | 0.213  |
| EUAP0727   | Acquaviva—Cima del Monte—Ouercia del Monaco  | 1       | 0.109  | 0.109 | 0.047  | 0.047 | 0.057   | 0.057  |
| EUAP0734   | Parco regionale della Valle del Lambro   | 2       | 0.102  | 0.237 | 0.063  | 0.109 | 0.057   | 0.179  |
| EUAP0838   | Monumento naturale Promontorio Villa Tiberio e Costa Torre<br>Capovento-Punta Cetarola | 1       | 0.151  | 0.151 | 0.003  | 0.003 | 0.111   | 0.111  |
| EUAP0839   | Riserva naturale orientata Monte Pellegrino  | 2       | 0.100  | 0 140 | 0.020  | 0.031 | 0.090   | 0.126  |
| EUAP0851   | Parco nazionale dell'Appennino I ucano—Val d'Agri—I ag-                                | 2<br>37 | 0.100  | 0.140 | 0.020  | 0.202 | 0.078   | 0.120  |
| 20/11/0001 | onegrese   | 51      | 0.144  | 0.240 | 0.000  | 0.202 | 0.070   | 0.190  |
| EUAP0852   | Parco nazionale dell'Alta Murgia   | 6       | 0.079  | 0.109 | 0.063  | 0.104 | 0.042   | 0.075  |
| EUAP0882   | Riserva naturale speciale del Sacro Monte di Oropa                                     | 1       | 0.161  | 0.161 | 0.111  | 0.111 | 0.118   | 0.118  |
| EUAP0886   | Parco naturale del Monte San Giorgio   | 1       | 0.147  | 0.147 | 0.018  | 0.018 | 0.085   | 0.085  |
| EUAP0887   | Parco naturale del Monte Tre Denti—Freidour  | 1       | 0.125  | 0.125 | 0.081  | 0.081 | 0.044   | 0.044  |
| EUAP0894   | Parco naturale regionale Terra delle Gravine   | 6       | 0.096  | 0.184 | 0.012  | 0.027 | 0.033   | 0.097  |
| EUAP0922   | Riserva naturale Il Bogatto  | 1       | 0.192  | 0.192 | 0.091  | 0.091 | 0.052   | 0.052  |
| EUAP0930   | Parco naturale provinciale dell' Adamello Brenta                                       | 11      | 0.156  | 0.266 | 0.124  | 0.288 | 0.103   | 0.275  |
| EUAP0937   | Parco naturale Dolomiti di Sesto   | 1       | 0.157  | 0.157 | 0.004  | 0.004 | 0.112   | 0.112  |
| EUAP0938   | Parco naturale Vedrette di Ries—Aurina   | 3       | 0.140  | 0.155 | 0.083  | 0.125 | 0.091   | 0.120  |
| EUAP0940   | Parco naturale Monte Corno   | 5       | 0.173  | 0.237 | 0.051  | 0.090 | 0.113   | 0.191  |
| EUAP0941   | Parco naturale dello Sciliar—Catinaccio  | 2       | 0.182  | 0.215 | 0.043  | 0.061 | 0.155   | 0.210  |
| EUAP0942   | Parco naturale Fanes—Sennes e Braies   | 2       | 0.207  | 0.241 | 0.071  | 0.087 | 0.204   | 0.272  |
| EUAP0943   | Parco naturale Gruppo di Tessa   | 4       | 0.206  | 0.254 | 0.078  | 0.133 | 0.203   | 0.263  |
| EUAP0944   | Parco nazionale del Golfo di Orosei e del Gennargentu                                  | 23      | 0.124  | 0.209 | 0.083  | 0.214 | 0.061   | 0.150  |
| EUAP0954   | Parco regionale del Partenio   | 5       | 0.135  | 0.153 | 0.075  | 0.106 | 0.069   | 0.093  |
| EUAP0955   | Parco regionale del Matese   | 13      | 0.164  | 0.235 | 0.069  | 0.122 | 0.109   | 0.186  |
| EUAP0956   | Parco regionale di Roccamonfina—Foce Garigliano  | 4       | 0.152  | 0.173 | 0.031  | 0.043 | 0.128   | 0.172  |
| FUAP0957   | Parco regionale del Taburno—Camposauro   | 2       | 0.100  | 0.173 | 0.022  | 0.031 | 0.032   | 0.033  |
| FUAP0961   | Parco regionale dei Laghi Suviana e Brasimone  | 2       | 0.164  | 0.124 | 0.022  | 0.080 | 0.002   | 0.118  |
| EUA P0062  | Parco naturale delle Dolomiti Friulane   | 2<br>6  | 0.158  | 0.194 | 0.181  | 0.000 | 0.104   | 0.110  |
| FUAP0065   | Parco naturale regionale dell'Antola   | 2       | 0.149  | 0.150 | 0.035  | 0.038 | 0.085   | 0.095  |
| FUAP0066   | Parco naturale regionale dell'Aveto  | -3      | 0.185  | 0.211 | 0.055  | 0.112 | 0.141   | 0.211  |
|            | Parco naturale regionale di Montemarcello_Magra  | 2       | 0.130  | 0.140 | 0.019  | 0.025 | 0.055   | 0.059  |
|            | Riserva naturale Foce Sele_Tanagro   | -<br>1  | 0.210  | 0.210 | 0.026  | 0.025 | 0.168   | 0.168  |
|            | Riserva naturale Foce Volturno Costa di Licola   | 1       | 0.131  | 0.131 | 0.012  | 0.012 | 0.107   | 0.107  |
| LUM 0912   | Riserva naturate i oce voltarito-Costa di Licola                                       | 1       | 0.131  | 0.151 | 0.012  | 0.012 | 0.107   | 0.107  |

## Table 9 (continued)

| EUAP code | Site name  | n plots | Mean B | Max B | Mean N | Max N | Mean OG | Max OG |
|-----------|--|---------|--------|-------|--------|-------|---------|--------|
| EUAP0973  | Riserva naturale Monti Eremita—Marzano   | 2       | 0.196  | 0.223 | 0.119  | 0.131 | 0.177   | 0.245  |
| EUAP0981  | Riserva naturale della Foce dell' Isonzo   | 1       | 0.205  | 0.205 | 0.047  | 0.047 | 0.204   | 0.204  |
| EUAP0983  | Riserva naturale dei Laghi di Doberdo' e Pietrarossa   | 2       | 0.109  | 0.115 | 0.031  | 0.048 | 0.040   | 0.052  |
| EUAP0987  | Riserva naturale di Monterufoli—Caselli  | 4       | 0.171  | 0.205 | 0.110  | 0.171 | 0.078   | 0.113  |
| EUAP0988  | Riserva naturale Foresta di Berignone  | 2       | 0.163  | 0.179 | 0.037  | 0.060 | 0.047   | 0.070  |
| EUAP0995  | Oasi naturale di Guardiaregia—Campochiaro  | 1       | 0.199  | 0.199 | 0.017  | 0.017 | 0.158   | 0.158  |
| EUAP1010  | Parco interprovinciale di Montioni   | 2       | 0.139  | 0.156 | 0.084  | 0.091 | 0.056   | 0.074  |
| EUAP1020  | Riserva naturale del Monti Rognosi   | 1       | 0.144  | 0.144 | 0.056  | 0.056 | 0.077   | 0.077  |
| EUAP1023  | Riserva naturale dell' Alpe della Luna   | 2       | 0.142  | 0.150 | 0.142  | 0.156 | 0.105   | 0.129  |
| EUAP1027  | Riserva naturale Acquerino Cantagallo  | 1       | 0.140  | 0.140 | 0.092  | 0.092 | 0.068   | 0.068  |
| EUAP1034  | Parco naturale di Veio   | 2       | 0.162  | 0.171 | 0.025  | 0.045 | 0.086   | 0.093  |
| EUAP1035  | Parco naturale dei Monti Aurunci   | 7       | 0.116  | 0.162 | 0.069  | 0.120 | 0.060   | 0.097  |
| EUAP1038  | Riserva naturale di Monte Catillo  | 1       | 0.098  | 0.098 | 0.025  | 0.025 | 0.037   | 0.037  |
| EUAP1039  | Riserva naturale di Nomentum   | 1       | 0.122  | 0.122 | 0.017  | 0.017 | 0.070   | 0.070  |
| EUAP1046  | Riserva naturale della Marcigliana   | 1       | 0.121  | 0.121 | 0.025  | 0.025 | 0.053   | 0.053  |
| EUAP1052  | Parco naturale regionale di Porto Conte  | 1       | 0.116  | 0.116 | 0.069  | 0.069 | 0.036   | 0.036  |
| EUAP1053  | Parco naturale di Gallipoli Cognato—Piccole Dolomiti<br>Lucane                                     | 12      | 0.146  | 0.178 | 0.120  | 0.227 | 0.093   | 0.167  |
| EUAP1054  | Parco naturale regionale della Gola della Rossa e di Frasassi                                      | 4       | 0.131  | 0.173 | 0.046  | 0.086 | 0.070   | 0.103  |
| EUAP1057  | Parco naturale delle Alpi Marittime  | 2       | 0.136  | 0.136 | 0.084  | 0.085 | 0.071   | 0.078  |
| EUAP1062  | Parco regionale del Delta del Po (VE)  | 1       | 0.120  | 0.120 | 0.031  | 0.031 | 0.099   | 0.099  |
| EUAP1067  | Parco nazionale delle Cinque Terre   | 3       | 0.135  | 0.178 | 0.064  | 0.133 | 0.089   | 0.153  |
| EUAP1069  | Riserva naturale guidata Abetina di Rosello  | 1       | 0.284  | 0.284 | 0.042  | 0.042 | 0.210   | 0.210  |
| EUAP1079  | Parco naturale regionale del complesso lacuale Bracciano-<br>Martignano                            | 3       | 0.145  | 0.220 | 0.060  | 0.090 | 0.103   | 0.163  |
| EUAP1089  | Riserva naturale guidata Monte Genzana e Alto Gizio  | 2       | 0.144  | 0.148 | 0.099  | 0.118 | 0.072   | 0.074  |
| EUAP1091  | Riserva naturale guidata Gole di S. Venanzio   | 1       | 0.126  | 0.126 | 0.021  | 0.021 | 0.024   | 0.024  |
| EUAP1103  | Riserva naturale orientata Bosco della Ficuzza, Rocca<br>Busambra, Bosco del Cappelliere e Gorgo d | 4       | 0.102  | 0.150 | 0.083  | 0.095 | 0.058   | 0.094  |
| EUAP1116  | Riserva naturale orientata Fiumedinisi e Monte Scuderi   | 1       | 0.114  | 0.114 | 0.134  | 0.134 | 0.044   | 0.044  |
| EUAP1121  | Riserva naturale orientata Bosco di Favara e Bosco Granza  | 3       | 0.134  | 0.160 | 0.077  | 0.102 | 0.069   | 0.080  |
| EUAP1123  | Riserva naturale orientata Monte Cammarata   | 1       | 0.121  | 0.121 | 0.116  | 0.116 | 0.074   | 0.074  |
| EUAP1126  | Riserva naturale orientata Bosco di Malabotta  | 2       | 0.142  | 0.158 | 0.152  | 0.178 | 0.107   | 0.111  |
| EUAP1130  | Riserva naturale orientata Monte Altesina  | 1       | 0.095  | 0.095 | 0.020  | 0.020 | 0.019   | 0.019  |
| EUAP1136  | Riserva naturale orientata Monti di Palazzo Adriano e Valle del Sosio                              | 6       | 0.097  | 0.117 | 0.059  | 0.092 | 0.040   | 0.073  |
| EUAP1140  | Riserva naturale orientata Monte Genuardo e Santa Maria del Bosco                                  | 2       | 0.099  | 0.112 | 0.104  | 0.104 | 0.034   | 0.049  |
| EUAP1143  | Riserva naturale orientata Sambuchetti-Campanito   | 1       | 0.151  | 0.151 | 0.067  | 0.067 | 0.060   | 0.060  |
| EUAP1154  | Riserva naturale orientata Rossomanno-Grottascura-Bellia   | 2       | 0.167  | 0.181 | 0.081  | 0.096 | 0.125   | 0.137  |
| EUAP1155  | Riserva naturale orientata Bosco di Santo Pietro   | 1       | 0.122  | 0.122 | 0.042  | 0.042 | 0.051   | 0.051  |
| EUAP1158  | Parco nazionale dell'Appennino Tosco-Emiliano  | 13      | 0.165  | 0.212 | 0.060  | 0.089 | 0.107   | 0.181  |
| EUAP1169  | Riserva naturale statale Gola del Furlo  | 4       | 0.142  | 0.157 | 0.082  | 0.107 | 0.068   | 0.100  |
| EUAP1171  | Riserva naturale statale Tenuta di Castelporziano  | 6       | 0.189  | 0.220 | 0.046  | 0.097 | 0.139   | 0.196  |
| EUAP1173  | Sistema territoriale di interesse naturalistico—ambientale<br>Monte Peglia Selva di Meana (STINA)  | 3       | 0.159  | 0.181 | 0.063  | 0.087 | 0.075   | 0.105  |
| EUAP1177  | Riserva naturale orientata Bosco Ronchetti   | 1       | 0.116  | 0.116 | 0.040  | 0.040 | 0.053   | 0.053  |
| EUAP1184  | Zona di salvaguardia del Monte Fenera  | 3       | 0.156  | 0.168 | 0.057  | 0.106 | 0.123   | 0.183  |
| EUAP1194  | Parco naturale regionale Litorale di Ugento  | 1       | 0.139  | 0.139 | 0.031  | 0.031 | 0.060   | 0.060  |
| EUAP1195  | Parco naturale regionale Fiume Ofanto  | 2       | 0.113  | 0.120 | 0.066  | 0.089 | 0.048   | 0.066  |
| EUAP1196  | Riserva naturale Monte Faverghera  | 1       | 0.159  | 0.159 | 0.047  | 0.047 | 0.107   | 0.107  |

# Table 10 B-N-OG mean estimates in Natura 2000 network habitats

| Natura 2000<br>habitat code | Habitat name  | n plots | Mean B | Max B | Mean N | Max N | Mean OG | Max OG |
|-----------------------------|---|---------|--------|-------|--------|-------|---------|--------|
| 91                          | European temperate forests  | 646     | 0.157  | 0.296 | 0.085  | 0.403 | 0.102   | 0.422  |
| 9110                        | Luzulo-Fagetum beech forests  | 315     | 0.168  | 0.327 | 0.088  | 0.403 | 0.122   | 0.422  |
| 9120                        | Atlantic acidophilous beech forests with Ilex and sometimes<br>also Taxus in the shrublayer (Quercion robori-petraeae or<br>Ilici-Fagenion)                         | 8       | 0.134  | 0.172 | 0.080  | 0.159 | 0.060   | 0.123  |
| 9130                        | Asperulo-Fagetum beech forests  | 292     | 0.174  | 0.327 | 0.086  | 0.333 | 0.131   | 0.422  |
| 9140                        | Medio-European subalpine beech woods with Acer and Rumex arifolius  | 49      | 0.167  | 0.266 | 0.090  | 0.288 | 0.122   | 0.275  |
| 9150                        | Medio-European limestone beech forests of the Cephalan-<br>thero-Fagion   | 131     | 0.170  | 0.259 | 0.072  | 0.271 | 0.118   | 0.356  |
| 9160                        | Sub-Atlantic and medio-European oak or oak-hornbeam forests of the Carpinion betuli   | 37      | 0.172  | 0.270 | 0.063  | 0.271 | 0.116   | 0.274  |
| 9180                        | Tilio-Acerion forests of slopes, screes and ravines   | 646     | 0.158  | 0.296 | 0.082  | 0.360 | 0.102   | 0.365  |
| 9190                        | Old acidophilous oak woods with Quercus robur on sandy plains   | 1       | 0.118  | 0.118 | 0.045  | 0.045 | 0.103   | 0.103  |
| 91AA                        | Eastern white oak woods   | 452     | 0.139  | 0.296 | 0.082  | 0.403 | 0.075   | 0.266  |
| 91B0                        | Thermophilous Fraxinus angustifolia woods   | 14      | 0.150  | 0.205 | 0.084  | 0.171 | 0.077   | 0.118  |
| 91D0                        | Bog woodland  | 71      | 0.179  | 0.284 | 0.130  | 0.333 | 0.154   | 0.322  |
| 91F0                        | Riparian mixed forests of Quercus robur, Ulmus laevis and<br>Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia,<br>along the great rivers (Ulmenion minoris) | 89      | 0.152  | 0.270 | 0.044  | 0.203 | 0.092   | 0.217  |
| 91H0                        | Pannonian woods with Quercus pubescens  | 32      | 0.150  | 0.194 | 0.059  | 0.156 | 0.075   | 0.216  |
| 91K0                        | Illyrian Fagus sylvatica forests (Aremonio-Fagion)  | 188     | 0.171  | 0.259 | 0.095  | 0.360 | 0.122   | 0.356  |
| 91L0                        | Illyrian oak-hornbeam forests (Erythronio-Carpinion)  | 201     | 0.160  | 0.284 | 0.059  | 0.194 | 0.089   | 0.282  |
| 91M0                        | Pannonian-Balkanic turkey oak -sessile oak forests  | 406     | 0.149  | 0.327 | 0.088  | 0.293 | 0.088   | 0.372  |
| 9210                        | Apeninne beech forests with Taxus and Ilex  | 830     | 0.149  | 0.296 | 0.082  | 0.293 | 0.087   | 0.365  |
| 9220                        | Apennine beech forests with Abies alba and beech forests with Abies nebrodensis   | 319     | 0.154  | 0.327 | 0.081  | 0.293 | 0.100   | 0.372  |
| 9250                        | Quercus trojana woods   | 25      | 0.103  | 0.184 | 0.026  | 0.104 | 0.040   | 0.097  |
| 9260                        | Castanea sativa woods   | 753     | 0.153  | 0.327 | 0.075  | 0.403 | 0.092   | 0.372  |
| 92A0                        | Salix alba and Populus alba galleries   | 641     | 0.143  | 0.271 | 0.078  | 0.293 | 0.079   | 0.273  |
| 92C0                        | Platanus orientalis and Liquidambar orientalis woods (Pla-<br>tanion orientalis)  | 13      | 0.124  | 0.182 | 0.057  | 0.171 | 0.071   | 0.151  |
| 92D0                        | Southern riparian galleries and thickets (Nerio-Tamaricetea and Securinegion tinctoriae)  | 123     | 0.126  | 0.220 | 0.093  | 0.273 | 0.059   | 0.180  |
| 9320                        | Olea and Ceratonia forests  | 78      | 0.119  | 0.200 | 0.097  | 0.273 | 0.048   | 0.146  |
| 9330                        | Quercus suber forests   | 234     | 0.131  | 0.293 | 0.083  | 0.280 | 0.066   | 0.245  |
| 9340                        | Quercus ilex and Quercus rotundifolia forests   | 925     | 0.140  | 0.293 | 0.073  | 0.293 | 0.075   | 0.267  |
| 9380                        | Forests of Ilex aquifolium  | 110     | 0.131  | 0.212 | 0.114  | 0.280 | 0.067   | 0.183  |
| 9410                        | Acidophilous Picea forests of the montane to alpine levels (Vaccinio-Piceetea)  | 249     | 0.175  | 0.284 | 0.100  | 0.360 | 0.139   | 0.356  |
| 9420                        | Alpine Larix decidua and/or Pinus cembra forests  | 231     | 0.174  | 0.284 | 0.108  | 0.403 | 0.137   | 0.322  |
| 9430                        | Subalpine and montane Pinus uncinata forests (* if on gyp-<br>sum or limestone)   | 31      | 0.162  | 0.255 | 0.098  | 0.271 | 0.121   | 0.274  |
| 9510                        | Southern Apennine Abies alba forests  | 16      | 0.189  | 0.284 | 0.074  | 0.121 | 0.137   | 0.210  |
| 9530                        | (Sub-) Mediterranean pine forests with endemic black pines  | 190     | 0.163  | 0.271 | 0.103  | 0.360 | 0.112   | 0.356  |
| 9540                        | Mediterranean pine forests with endemic Mesogean pines  | 141     | 0.138  | 0.247 | 0.066  | 0.203 | 0.071   | 0.183  |
| 9560                        | Endemic forests with Juniperus spp.   | 25      | 0.140  | 0.244 | 0.081  | 0.164 | 0.077   | 0.254  |
| 9580                        | Mediterranean Taxus baccata woods   | 99      | 0.129  | 0.212 | 0.126  | 0.280 | 0.061   | 0.155  |
| 95A0                        | High oro-Mediterranean pine forests   | 19      | 0.144  | 0.238 | 0.096  | 0.249 | 0.084   | 0.197  |

Table 11 B-N-OG results per Natura 2000 site types

|           |   | n° plots | B mean | N mean | OG mean |
|-----------|---|----------|--------|--------|---------|
| Site type | A | 542      | 0.149  | 0.080  | 0.093   |
|           | В | 1035     | 0.148  | 0.076  | 0.088   |
|           | С | 347      | 0.153  | 0.073  | 0.097   |

# Appendix D: Analysis of variance (ANOVA)

#### See Table 12.

 Table 12 P-values of plots located inside or outside protected areas (both EUAP and Natura 2000), and between "conifers" and "broadleaves"

| Protected area         | as                            | Indicator    | <i>p</i> -value          | Signifi-<br>cance |  |
|------------------------|-------------------------------|--------------|--------------------------|-------------------|--|
| Inside                 | Outside                       | B<br>N<br>OG | 0.487<br><0.001<br>0.004 | ns<br>***<br>**   |  |
| Forest categories      |                               | Indicator    | <i>p</i> -value          | Signifi-<br>cance |  |
| Conifers               | Broadleaves                   | В            | < 0.001                  | ***               |  |
| (Forest                | (Forest catego-<br>ries 8–19) | Ν            | < 0.001                  | ***               |  |
| categories<br>1–7, 20) |                               | OG           | < 0.001                  | ***               |  |

Acknowledgements Paper was partially supported by the following projects: MULTIFOR "Multi-scale observations to predict Forest response to pollution and climate change" PRIN 2020 Research Project of National Relevance funded by the Italian Ministry of University and Research (prot. 2020E52THS); SUPERB "Systemic solutions for upscaling of urgent ecosystem restoration for forest related biodiversity and ecosystem services" H2020 project funded by the European Commission, number 101036849 call LC-GD-7-1-2020; EFINET "European Forest Information Network" funded by the European Forest, Institute Network Fund G-01-2021; FORWARDS "The ForestWard Observatory to Secure Resilience of European Forests," HORIZON project funded by the European Commission, number 101084481 call HORIZON-CL6-2022-CLIMATE-01

Author contributions G.C., C.B. conceptualized the study; C.B. curated the data; C.B., S.F. helped in formal analysis; C.B., F.P., F.L. investigated the study; C.B., S.F. contributed to methodology; G.C. administrated the project; C.B. wrote the original draft; S.F., F.P., R.M., F.L., S.N., A.M., D.T., and G.C. helped in writing—review and editing. All authors have read and agreed to the published version of the manuscript.

**Funding** Open access funding provided by Università degli Studi di Firenze within the CRUI-CARE Agreement. Not applicable.

**Data availability** The datasets generated during the current study are available from the corresponding author on reasonable request.

Code availability Code available on request.

#### Declarations

**Conflict of interest** The authors have no competing interests to declare that are relevant to the content of this article.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

#### References

- Arekhi M, Yılmaz OY, Yılmaz H, Akyüz YF (2017) Can tree species diversity be assessed with Landsat data in a temperate forest? Environ Monit Assess 189:586. https://doi.org/10.1007/ s10661-017-6295-6
- Aronson MFJ, La Sorte FA, Nilon CH et al (2014) A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc R Soc B Biol Sci 281:20133330. https://doi.org/10.1098/rspb.2013.3330
- Asbeck T, Kozák D, Spînu AP et al (2022) Tree-Related Microhabitats Follow Similar Patterns but are More Diverse in Primary Compared to Managed Temperate Mountain Forests. Ecosystems 25:712–726. https://doi.org/10.1007/s10021-021-00681-1
- Badalamenti E, Cairone A (2017) Living and Dead Aboveground Biomass in Mediterranean Forests: Evidence of Old-Growth Traits in a Quercus pubescens Willd. s.l. Stand. Forests 8:187. https:// doi.org/10.3390/f8060187
- Barbati A, Marchetti M, Chirici G, Corona P (2014) European forest types and forest Europe SFM indicators: tools for monitoring progress on forest biodiversity conservation. For Ecol Manage 321:145–157. https://doi.org/10.1016/j.foreco.2013.07.004
- Barredo JI, Brailescu C, Teller A, et al (2021) Mapping and assessment of primary and old-growth forests in Europe
- Basile M, Asbeck T, Jonker M et al (2020) What do tree-related microhabitats tell us about the abundance of forest-dwelling bats, birds, and insects? J Environ Manage 264:110401. https://doi.org/10. 1016/j.jenvman.2020.110401
- Bertini G, Fabbio G, Piovosi M, Calderisi M (2010) Tree biomass and deadwood density into ageing Turkey oak coppices in Tuscany. For Riv Di Selvic Ed Ecol for 7:88–103. https://doi.org/10.3832/ efor0620-007
- Biondi E, Blasi C, Burrascano S, et al (2010) Manuale Italiano di interpretazione degli habitat della Direttiva 92/43/CEE
- Blasi C, Biondi E (2017) La flora in Italia. Ministero dell'Ambiente e della Tutela del Territorio e del Mare
- Blasi C, Burrascano S, Maturani A, Sabatini FM (2010) Old-growth forests in Italy. A thematic contribution to the national biodiversity strategy. pp 1–28
- Błońska E, Prażuch W, Lasota J (2023) Deadwood affects the soil organic matter fractions and enzyme activity of soils in altitude gradient of temperate forests. For Ecosyst 10:100115. https://doi. org/10.1016/j.fecs.2023.100115
- Bohn FJ, Huth A (2017) The importance of forest structure to biodiversity-productivity relationships. R Soc Open Sci 4:160521. https://doi.org/10.1098/rsos.160521

- Boitani L, Falcucci A, Maiorano L, Montemaggiori A (2003) Italian ecological network: the role of protected areas in the conservation of vertebrates
- Bossard M, Feranec J, Otahel J, Steenmans C (2000) CORINE land cover technical guide-Addendum 2000
- Brockerhoff EG, Barbaro L et al (2017) Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodivers Conserv 26:3005–3035. https://doi.org/10.1007/ s10531-017-1453-2
- Buchwald E (2005) A hierarchical terminology for more or less natural forests in relation to sustainable management and biodiversity conservation. Third Expert Meet Harmon For Defin pp 111–127
- Burrascano S, Chianucci F, Trentanovi G et al (2023) Where are we now with European forest multi-taxon biodiversity and where can we head to? Biol Conserv 284:110176. https://doi.org/10. 1016/j.biocon.2023.110176
- Camia A, Gliottone I, Dowell M, Gilmore R, Coll M, Skidmore A, Chirici G, Caimi C, Brink A, Robuchon M, Ferrario I (2023) Earth observation in support of EU policies for biodiversity—a deep-dive assessment of the knowledge centre on earth observation. Publ off Eur Union Luxembourg. https://doi.org/10.2760/ 185588
- Capotorti G, Zavattero L, Anzellotti I et al (2012) Do national parks play an active role in conserving the natural capital of Italy? Plant Biosyst Int J Deal with All Asp Plant Biol 146:258–265. https://doi.org/10.1080/11263504.2012.695298
- CBD (2006) Convention on biological diversity. https://www.cbd.int/ convention/articles/?a=cbd-02#:~:text=%22Biological diversity%22 means the variability,between species and of ecosystems. Accessed 28 Jul 2022
- Chambers JM (2008) Software for data analysis: programming with R. Springer
- Chirici G, Giuliarelli D, Biscontini D et al (2011) Large-scale monitoring of coppice forest clearcuts by multitemporal very high resolution satellite imagery. a case study from central Italy. Remote Sens Environ 115:1025–1033. https://doi.org/10.1016/j.rse.2010. 12.007
- Chirici G, McRoberts RE, Winter S et al (2012) National forest inventory contributions to forest biodiversity monitoring. For Sci 58:257–268. https://doi.org/10.5849/forsci.12-003
- Ciancio O, Nocentini S (2004) The coppice forest. Silviculture, regulation, management. bosco ceduo. Selvic. assestamento, Gest. pp 679–701
- Commissione Europea (2013) Manuale di Interpretazione degli Habitat dell'Unione Europea
- Congedo L, Sallustio L, Munafò M et al (2016) Copernicus highresolution layers for land cover classification in Italy. J Maps 12:1195–1205. https://doi.org/10.1080/17445647.2016.1145151
- Convention on Biological Diversity (2019) Sixth national report for the convention on biological diversity. pp 1–112
- Cordonnier T, Kunstler G (2015) The Gini index brings asymmetric competition to light. Perspect Plant Ecol Evol Syst 17:107–115. https://doi.org/10.1016/j.ppees.2015.01.001
- Corona P (2016) Consolidating new paradigms in large-scale monitoring and assessment of forest ecosystems. Environ Res 144:8–14. https://doi.org/10.1016/j.envres.2015.10.017
- Corona P, Chirici G, McRoberts RE et al (2011) Contribution of largescale forest inventories to biodiversity assessment and monitoring. For Ecol Manage 262:2061–2069. https://doi.org/10.1016/j. foreco.2011.08.044
- Ćosović M, Bugalho M, Thom D, Borges J (2020) Stand structural characteristics are the most practical biodiversity indicators for forest management planning in Europe. Forests 11:343. https:// doi.org/10.3390/f11030343

- Côté S, Bélanger L, Beauregard R et al (2019) A conceptual model for forest naturalness assessment and application in Quebec's boreal forest. Forests 10:325. https://doi.org/10.3390/f10040325
- Côté S, Beauregard R, Margni M, Bélanger L (2021) Using naturalness for assessing the impact of forestry and protection on the quality of ecosystems in life cycle assessment. Sustainability 13:8859. https://doi.org/10.3390/su13168859
- Crist TO, Veech JA, Gering JC, Summerville KS (2003) Partitioning species diversity across landscapes and regions: a hierarchical analysis of  $\alpha$ ,  $\beta$ , and  $\gamma$  diversity. Am Nat 162:734–743. https:// doi.org/10.1086/378901
- Curtis PG, Slay CM, Harris NL et al (2018) Classifying drivers of global forest loss. Science 80(361):1108–1111. https://doi.org/ 10.1126/science.aau3445
- Czerepko J, Gawryś R, Szymczyk R et al (2021) How sensitive are epiphytic and epixylic cryptogams as indicators of forest naturalness? testing bryophyte and lichen predictive power in stands under different management regimes in the Białowieża forest. Ecol Indic 125:107532. https://doi.org/10.1016/j.ecolind.2021. 107532
- De Meo I, Agnelli AE, Graziani A et al (2017a) Deadwood volume assessment in Calabrian pine (Pinus brutia Ten.) peri-urban forests: comparison between two sampling methods. J Sustain for 36:666–686. https://doi.org/10.1080/10549811.2017.1345685
- De Meo I, Graziani A, Cantiani P, Paletto A (2017b) Stima del volume di legno morto in rimboschimenti di pino nero (Pinus nigra J. F . Arnold) in Toscana : confronto tra casi studio. di:
- De Meo I, Becagli C, Casagli A, Paletto A (2022) Characteristics of deadwood and implications for biodiversity in Douglas fir (Pseudotsuga menziesii (Mirb) Franco) planted forests in Italy. Trees for People 10:100341. https://doi.org/10.1016/j.tfp.2022.100341
- DeWalt SJ, Maliakal SK, Denslow JS (2003) Changes in vegetation structure and composition along a tropical forest chronosequence: Implications for wildlife. For Ecol Manage 182:139– 151. https://doi.org/10.1016/S0378-1127(03)00029-X
- Didier L (2001) Invasion patterns of European larch and Swiss stone pine in subalpine pastures in the French Alps. For Ecol Manage 145:67–77. https://doi.org/10.1016/S0378-1127(00)00575-2
- Drever CR, Peterson G, Messier C et al (2006) Can forest management based on natural disturbances maintain ecological resilience? Can J for Res 36:2285–2299. https://doi.org/10.1139/x06-132
- ESA (2018) Copernicus HRL: Tree Cover Density. https://land.coper nicus.eu/pan-european/high-resolution-layers/forests/tree-coverdensity/status-maps/tree-cover-density-2018. Accessed 13 Jul 2023
- Ette J-S, Geburek T (2021) Why European biodiversity reporting is not reliable. Ambio 50:929–941. https://doi.org/10.1007/ s13280-020-01415-8
- Ette J-S, Sallmannshofer M, Geburek T (2023) Assessing forest biodiversity: a novel index to consider ecosystem, species, and genetic diversity. Forests 14:709. https://doi.org/10.3390/f14040709
- European Commission (2020) EU biodiversity strategy for 2030. In: 2020. https://environment.ec.europa.eu/strategy/biodiversitystrategy-2030\_en. Accessed 28 Jul 2022
- Forest Europe (2020) State of Europe's forests 2020
- European environment agency (2014) Developing a forest naturalness indicator for Europe. Concept and methodology for a high nature value (HNV) forest indicator
- European Environment Agency (2018) Copernicus land monitoring service high resolution land cover characteristics. In: Imperviousness 2018, Imperviousness Change 2015 – 2018 and Built-up 2018. Online Permalink: 7860bc42f4c1494599f1e135c832788c
- Fabbio G (2016) Coppice forests, or the changeable aspect of things, a review. Ann Silvic Res 40:108–132. https://doi.org/10.12899/ asr-1286
- FAO (2015) Global forest resource assessment

- FAO (2020) Global Forest Resources Assessment 2020: terms and definitions. For Resour Assess Work Pap 32
- Felipe-Lucia MR, Soliveres S, Penone C et al (2020) Land-use intensity alters networks between biodiversity, ecosystem functions, and services. Proc Natl Acad Sci 117:28140–28149. https://doi.org/ 10.1073/pnas.2016210117
- FISE (2021) Europe forest. https://forest.eea.europa.eu/countries/regio ns/european-union. Accessed 17 Nov 2021
- FAO and UNEP (2020) Forests, biodiversity and people. State World's for 2020:227–249
- Franklin JF (1981) Ecological characteristics of old-growth Douglas-fir forests. US Department of Agriculture, Forest Service, Pacific Northwest Forest and
- Galluzzi M, Giannetti F, Puletti N et al (2019) A plot-level exploratory analysis of European forest based on the results from the biosoil forest biodiversity project. Eur J for Res 138:831–845. https:// doi.org/10.1007/s10342-019-01205-2
- Gao T, Hedblom M, Emilsson T, Nielsen AB (2014) The role of forest stand structure as biodiversity indicator. For Ecol Manage 330:82–93. https://doi.org/10.1016/j.foreco.2014.07.007
- Gao T, Nielsen AB, Hedblom M (2015) Reviewing the strength of evidence of biodiversity indicators for forest ecosystems in Europe. Ecol Indic 57:420–434. https://doi.org/10.1016/j.ecolind.2015. 05.028
- Gasparini P, Tabacchi G (2011) L'Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio - INFC-2005. Secondo inventario forestale nazionale italiano. Edagricole
- Giannetti F, Chirici G, Vangi E et al (2022) Wall-to-wall mapping of forest biomass and wood volume increment in Italy. Forests 13:1989. https://doi.org/10.3390/f13121989
- Gibbons P, Lindenmayer D (2002) Tree hollows and wildlife conservation in Australia. CSIRO publishing
- Gilhen-Baker M, Roviello V, Beresford-Kroeger D, Roviello GN (2022) Old growth forests and large old trees as critical organisms connecting ecosystems and human health. A Rev Environ Chem Lett 20:1529–1538. https://doi.org/10.1007/s10311-021-01372-y
- Hahn K, Christensen M (2005) Dead wood in European forest reserves-a reference for forest management. Monit Indic For Biodivers Eur ideas to Oper 181
- Haines-Young R, Potschin MB (2018) Common international classification of ecosystem services (CICES) V5.1 and guidance on the application of the revised structure
- Harmon ME, Krankina ON, Yatskov M, Matthews E (2001) Predicting broad-scale carbon stores of woody detritus from plot-level data. assess. methods soil carbon pp 533–552
- Heink U, Kowarik I (2010) What are indicators? on the definition of indicators in ecology and environmental planning. Ecol Indic 10:584–593. https://doi.org/10.1016/j.ecolind.2009.09.009
- Heym M, Uhl E, Moshammer R et al (2021) Utilising forest inventory data for biodiversity assessment. Ecol Indic 121:107196
- Hill MO (1973) Diversity and evenness: a unifying notation and its consequences. Ecology 54:427–432
- Hilmers T, Friess N, Bässler C et al (2018) Biodiversity along temperate forest succession. J Appl Ecol 55:2756–2766. https://doi.org/ 10.1111/1365-2664.13238
- Hirschmugl M, Sobe C, Di Filippo A et al (2023) Review on the possibilities of mapping old-growth temperate forests by remote sensing in Europe. Environ Model Assess. https://doi.org/10.1007/ s10666-023-09897-y
- INFC (2007a) Le stime di superficie 2005: Seconda parte. Inventar. Naz. delle For. e dei Serbatoi For. di Carbonio
- INFC (2007b) Le stime di superficie 2005: Prima parte. Inventar. Naz. delle For. e dei Serbatoi For. di Carbonio
- Jalas J (1955) Hemerobe and hemerochore Pflanzenarten. Acta Soc pro Fauna Flora Fenn 72:1–15

- Kok MTJ, Kok K, Peterson GD et al (2017) Biodiversity and ecosystem services require IPBES to take novel approach to scenarios. Sustain Sci 12:177–181. https://doi.org/10.1007/s11625-016-0354-8
- Kondratyeva A, Knapp S, Durka W et al (2020) Urbanization effects on biodiversity revealed by a two-scale analysis of species functional uniqueness vs. Front Ecol Evol, Redundancy. https://doi. org/10.3389/fevo.2020.00073
- Kozák D, Mikoláš M, Svitok M et al (2018) Profile of tree-related microhabitats in European primary beech-dominated forests. For Ecol Manage 429:363–374. https://doi.org/10.1016/j.foreco. 2018.07.021
- Kuc G, Chormański J (2019) Sentinel-2 imagery for mapping and monitoring imperviousness in urban areas. Int Arch Photogramm Remote Sens Spat Inf Sci XLII-1/W2:43–47
- Larrieu L, Cabanettes A, Courbaud B et al (2021) Co-occurrence patterns of tree-related microhabitats: A method to simplify routine monitoring. Ecol Indic 127:107757. https://doi.org/10.1016/j. ecolind.2021.107757
- Larrieu L, Courbaud B, Drénou C et al (2022) Key factors determining the presence of tree-related microhabitats: a synthesis of potential factors at site, stand and tree scales, with perspectives for further research. For Ecol Manage 515:120235. https://doi.org/ 10.1016/j.foreco.2022.120235
- Lassauce A, Paillet Y, Jactel H, Bouget C (2011) Deadwood as a surrogate for forest biodiversity: meta-analysis of correlations between deadwood volume and species richness of saproxylic organisms. Ecol Indic 11:1027–1039. https://doi.org/10.1016/j.ecolind.2011. 02.004
- Lexerød NL, Eid T (2006) An evaluation of different diameter diversity indices based on criteria related to forest management planning. For Ecol Manage 222:17–28. https://doi.org/10.1016/j.foreco. 2005.10.046
- Liang J, Crowther TW, Picard N et al (2016) Positive biodiversityproductivity relationship predominant in global forests. Science 80:354. https://doi.org/10.1126/science.aaf8957
- Lier M, Köhl M, Korhonen KT et al (2022) The new EU forest strategy for 2030: a new understanding of sustainable forest management? Forests 13:245. https://doi.org/10.3390/f13020245
- Lombardi F, Lasserre B, Chirici G et al (2012) Deadwood occurrence and forest structure as indicators of old-growth forest conditions in Mediterranean mountainous ecosystems. Ecoscience 19:344–355
- Lyashevska O, Farnsworth KD (2012) How many dimensions of biodiversity do we need? Ecol Ind 18:485–492. https://doi.org/10. 1016/j.ecolind.2011.12.016
- Maes J, Teller A, Erhard M, et al (2018) Mapping and Assessment of ecosystems and their services: an analytical framework for mapping and assessment of ecosystem condition in EU
- Marziliano P, Antonucci S, Tognetti R et al (2021) Factors affecting the quantity and type of tree-related microhabitats in mediterranean mountain forests of high nature value. Forest Biogeosci for 14:250–259. https://doi.org/10.3832/ifor3568-014
- Maser C, Anderson RG, Cromack K Jr et al (1979) Dead and down woody material. Wildl Habitats Manag for Blue Mt Oregon Washington Agric Handb 553:78–95
- McElhinny C, Gibbons P, Brack C, Bauhus J (2005) Forest and woodland stand structural complexity: Its definition and measurement. For Ecol Manage 218:1–24. https://doi.org/10.1016/j.foreco. 2005.08.034
- McRoberts RE, Winter S, Chirici G, LaPoint E (2012) Assessing forest naturalness. For Sci 58:294–309. https://doi.org/10.5849/forsci. 10-075
- Meyer P, Aljes M, Culmsee H et al (2021) Quantifying old-growthness of lowland European beech forests by a multivariate indicator for

forest structure. Ecol Indic 125:107575. https://doi.org/10.1016/j. ecolind.2021.107575

- Ministerial Conference on the Protection of Forests in Europe (2007) Fifth MCPFE
- Ministry of Environment and Energy Security (2022) SIC, ZSC e ZPS in Italia. https://www.mase.gov.it/pagina/sic-zsc-e-zps-italia#:~: text=All'interno dei siti Natura,ai sensi della Direttiva Uccelli. Accessed 8 Aug 2023
- Moglen GE, Kim S (2007) Limiting imperviousness: are thresholdbased policies a good idea? J Am Plan Assoc 73:161–171
- Montréal Process (2009) Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. 100
- Mori AS, Lertzman KP, Gustafsson L (2017) Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology. J Appl Ecol 54:12–27. https://doi.org/10.1111/ 1365-2664.12669
- Motta R, Berretti R, Lingua E, Piussi P (2006) Coarse woody debris, forest structure and regeneration in the Valbona forest reserve, Paneveggio, Italian Alps. For Ecol Manage 235:155–163. https:// doi.org/10.1016/j.foreco.2006.08.007
- Motta R, Garbarino M, Lingua E et al (2022) The current Italian research and its role in the establishment of an Italian network of "old-growth forests." For Riv Di Selvic Ed Ecol for 19:36–48. https://doi.org/10.3832/efor4110-019
- Newbold T, Hudson LN, Hill SLL et al (2015) Global effects of land use on local terrestrial biodiversity. Nature 520:45–50. https:// doi.org/10.1038/nature14324
- Olson JS (1963) Energy storage and the balance of producers and decomposers in ecological systems. Ecology 44:322–331
- Orsi F, Ciolli M, Primmer E et al (2020) Mapping hotspots and bundles of forest ecosystem services across the European Union. Land Use Policy 99:104840. https://doi.org/10.1016/J.LANDU SEPOL.2020.104840
- Ozdemir I, Norton D, Ozkan U et al (2008) Estimation of tree size diversity using object oriented texture analysis and aster imagery. Sensors 8:4709–4724. https://doi.org/10.3390/s8084709
- Paillet Y, Bergès L, Hjältén J et al (2010) Biodiversity differences between managed and unmanaged forests: meta-analysis of species richness in Europe. Conserv Biol 24:101–112. https://doi. org/10.1111/j.1523-1739.2009.01399.x
- Parisi F, Lombardi F, Sciarretta A et al (2016) Spatial patterns of saproxylic beetles in a relic silver fir forest (Central Italy), relationships with forest structure and biodiversity indicators. For Ecol Manage 381:217–234. https://doi.org/10.1016/j.foreco.2016.09. 041
- Parisi F, Di Febbraro M, Lombardi F et al (2019) Relationships between stand structural attributes and saproxylic beetle abundance in a Mediterranean broadleaved mixed forest. For Ecol Manage 432:957–966. https://doi.org/10.1016/j.foreco.2018.10. 040
- Parisi F, Frate L, Lombardi F et al (2020a) Diversity patterns of coleoptera and saproxylic communities in unmanaged forests of mediterranean mountains. Ecol Indic 110:105873. https://doi.org/10. 1016/j.ecolind.2019.105873
- Parisi F, Lombardi F, Marziliano PA et al (2020b) Diversity of saproxylic beetle communities in chestnut agroforestry systems. For Biogeosci for 13:456–465. https://doi.org/10.3832/ifor3478-013
- Parisi F, Innangi M, Tognetti R et al (2021) Forest stand structure and coarse woody debris determine the biodiversity of beetle communities in Mediterranean mountain beech forests. Glob Ecol Conserv 28:e01637. https://doi.org/10.1016/j.gecco.2021. e01637
- Parisi F, Vangi E, Francini S et al (2022) Monitoring the abundance of saproxylic red-listed species in a managed beech forest by

landsat temporal metrics. For Ecosyst 9:100050. https://doi.org/ 10.1016/j.fecs.2022.100050

- Pereira HM, Ferrier S, Walters M, Geller GN, Jongman RHG, Scholes RJ, Bruford MW, Brummitt N, Butchart SHM, Cardoso AC, Coops NC, Dulloo E, Faith DP, Freyhof J, Gregory RD, Heip C, Hoft R, Hurtt G, Jetz W, Karp DS, McGeoch MA, Obura D, Onoda Y, Pettorelli N, Reyers B, Sayre R, Scharlemann JPW, Stuart SN, Turak E, Walpole M, Wegmann M (2013) Essential biodiversity variables. Science 339(6117):277–278. https://doi. org/10.1126/science.1229931
- Pielou EC (1969) An introduction to mathematical ecology. An Introd to Math Ecol
- Pignatti G, De Natale F, Gasparini P, Paletto A (2009) Deadwood in Italian forests according to national forest inventory results. For Riv Di Selvic Ed Ecol for 6:365–375. https://doi.org/10.3832/ efor0598-006
- Pignatti G, De Natale F, Gasparini P et al (2012) High nature value forest areas: a proposal for Italy based on national forest inventory data. L'italia for e Mont. https://doi.org/10.4129/ifm.2012.3.06
- Potapov P, Hansen MC, Laestadius L, Turubanova S, Yaroshenko A, Thies C, Esipova E (2017) The last frontiers of wilderness: tracking loss of intact forest landscapes from 2000 to 2013. Sci Adv 3(1):e1600821
- Puletti N, Canullo R, Mattioli W et al (2019) A dataset of forest volume deadwood estimates for Europe. Ann for Sci 76:68. https://doi. org/10.1007/s13595-019-0832-0
- Reif A, Walentowski H (2008) The assessment of naturalness and its role for nature conservation and forestry in Europe. Waldökologie, Landschaftsforsch Und Naturschutz 6:63–76
- Reineke LH (1933) Perfection a stand-density index for even-aged forest. J Agric Res 46:627–638
- Reise J, Kukulka F, Flade M, Winter S (2019) Characterising the richness and diversity of forest bird species using National forest inventory data in Germany. For Ecol Manage 432:799–811. https://doi.org/10.1016/j.foreco.2018.10.012
- Riitano N, Congedo L, Garofalo V, et al (2016) Stima del consumo di suolo a livello nazionale. In: Consumo di suolo, dinamiche territoriali e servici ecosistemici. ISPRA, p 150
- Romano B (1995) National Parks Policy and Mountain Depopulation: A Case Study in the Abruzzo Region of the Central Apennines. Italy Mt Res Dev 15:121. https://doi.org/10.2307/3673876
- Romano B, Zullo F, Fiorini L, Marucci A (2021) "The park effect"? an assessment test of the territorial impacts of Italian National Parks, thirty years after the framework legislation. Land Use Policy 100:104920. https://doi.org/10.1016/j.landusepol.2020. 104920
- Rondeux J, Bertini R, Bastrup-Birk A et al (2012) Assessing deadwood using harmonized national forest inventory data. For Sci 58:269–283. https://doi.org/10.5849/forsci.10-057
- Saint-André L, Hervé J-C (2015) DIABOLO-Distributed, integrated and harmonised forest information for bioeconomy outlooks: WP2 Overview and work and operational plan for 2015. Kickoff meeting, HAL Open Science
- Sallustio L, Quatrini V, Geneletti D et al (2015) Assessing land take by urban development and its impact on carbon storage: findings from two case studies in Italy. Environ Impact Assess Rev 54:80–90. https://doi.org/10.1016/j.eiar.2015.05.006
- Sallustio L, De Toni A, Strollo A et al (2017) Assessing habitat quality in relation to the spatial distribution of protected areas in Italy. J Environ Manage 201:129–137. https://doi.org/10.1016/j.jenvm an.2017.06.031
- Santopuoli G, Vizzarri M, Spina P et al (2022) How individual tree characteristics and forest management influence occurrence and richness of tree-related microhabitats in Mediterranean mountain forests. For Ecol Manage 503:119780. https://doi.org/10.1016/j. foreco.2021.119780

- Schleicher-Tappeser R (2018) Sustainable development in the European Union - monitoring report on progress towards the sdgs in an eu context
- Seto KC, Güneralp B, Hutyra LR (2012) Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proc Natl Acad Sci 109:16083–16088. https://doi.org/10. 1073/pnas.1211658109
- Shannon CE (1948) A mathematical theory of communication. Bell Syst Tech J 27:379–423. https://doi.org/10.1002/j.1538-7305. 1948.tb01338.x
- Spies TA (1998) Forest structure: a key to the ecosystem. Northwest Sci 72:34–36
- Stirling G, Wilsey B (2001) Empirical relationships between species richness, evenness, and proportional diversity. Am Nat 158:286– 299. https://doi.org/10.1086/321317
- Stockemer D, Lentz T, Mayer D (2018) Individual predictors of the radical right-wing vote in Europe: a meta-analysis of articles in peer-reviewed journals (1995–2016). Gov Oppos 53:569–593. https://doi.org/10.1017/gov.2018.2
- Storch F, Dormann CF, Bauhus J (2018) Quantifying forest structural diversity based on large-scale inventory data: a new approach to support biodiversity monitoring. For Ecosyst 5:34. https://doi. org/10.1186/s40663-018-0151-1
- Strand G-H (2022) Accuracy of the copernicus high-resolution layer imperviousness density (HRL IMD) assessed by point sampling within pixels. Remote Sens 14:3589. https://doi.org/10.3390/ rs14153589
- Sullivan TP, Sullivan DS, Lindgren PMF (2001) Stand structure and small mammals in young lodgepole pine forest: 10-year results after thinning. Ecol Appl 11:1151–1173
- Tabacchi G, Di Cosmo L, Gasparini P (2011) Aboveground tree volume and phytomass prediction equations for forest species in Italy. Eur J for Res 130:911–934
- Toivonen J, Kangas A, Maltamo M, et al (2022) Assessing biodiversity using forest structure indicators based on point cloud data. Ecol Indic
- Travaglini D, Paffetti D, Bianchi L et al (2012) Characterization, structure and genetic dating of an old-growth beech-fir forest in the northern Apennines (Italy). Plant Biosyst - an Int J Deal with All Asp Plant Biol 146:175–188. https://doi.org/10.1080/11263 504.2011.650731

United Nations (2019) United nations strategic plan for forests 2030. 20

- Valbuena R, Maltamo M, Packalen P (2016) Classification of multilayered forest development classes from low-density national airborne lidar datasets. Forestry 89:392–401. https://doi.org/10. 1093/forestry/cpw010
- Van Den Meersschaut D, Vandekerkhove K (2000) Development of a stand-scale forest biodiversity index based on the State Forest Inventory. Hansen Mark; Burk, Tom, (eds) Integr tools Nat Resour Invent 21st century Gen Tech Rep NC-212 St Paul, MN US Dept Agric For Serv North Cent For Exp Station 340-350 212

- Vangi E, D'Amico G, Francini S et al (2021) The Effect of Forest Mask Quality in the Wall-to-Wall Estimation of Growing Stock Volume. Remote Sens 13:1038. https://doi.org/10.3390/rs13051038
- Varga P, Chen HY, Klinka K (2005) Tree-size diversity between singleand mixed-species stands in three forest types in western Canada. Can J for Res 35:593–601. https://doi.org/10.1139/x04-193
- Vuidot A, Paillet Y, Archaux F, Gosselin F (2011) Influence of tree characteristics and forest management on tree microhabitats. Biol Conserv 144:441–450. https://doi.org/10.1016/j.biocon. 2010.09.030
- Waldron A, Miller DC, Redding D et al (2017) Reductions in global biodiversity loss predicted from conservation spending. Nature 551:364–367. https://doi.org/10.1038/nature24295
- Wei T, Simko V, Levy M et al (2017) Package 'corrplot.' Statistician 56:e24
- Wilson (1988) EO biodiversity; National Academies Press: Washington. DC, USA
- Winter S (2012) Forest naturalness assessment as a component of biodiversity monitoring and conservation management. Forestry 85:293–304. https://doi.org/10.1093/forestry/cps004
- Winter S, Chirici G, McRoberts RE et al (2008) Possibilities for harmonizing national forest inventory data for use in forest biodiversity assessments. Forestry 81:33–44. https://doi.org/10.1093/ forestry/cpm042
- Winter S, Fischer HS, Fischer A (2010) Relative quantitative reference approach for naturalness assessments of forests. For Ecol Manage 259:1624–1632. https://doi.org/10.1016/j.foreco.2010.01.040
- Winter S, Borrass L, Geitzenauer M et al (2014) The impact of Natura 2000 on forest management: a socio-ecological analysis in the continental region of the European Union. Biodivers Conserv 23:3451–3482. https://doi.org/10.1007/s10531-014-0822-3
- Wirth C, Gleixner G, Heimann M (2009a) Old-growth forests: function, fate and value – an overview. pp 3–10
- Wirth C, Messier C, Bergeron Y, et al (2009b) Old-growth forest definitions: a pragmatic view. pp 11–33
- Zeide B (2005) How to measure stand density. Trees 19:1–14. https:// doi.org/10.1007/s00468-004-0343-x
- Zenner EK (2000) Do residual trees increase structural complexity in Pacific Northwest coniferous forests? Ecol Appl 10:800–810
- Zhang Y, Chen HYH, Reich PB (2012) Forest productivity increases with evenness, species richness and trait variation: a global meta-analysis. J Ecol 100:742–749. https://doi.org/10.1111/j. 1365-2745.2011.01944.x
- Ziegler SS (2000) A comparison of structural characteristics between old-growth and postfire second-growth hemlock-hardwood forests in Adirondack Park, New York USA. Glob Ecol Biogeogr 9:373–389. https://doi.org/10.1046/j.1365-2699.2000.00191.x

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.