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# Assessing the conservation value of forests: the redefinition of the Forest Status Quality indicator in a multiscale approach and its application in northern Italy (Lombardy)

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**Abstract**
The purpose of this study is to evaluate the Forest Status Quality (FSQ) indicator, which has been recently formulated in literature, using a new multiscale approach. The FSQ indicator combines the floristic composition (derived, in the present manuscript, from 81 phytosociological tables composed of 484 phytosociological relevés, distributed in 278 localities and 10 provinces of the Region Lombardy) and the stratification of the considered forest types in a unique value, also considering the size of the forest patches.We apply the new theoretical framework to a real case study (Lombardy, in the northern part of Italy) with the aim of: (i) assessing the forest conservation value at different territorial levels: Municipality, Province, and Phytogeographical belt, and (ii) exploring the management implications of our results. At the first level of multiscale analysis, we have very detailed information, with a very good differentiation among municipalities, as proved by the statistical analysis of the resulting data. At the intermediate multiscale level, we have too generic information with a very little difference among provinces. At regional phytogeographical level, the highest resolution of the multiscale analysis, we have information expressing a global forest quality for a wide territory, but with still a good differentiation among phytogeographical belts. The proposed indicator allows also to define the forest types obtaining the best evaluation and thus considered of high conservation concern (we call them the Top forests). The resulted Top forests are the 27% of the total number of assessed forest types. In mountain areas, generally, forests are well preserved and the major efforts in the management of protected areas should be directed to the conservation of other ecosystems (grasslands and/or shrublands), while in the plain and low hilly areas, a particular attention should be dedicated to the restoration of woods. Furthermore, we propose detailed policies of habitat restoration and requalification for each one of the five classes of forest quality: in particular, for class 1 and 2, forest restoration is mandatory, for class 3 and 4 the attention is focused on the conservation of existing forests, while for class 5 restoration of other habitats is highly suggested. A further application of the FSQ could be considered in the monitoring of forest habitats (according to the Habitat Directive), particularly in the SCIs of the Natura 2000 network.

Key words: alien/protected species, computer assisted data analysis, forest quality indicator, Geographical Information Systems (GIS), multiscale spatial analysis, vertical stratification.

## Introduction

Due to the increasing human impact on the structure and function of natural ecosystems, resulting in shifts of species composition and species extinction, there is an increasing need for assessing and monitoring the biodiversity and conservation value of biological communities (Landi & Chiarucci, 2010). Thus, biodiversity conservation has become a key issue in policy and management of all natural resources, not least forest ecosystems (Gao *et al*., 2015).

Three primary attributes of biodiversity are widely recognized as providing a framework for research on forest biodiversity and conservation: (1) species/composition (identity and variety of elements, including species lists and measures of species diversity), (2) structure (physiognomy of forest as measured within a stand to variation at forest scale and on the pattern of forest patches at a landscape scale), and (3) function (ecological and evolutionary processes, including gene flow, disturbances and nutrient cycling) (Gao *et al*., 2015).

Usually, indicators or tools developed to assess the biodiversity and conservation value of forests consider such primary attributes (species/composition, structure, and function) separately. Thus, we can recognize different types of indicators based on one, and only one attribute, among forest structure, species composition, or function. In some cases, indicators based on different primary attributes were used together to predict forest biodiversity (Sabatini *et al*., 2016). At the landscape level, indicators were developed considering the size and shape of the patches occupied by forests with the aim to assess their fragmentation, and consequently their quality. In fact, patches smaller than 1 ha generally show low species richness (Digiovinazzo *et al*., 2010) and low floristic quality, due to the edge effect, which can increase the abundance of weedy and alien species (Saunders *et al*., 1991; Laurance *et al*., 2002). Furthermore, a correlation between the shape and the species richness of forest patches can be found when the patch size is sufficiently high. Honnay *et al*. (2002) analysed 234 forest patches varying in size between 0.5 and 5216 ha and found a correla-

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tion between the Patton shape index and the number of woody species and lianas and, as a consequence, with the total number of forest plant species.

Here, we considered species/composition based indicators and structural indicators because they are more amenable to measurement by forest researchers (Ferris & Humphrey, 1999) when the focus is on forest biodiversity indicators. In addition, species/composition and structural elements may act as surrogate functional indicators (Gao *et al*., 2015). According to the review of Gao *et al*. (2015), structural indicators include deadwood, vegetation structure, and temporal and other structural parameters. Particularly, vegetation structure can consider tree canopy cover, shrub cover, field layer cover, vertical stratification, forest shape, basal area of trees, stem density, tree height and other parameters. Species/composition based indicators consider bird, mammal/reptile, invertebrate, vascular plants, bryophyte, lichen, fungus.

In relation to the floristic composition, indices which not discriminate between the communities composed of common and widely distributed species and those composed of specialized or rarer ones (Francis *et al*., 2000), are of little use for conservation purposes (Landi & Chiarucci, 2010).

On the contrary, indices that weight the 'value' of the species making up the communities (Francis *et al*., 2000; Lopez & Fennessy, 2002; DeKeyser *et al*., 2003; Matthews, 2003) are very useful for such purposes.

The Floristic Quality Index (FQI) is a widely applied method developed in North America to assess the quality of a flora based on the assignment of scores, by an expert judgement, to plant species and subsequent calculation of indices. It was developed to quantify the extent to which communities contain rare species and allow for objective comparisons among sites in order to prioritize conservation interventions (Swink & Wilhelm, 1979; 1994). Since the assignment of the scores to the species is subjective, it may affects the results (Herman *et al*., 1997; Taft *et al*., 1997; Andreas *et al*., 2004). This problem can be even more important in countries with a long history of human exploitation, where it is difficult to distinguish between natural and human derived habitats (Landi &Chiarucci, 2010), as in the case of Europe and its forests, where the human activities modified forest composition and structure for centuries.

The Forest Status Quality (FSQ) indicator, both in its original, basic formulation (Assini & Albanesi, 2015a) and in its multiscale reformulation, here proposed, differs from the others in literature because it combines the floristic composition (*without* assigning a particular score to the considered species) and the structure (stratification) in a unique indicator to assess the conservation value of forests. To collect, at the same time, data on floristic composition and stratification, the phytosociological approach (Braun-Blanquet, 1931; Biondi, 2011; Pott, 2011) was applied. For the stratification, this approach usually considers the tree layer, high-shrub layer, low shrub layer and herb layer (average % cover and height).

Particularly, the following components have been considered: protected species, according to the Lombardy regional law [L.R. 10/2008], and alien species, for the floristic composition, and vertical stratification, for the structure. Furthermore, as better explained in Materials and methods, the size of the forest area is also considered in weighting the importance of such components.

Some considerations are useful to motivate the choice of these components. The vertical stratification is important for biodiversity; the increasing in the number of layers (due to the absence of disturbances, usually related to forestry and/or other human activities) can increase the quantity and/or quality of floristic richness and ecosystem functions, and, consequently, the conservation value (Lelli *et al*., 2018). Protected species, often corresponding to true forest species (such as *Anemonoides nemorosa* (L.) Holub, *Campanula trachelium* L., *Carex elongata* L., *Convallaria majalis* L., *Listera ovata* (L.) R. Br., *Neottia nidus-avis* (L.) Rich., *Primula vulgaris* Huds., etc.), and/or rare species indicate good biodiversity and, consequently, high and good conservation value. The absence or the low presence of alien species indicates the lack of disturbance that in natural communities represents a mode of introduction for species with low floristic integrity (e.g. invasive or cosmopolitan species); therefore, sites dominated by such species typically have low floristic quality values (De Berry & Perry, 2015). The FSQ indicator was previously tested on very limited areas of the Lombardy Region (Assini & Albanesi, 2015a; Assini & Albanesi, 2015b; Assini & Albanesi, 2016). In this work, we applied it in a multiscale case study on the whole Region, with the aim of: (i) assessing the forest conservation value at different scales corresponding to the administrative levels used in Italy for conservation policies: Municipality, Province, and Region and (ii) exploring the management implications of our results.

## Materials and methods

### *Study area*

In this study, the territory under investigation is the Region Lombardy (Fig. 1). It is one of the most important regions of Italy, being the fourth largest region and hosting over 10 million people (population density 420/square kilometre, or 1,100/square mile), about one-sixth of total Italian population. Here, about the 36% of Italy's GDP is produced, making it the most populous and richest region in the country and one of the richest regions in Europe (European Commission 2017). For these reasons, the Region Lombardy is a big challenge in the study of environmental issues, for the presence of the strong pressure of population, industry and agriculture settlements and a dramatic land use growth, as also estimated in the last years in literature by standard (ERSAF, 2012) and new indicators (Albanesi & Albanesi, 2013).

Administratively, Region Lombardy is divided in 12 Provinces and 1544 Municipalities. It is particularly interesting, as a case study, because it is very differentiated in terms of geographic, geological, morphological and climatic features, which cause a great diversity in natural landscapes, flora and vegetation (including forests). Five principal physiographic areas can be distinguished: the Apennine, the Po Plain, the Pre-Alps, the Southern Alps and the Central Alps. The altitude ranges between 0 of the Po Plain and 4,048.6 m (13,283 ft) of Piz Bernina (Alpine Mountains).

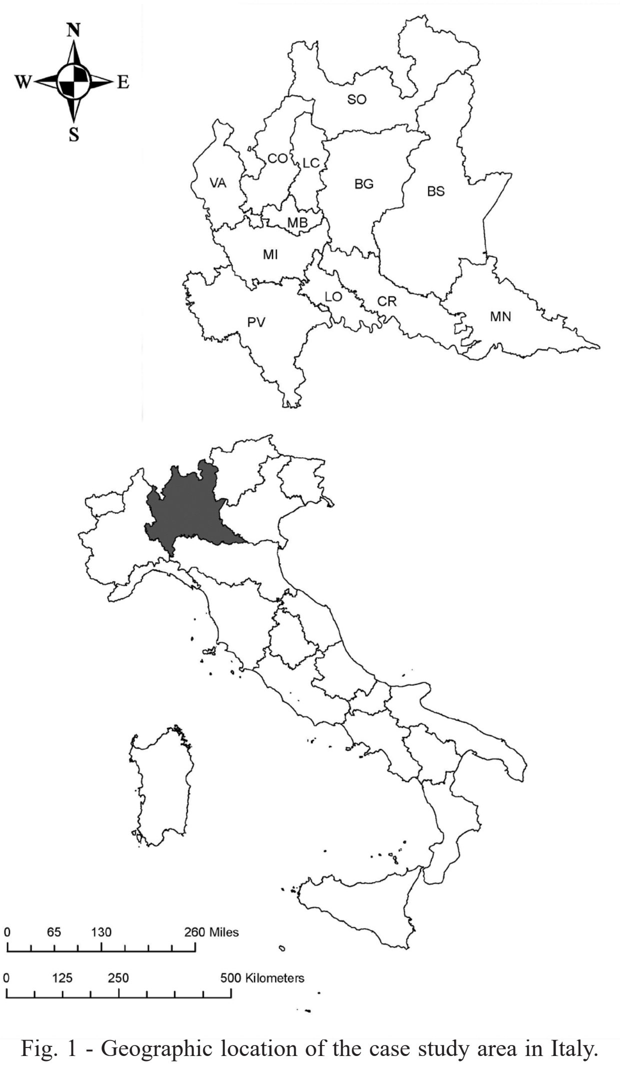


Fig. 1 - Geographic location of the case study area in Italy. The Region Lombardy is in grey, the twelve provinces are also shown: BG = Province of Bergamo, BS = Province of Brescia, CO = Province of Como, CR = Province of Cremona, LC = Province of Lecco, LO = Province of Lodi, MB = Province of Monza-Brianza, MI = Province of Milano, MN = Province of Mantova, PV = Province of Pavia, SO = Province of Sondrio, VA = Province of Varese.

The Region Lombardy is characterized by a thermal and rainfall gradient, depending on altitude. The following climatic zones can be distinguished: the internal alpine valleys characterized by a continental climate; the pre-alpine region characterized by an oceanic climate; the Apennine characterized by a sub Mediterranean rainfall regime, and the Po Plain with a continental climate. As far as land cover is concerned, the study area has been evaluated since the early 2000s.

Land use is particularly dramatic for the study area. In fact, the most recent analysis (ISPRA, 2017), show a land use, referred to 2016, of 12.96% for the Region Lombardy, if compared to the national average of 7.64%.

The Region Lombardy counts plenty of protected areas: the most important are the 193 SCI (Sites of Community Importance) of the Natura 2000 network, defined on the basis of the Council Directive 92/43/EEC (known as Habitat Directive) and covering an area of 224.199 ha. Other important protected areas include the Stelvio National Park (the largest Italian natural park), with typically alpine wildlife (red deer, roe deer, ibex, chamois, foxes, ermine and also golden eagles), and the Ticino Valley Natural Park (an UNESCO Man and Biosphere Reserve), instituted to protect and conserve one of the last major examples of fluvial forest in northern Italy.

***Data sources***

We used several data sources, as input of the software procedures developed for the FSQ computation at multiscale level, described as follows. Their combined use will be fully explained in the next paragraphs.

Firstly, the Geographical Information System (GIS) maps of the ERSAF Database "Map of the Forest Types of Lombardy" (ERSAF, 2011) classify forests on the basis of their physiognomy (dominant woody species) and the ecological characteristics of the site where they occur (geological substrate, type of soil, etc.) (Del Favero, 2001). It classifies only natural and semi-natural forests, and plantations in rural-natural landscapes of the plain-hilly-mountain areas. Urban forests are not considered. The ERSAF Database gives a detailed geo-localized position of all the Forest Types, according to a global census of the Region Lombardy. They are raster data, defined on cells of 50X50 metres, with the reference system WGS84/UTM32N.

Secondly, the ISTAT GIS map gives the administrative boundaries of the Provinces and Municipalities (ISTAT, 2011). This data sources allows to exactly defining which of the Forests Types of the ERSAF Database belongs to each Province or Municipality of Lombardy.

Thirdly, the ISTAT database provides the classification of each municipality according to the standard, historical definition of statistical districts (ISTAT, 1958). This data source is the starting point to classify a municipality according to its altimetry characteristics and then to include it in one of the phytogeographical belts described in the next paragraph. In particular, the ISTAT defines three types of zones:

(a) Mountain zone, for municipality whose territory is prevalently occupied by mountain massifs above 600 m a.s.l.

(b) Hill zone: for municipality whose territory is prevalently occupied by mountain massifs below 600 m.

(c) Plain zone: for municipality whose territory is characterized by the absence of massifs.

Finally, the phytosociological tables included in Andreis & Sartori (2011) were used to assess the quality of the Lombardy forest vegetation. Each of such phytosociological tables reports phytosociological relevès, according to the Braun-Blanquet approach (Biondi, 2011; Pott, 2011), describing a forest association or community occurring in Lombardy. Particularly, all the species observed in the relevès are reported, according to the different strata in which they occur (tree layer, high shrub layer, low shrub layer, herb layer), with their cover-abundance values, according to the Braun-Blanquet scale.

Andreis & Sartori (2011) also indicate the distribution of each forest association or community in the Provinces of Lombardy and give the correspondence with the Forest Types of Del Favero (2001), reported in the ERSAF Database Map of the Forest Types of Lombardy. Each Forest Type can correspond to one or more phytosociological forest association or community, due to the different approach used for the classification. The Forest Types are based on a physiognomic approach that considers only the dominant woody species, while the phytosociological forest association or community are based on a floristic approach (Braun-Blanquet, 1931) which considers all the floristic composition.

Consequently, the Forest Type approach resulted in wide classification units, while the phytosociological approach resulted in more detailed classification units. For some forest types, we considered phytosociological relevés from other literature sources (Andreucci & Castelli, 2008; Corbetta, 1968; Sartori, 1985) or personnel relevés because Andreis & Sartori did not report phytosociological data.

Overall, we used 81 phytosociological tables composed of 484 phytosociological relevés, distributed in 278 localities and 10 provinces of the Region Lombardy.

### *The multiscale methodology of analysis*

The main innovative aspect of this research contribution to the theory of the Forest Status Quality indicator (Assini & Albanesi, 2015a; Assini & Albanesi, 2015b; Assini & Albanesi, 2016) is its application to the wide area of Lombardy in a multiscale approach. The multiscale analysis is a powerful method to describe and understand complex phenomena: by finding the proper resolution, it is possible to highlight unexpected, new aspects of the topic under investigation, which are not so evident without a multiscale approach. However, it is important to choose a useful criteria to build the multiresolution decomposition. In this study, we propose three levels for a possible multiscale analysis of the FSQ on the overall territory under investigation, on the basis of several considerations about management policy opportunities and/or phytogeographical features:

*(1) Level of Municipality*: it is the finest level of the multiscale analysis. We have a total of 1544 municipalities, with growing areas (from a minimum of 1.2 square km to 182.1 square km). The choice of this level of resolution is due to the fact that in Italy the municipality is the main administrative body that can decide local policies for environmental preservation, such as forest plantations and land use management. Therefore, at this level we computed 1544 values of FSQ. We denote this first multiresolution version of FSQ as $FSQ^1(j)$, for j =1, 2. … 1544).

*(2) Level of Province*: to enlarge at a coarser degree the previous administrative perspective, we choose as the second level of the multiscale the Province. Therefore, at this level, we computed 12 values of FSQ. We denote the second multiresolution version of FSQ as $FSQ^2(j)$, for j =1, 2. … 12), with j defining one of the following provinces: Bergamo, Brescia, Como, Cremona, Lecco, Lodi, Mantova, Milano, Monza & Brianza, Pavia, Sondrio, and Varese (see Fig. 1 for their geographic localization).

*(3) Level of Region*: divided in phytogeographical belts: to enlarge further at a coarser degree the previous administrative perspectives, the Region was chosen as third level of multiscale. However, due to the great variability of climate, orography, geology, flora and vegetation throughout Lombardy, as previously described, defining a single forest quality value for the entire Lombardy should not be useful for forest management purposes. Furthermore, such value could not be compared with other regions of Italy, due to their lacking of the same data sets here used to compute the indicator. For this reason, we have considered five distinct belts, which correspond to the principal phytogeographical areas characterizing Lombardy (Fig. 2), defined on the basis of their climate, forest vegetation and floristic features. They are:

(a) the *Alpine Mountain* belt (a northern mountainous area constituted by the Alpine relief, characterized by a rugged alpine climate, both zonal coniferous and zonal broad-leaved forest vegetation and a typical alpine flora);

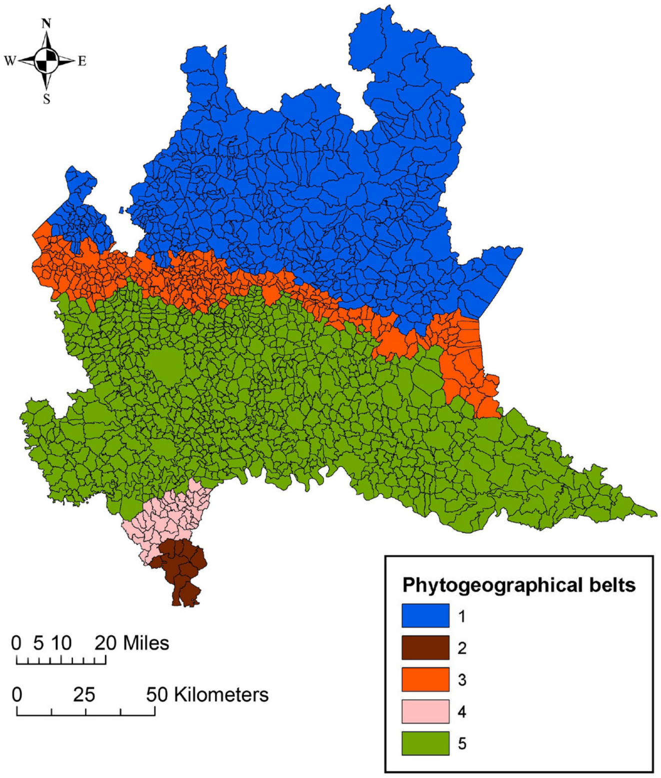


Fig. 2 - The third level of the multiscale approach: the phytogeographical belts. Legenda: 1 = Alpine Mountain; 2 = Apennine Mountain, 3 = Alpine Hill, 4 = Apennine Hill, and 5 = Po Plain.

(b) the *Alpine Hill* belt (a northern pre-alpine area, characterized by a temperate climate, zonal broad-leaved forest vegetation and a flora rich in endemics);

(c) the *Po Plain* belt (a central area crossed by the main Italian river, the Po, characterized by a continental climate, azonal and zonal broad-leaved forest vegetation and a flora rich in alien species due to the intensive human exploitation);

(d) the *Apennine Hill* belt (a southern pre-apennine area, characterized by a continental-sub-mediterranean climate, zonal broad-leaved forest vegetation and a sub Mediterranean flora);

(e) the A*pennine Mountain* belt (a southern Apennine area, characterized by a sub-oceanic-sub-mediterranean climate, zonal *Fagus sylvatica* L. forest vegetation and a mixed flora with alpine, sub-mediterranean and apennine elements).

Therefore, at this level we computed 5 values of FSQ. We denote this third multiresolution version of FSQ as $FSQ^3(j)$, for j =1, …5), where the index j determines one of the following belts: *Alpine Mountain*, *Apennine Mountain*, *Alpine Hill*, *Apennine Hill*, and *Po Plain*. In Tab. 1, the three levels of the multiscale approach and their main characteristics are reported.

### *The redefinition of FSQ in the multiscale approach*

As pointed out in the introduction, the FSQ indicator has been already described in literature, at least in its "plain" version, i.e., without the introduction of the multiresolution. Therefore, we report here only a summarized description to appreciate the discussion of the results (for details of the definition, see Assini & Albanesi, 2015a). Moreover, in this paper we have to reformulate its definition at different levels of the multiscale analysis. This reformulation has to take into account that the area under investigation is different, by varying the level of the multiscale analysis, because it corresponds, in turn, at the area of the municipality, the province, or the phytogeographical belt. It is important to notice that the method of reformulation is quite general, and it could be applied independently on the number of levels and/or their definition. The reformulation is necessary to perform the effective computation on the case study of the entire Region Lombardy, at different scales.

In the FSQ computation, we consider two important constraints on input data:

*(1) Constraint n.1*: only natural forests have been considered, i.e., plantations were excluded, and

*(2) Constraint n. 2*: only forests occurring on areas greater than 10,000 square m have been considered. As written in the introduction, patches smaller than 1 ha generally show low species richness (Digiovinazzo *et al*., 2010) and a low floristic quality due to the edge effect which can increase the abundance of weedy and alien species (Saunders *et al*., 1991; Honnay *et al*., 2002; Laurance *et al*., 2002).

In order to compute the FSQ indicator for each target

Tab. 1 - The three levels of the multiscale approach here proposed and their main characteristics.

| Level of multiscale approach | Characteristics | |
|---|---|---|
| | *Number of items* | *Meaning* |
| 1<br>Municipality | 1544 | The smallest administrative body in the Italian geo-political organization. |
| 2<br>Province | 12, i.e., Bergamo, Brescia, Como, Cremona, Lecco, Lodi, Mantova, Milano, Monza and Brianza, Pavia, Sondrio, and Varese. | The intermediate administrative body in the Italian Regions, which gather municipalities according homogenous geographical, social and economical characteristics. |
| 3<br>Region, phytogeographical belts | 5, i.e., Alpine Mountain, Apennine Mountain, Alpine Hill, Apennine Hill, and Po Plain. | Homogenous climatic, vegetational and floristic belts. |

territory of the multiscale analysis, we derive on the GIS data of ERSAF and ISTAT GIS maps the measures of the areas of each sub-region occupied by natural forest $F_i$ (i = 1, 2, …. n), where n is the number of Forest Types located in the target territory. Each of $F_i$ may have one or more occurrences, denoted by the index k (k = 1, 2, max(i)). Each k-th occurrence is characterizes by: (a) an area $A^k_i$, expressed in square meters, for i= 1, 2,…n and k = 1, 2,… max(i) and (b) a Forest Type $T_i$, derived from the GIS ERSAF Database, previously described.

In Tab. 2, a list of all the types $T_i$ of Region Lombardy is provided, indicating the corresponding alliance/s-suballiance/s and Habitat/s of the Habitat Directive. It is the first result of our pre-processing, performed on the data of ERSAF Database, with software QGIS (2017), in order to fit the two *Constraints* previously defined.

For each forest $T_i$ on Tab. 2, we considered the association or community, and the related phytosociological tables and distribution, attributed to such forest $T_i$ by Andreis & Sartori (2011). As already stated, for few $T_i$ we considered other literature (Corbetta, 1968; Sartori, 1985; Andreucci & Castelli, 2008) or personnel relevés because Andreis & Sartori did not report phytosociological data.

For each Forest Type $T_i$, we defined a set of the following indicator components ($s_i$, $a_i$, $p_i$):

(1) Stratification (number of layers) of a Forest Type i ($s_i$): this component analyses the quality of the forest structure. The tree and the herb layers are always present in a forest. The shrub layers (high-shrub and/or low-shrub layers) were considered valuable if their total cover were > of 10% of the sampled forest area (indicated in the phytosociological tables) or at least one species presented a cover-abundance value equal to 2.

(2) Frequency percentage of alien species ($a_i$) in the corresponding phytosociological table/s. When more than one phytosociological tables described a Forest Type $T_i$, a mean value between the percentages of each table was calculated.

(3) Frequency percentage of protected species ($p_i$) in the corresponding phytosociological table/s. When more phytosociological tables described a Forest Type $T_i$, a mean value between the percentages of each table was calculated.

The three components can assume only discrete values, from 0 to 3, according to an *if-then-else* algorithm (Assini & Albanesi, 2015a), which takes into consideration the number of layers, the percentage of protected species, and the percentage of alien species.

The ecological bases of the *if-then-else* algorithm are here summarized for completeness. The definition of quality of stratification was considered independent on the altitude of the forest, because more linked to the human intervention that has generated a simplification of forest ecosystems, with a consequent decrease of several sensitive and narrow-range species depending on structures and processes of old growth forests (Brunet *et al*., 2010; Paillet *et al*., 2010; Lelli *et al*., 2017). The same does not hold for the other two components, i.e., the percentages of alien and protected species, for which the impact of human activities strongly decreases with the altitude. Thus, naturalness is higher in the montane belt than in planar belt. We differentiate between forest types belonging to the class "high hilly and montane" (altitude ≥ 500 m) and forest types belonging to the class "planar and low hilly" (altitude < 500 m). The three components ($s_i$, $a_i$, $p_i$) are defined according to an empirical *if-then-else* algorithm (Tab. 3).

The discretization of the three components in the range [0, 3] of the values meets the contrasting need, on the one hand, of having a sufficient number of values to discriminate the various cases of the algorithm, and on the other, not to introduce a too fine discretization that would not add significant information.

We have defined the relative value set of ($s_i$, $a_i$, $p_i$) for each of the Forest Type $T_i$, i.e., on the entire region Lombardy; in Assini & Albanesi (2015b), only two provinces have been considered, i.e., Pavia and Lodi, for a total number of 33 Forest Types. In Appendix I, the list of all 126 Forest Types of region Lombardy is reported, together with the value set ($s_i$, $a_i$, $p_i$) and the province(s) of occurrence for each Forest Type. This is the second set of results, coming from our processing on the data of ERSAF database and value set definition.

In some, rather few, cases, the same Forest Type obtains multiple value sets according to its geographical position, i.e., in which province it is located. This is because in different provinces we can find different phytosociological tables corresponding to the same Forest Type, due to the variation of the floristic composition and the presence of protected and/or alien species according to the geographical localization.

After determining the values of the set of components for stratification, alien and protected species, it is now possible to give a new multiscale definition of the Forest Status Quality Indicator as:

$$FSQ^m(j) = \sum_i \sum_k (s_i + a_i + p_i) * A^k_i / S^m(j) \qquad (1)$$

Where i is one of the Forest Types which is present in j-th the territory under investigation at multiscale level m, $A^k_i$, is the area of the k-th occurrence of the Forest Type i, which is present in j-th the territory under investigation at multiscale level m, and $S^m(j)$, is the area of the target territory. If m = 1, the target territory is the Municipality, and j goes from 1 to 1544, if m = 2 it is the Province (j = 1, 2, .. 12) and if m = 3 it is the Phytogeographical belt (j = 1, 2, …5).

The $FSQ^m$ definition is the weighted values of the

Tab. 2 - The list of forest types of Region Lombardy (according to the defined constraints), with the indication of the corresponding alliance/s or suballiance/s (according Andreis & Sartori, 2011) and Habitat/s of the Habitat Directive. Nomenclature follows Biondi *et al*., 2014.

| Type Label | Forest Type (Del Favero, 2000) | Alliance/s - Sub-alliance/s (Andreis & Sartori, 2011) | Habitat/s of the Directive Habitat |
|---|---|---|---|
| 1 | Oak-Hornbeam wood of the lowland | *Ulmenion minoris* Oberd. 1953 - *Carpinion betuli* Issler 1931 | 91F0 [Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)] - 9160 [Sub-Atlantic and medio-European oak or oakhornbeam forests of the *Carpinion betuli*] |
| 2 | Oak-Hornbeam wood of the lowland, eastern variant | *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 | 91L0 [Illyrian oak-hornbeam forests (*Erythronio-Carpinion*)] |
| 3 | Oak-Hornbeam wood of the highland | *Carpinion betuli* Issler 1931 | 9160 [Sub-Atlantic and medio-European oak or oakhornbeam forests of the *Carpinion betuli*] |
| 4 | Oak-Hornbeam wood of the highland, alluvial variant | | |
| 5 | Oak-Hornbeam of the hills | | |
| 6 | *Ostrya carpinifolia* wood with *Carpinus betulus* | *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 | 91L0 [Illyrian oak-hornbeam forests (*Erythronio-Carpinion*)] |
| 9 | Oak wood with *Quercus robur* and/or *Quercus petraea* of the western morainic circles | *Carpinion betuli* Issler 1931 | 9160 [Sub-Atlantic and medio-European oak or oakhornbeam forests of the *Carpinion betuli*] |
| 10 | Oak wood with *Quercus robur* and/or *Quercus petraea* of the Pianalto | *Quercion roboris* Malcuit 1929 | 9190 [Old acidophilous oak woods with *Quercus robur* on sandy plains] |
| 11 | Oak wood with *Quercus robur* and/or *Quercus petraea* of the Pianalto, *Carpinus betulus* variant | | |
| 12 | Oak wood of inland sand dunes ("dossi") | Any connection with syntaxa | |
| 13 | Oak wood of stony river beds | *Quercion roboris* Malcuit 1929 | 91F0 [Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)] |
| 14-15 | Oak-Elm wood (also including the Black Alder variant) | *Ulmenion minoris* Oberd. 1953 | 91F0 [Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)] |
| 16 | Oak-Elm wood, shrubby variant | *Quercion roboris* Malcuit 1929 | 9190 [Old acidophilous oak woods with *Quercus robur* on sandy plains] |
| 17 | *Quercus ilex* wood | *Carpinion orientalis* Horvat 1958 | 9340 [*Quercus ilex* and *Quercus rotundifolia* forests] |
| 18 | *Quercus pubescens* wood with *Cotinus coggygria* | | 91AA* [Eastern white oak woods] |
| 20, 23 | *Quercus pubescens* wood of the carbonatic substrates (also including the Chestnut variant) | | |
| 21 | *Quercus pubescens* wood of the carbonatic substrates, *Erica arborea* variant | | |
| 22 | *Quercus pubescens* wood of the carbonatic substrates, *Quercus cerris* variant | | |
| 24 | *Quercus pubescens* wood of the carbonatic substrates, *Carpinus betulus* variant | *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 | 91L0 [Illyrian oak-hornbeam forests (*Erythronio-Carpinion*)] |
| 26, 27 | *Quercus petraea* wood of the carbonatic substrates and mesic soils (also including the Chestnut variant) | *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 - *Erythronio dens-canis-Quercion petraeae* Ubaldi (1988) 1990 | 91L0 [Illyrian oak-hornbeam forests (*Erythronio-Carpinion*)] |
| 28 | *Quercus cerris* wood | *Carpinion orientalis* Horvat 1958 - *Erythronio dens-canis-Quercion petraeae* Ubaldi (1988) 1990 | Any connection with Habitat |
| 32 | *Quercus cerris* wood, variant of the eastern morainic circles | *Carpinion orientalis* Horvat 1958 | |
| 33 | *Quercus petraea* wood of the silicatic substrates and xeric soils | *Genisto germanicae-Quercion* Neuhausl & Neuhauslova-Novotna 1967 | |
| 34 | *Quercus petraea* wood of the silicatic substrates and xeric soils, pioneer variant | | |
| 38 | *Quercus petraea* wood of the silicatic substrates and xeric soils, *Betula pubescens* variant | | |
| 39 | *Quercus petraea* wood of the silicatic substrates and xeric soils, *Pinus sylvestris* variant | | |
| 40 | *Quercus petraea* wood of the silicatic substrates and xeric soils, *Castanea sativa* variant | | |
| 41 | *Quercus petraea* wood of the silicatic substrates and xeric soils, *Fagus sylvatica* variant | *Luzulo luzoloidis-Fagion sylvaticae* Lohmeyer & Tüxen in Tüxen 1954 | |

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|---|---|---|---|
| 42 | *Quercus petraea* wood of the silicatic substrates and mesic soils | *Carpinion betuli* Issler 1931 | 9160 [Sub-Atlantic and medio-European oak or oakhornbeam forests of the *Carpinion betuli* ] |
| 45, 48, 49, 50, 57 | Chestnut wood on drift; Chestnut wood of the carbonatic substrates (mesic soils, meso-xeric soils, xeric soils); Chestnut wood of the silicatic substrates and mesic soils | *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 - *Erythronio dens-canis-Quercion petraeae* Ubaldi (1988) 1990 - *Carpinion betuli* Issler 1931 | 9260 [*Castanea sativa* woods] |
| 46 | Chestnut wood of the western morainic circles | *Carpinion betuli* Issler 1931 | |
| 47 | Chestnut wood of the western morainic circles, *Quercus robur* variant | | |
| 52 | Chestnut wood of the silicatic substrates and xeric soils | *Genisto germanicae-Quercion* Neuhausl & Neuhauslova-Novotna 1967 | |
| 53 | Chestnut wood of the silicatic substrates and meso-xeric soils | *Carpinion betuli* Issler 1931 - *Quercion roboris-* Malcuit 1929 - *Genisto germanicae-Quercion* Neuhausl & Neuhauslova-Novotna 1967 | |
| 54 | Chestnut wood of the silicatic substrates and meso-xeric soils, Lime variant | *Quercion roboris* Malcuit 1929 | |
| 55 | Chestnut wood of the silicatic substrates and meso-xeric soils, *Quercus petraea* variant | | |
| 56 | Chestnut wood of the silicatic substrates and meso-xeric soils, *Larix decidua* variant | *Genisto germanicae-Quercion* Neuhausl & Neuhauslova-Novotna 1967 | |
| 61 | Chestnut wood of the silicatic substrates and mesic soils, *Larix decidua* variant | *Carpinion betuli* Issler 1931 | |
| 62 | *Ostrya carpinifolia* and *Fraxinus ornus* wood of gorge | Any connection with syntaxa | Any connection with Habitat |
| 63, 64, 65 | *Ostrya carpinifolia* and *Fraxinus ornus* wood (of layer, of cliff, typical) | *Carpinion orientalis* Horvat 1958 | |
| 66 | Typical *Ostrya carpinifolia* and *Fraxinus ornus* wood, *Quercus ilex* variant | | |
| 67 | Typical *Ostrya carpinifolia* and *Fraxinus ornus* wood, *Quercus cerris* variant | *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 - *Carpinion orientalis* Horvat 1958 | |
| 68 | Typical *Ostrya carpinifolia* and *Fraxinus ornus* wood, *Fagus sylvatica* variant | *Aremonio agrimonoidis-Fagion sylvaticae* (Horvat) Borhidi in Török, Podani & Borhidi 1989 | |
| 69 | Typical *Ostrya carpinifolia* and *Fraxinus ornus* wood, *Pinus sylvestris* variant | *Erico-Fraxinion orni* Horvat 1959 nom. inv. prop. Teurillat, Aeschimann, Küpfer & Spichiger 1995 | |
| 70 | Typical *Ostrya carpinifolia* and *Fraxinus ornus* wood, *Carpinus betulus* variant | *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 | |
| 72 | Maple-Ash wood with *Ostrya carpinifolia* | *Tilio platyphylli-Acerion pseudoplatani* Klika 1955 - *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 | 9180* [*Tilio-Acerion* forests of slopes, screes and ravines] |
| 73 | Typical Maple-Ash wood | *Tilio platyphylli-Acerion pseudoplatani* Klika 1955 | |
| 75 | Typical Maple-Ash wood, Lime variant | | |
| 77 | Typical Maple-Ash wood, *Carpinus betulus* variant | *Erythronio dentis-canis-Carpinion betuli* (Horvat 1958) Marinzek, Wallnöfer, Mucina & Grass 1993 | 91L0 [Illyrian oak-hornbeam forests (*Erythronio-Carpinion* )] |
| 78 | Typical Maple-Ash wood, *Alnus glutinosa* variant | *Tilio platyphylli-Acerion pseudoplatani* Klika 1955 | 9180* [*Tilio-Acerion* forests of slopes, screes and ravines] |
| 79 | Maple-Ash wood with *Fagus sylvatica* | | |
| 81 | Maple-Ash wood with *Alnus incana* | | |
| 82 | Maple-Lime wood | | |
| 83 | Pioneer Birch wood | *Sambuco racemosae-Salicion capreae* Tüxen & Neumann in Tüxen 1950 | Any connection with Habitat |
| 84 | Secondary Birch wood | | |
| 88 | Primitive Beech wood | | |
| 89, 96, 97, 105 | Submontane Beech wood of the carbonatic substrates (high-montane, montane, montane of xeric soils, submontane) | *Galio odorati-Fagion sylvaticae* Knapp ex Tüxen & Oberdorfer 1958 nom. mut. - *Aremonio agrimonoidis-Fagion sylvaticae* (Horvat) Borhidi in Török, Podani & Borhidi 1989 | 9130 [*Asperulo-Fagetum* beech forests] - 91K0 [Illyrian *Fagus sylvatica* forests (*Aremonio-Fagion* )] |
| 91 | Submontane Beech wood of the carbonatic substrates, *Pinus sylvestris* variant | Any connection with syntaxa | Any connection with Habitat |

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|---|---|---|---|
| 93 | Submontane Beech wood of the carbonatic substrates, mesic soil variant | *Galio odorati-Fagion sylvaticae* Knapp ex Tüxen & Oberdorfer 1958 nom. mut. | 9130 [*Asperulo-Fagetum* beech forests] |
| 94 | Submontane Beech wood of the silicatic substrates | *Luzulo luzuloidis-Fagion sylvaticae* Lohmeyer & Tüxen in Tüxen 1954 | 9110 [*Luzulo-Fagetum* beech forests] |
| 98 | Montane Beech wood of the carbonatic substrates, *Picea abies* variant | *Galio odorati-Fagion sylvaticae* Knapp ex Tüxen & Oberdorfer 1958 nom. mut. - *Aremonio agrimonoidis-Fagion sylvaticae* (Horvat) Borhidi in Török, Podani & Borhidi 1989 | 9130 [*Asperulo-Fagetum* beech forests] - 91K0 [Illyrian *Fagus sylvatica* forests (*Aremonio-Fagion*)] |
| 99 | Montane Beech wood of the silicatic substrates and mesic soils | *Luzulo luzuloidis-Fagion sylvaticae* Lohmeyer & Tüxen in Tüxen 1954 - *Galio odorati-Fagion sylvaticae* Knapp ex Tüxen & Oberdorfer 1958 nom. mut. | 9110 [*Luzulo-Fagetum* beech forests] - 9130 [*Asperulo-Fagetum* beech forests] |
| 100 | Montane Beech wood of the silicatic substrates and mesic soils, *Picea abies* variant | *Luzulo luzuloidis-Fagion sylvaticae* Lohmeyer & Tüxen in Tüxen 1954 | 9110 [*Luzulo-Fagetum* beech forests] |
| 102 | Montane Beech wood of the silicatic substrates and acid soils | | |
| 110 | Highmontane Beech wood of the silicatic substrates | | |
| 111 | Macrotherm Mountain Pine wood | *Erico-Fraxinion orni* Horvat 1959 nom. inv. prop. Teurillat, Aeschimann, Küpfer & Spichiger 1995 | Any connection with Habitat |
| 112 | Mesotherm Mountain Pine wood | *Rhododendro-Vaccinion* (Br.-Bl. in Br.-Bl. et Jenny 1926) Br.-Bl. 1931 - *Erico-Pinion mugo* Leibundgut 1948 nom. inv. | 9430* [Subalpine and montane *Pinus uncinata* forests (* if on gypsum or limestone)] |
| 115 | Microtherm Mountain Pine wood of the carbonatic substrates | *Erico-Pinion mugo* Leibundgut 1948 nom. inv. | |
| 117 | Microtherm Mountain Pine wood of the silicatic substrates | *Rhododendro-Vaccinion* (Br.-Bl. in Br.-Bl. et Jenny 1926) Br.-Bl. 1931 | |
| 119 | Pioneer Scots Pine wood of stone | *Erico carneae-Pinion sylvestris* Br.Bl. in Br.-Bl., Sisingh & Vlieger 1930 nom. inv. prop. Theurillat, Aschimann, Küpfer & Spichiger 1995 - *Erico-Fraxinion orni* Horvat 1959 nom. inv. prop. Theurillat, Aeschimann, Küpfer & Spichiger 1995 | Any connection with Habitat |
| 120 | Pioneer Scots Pine wood of detrital aquifer | *Erico carneae-Pinion sylvestris* Br.Bl. in Br.-Bl., Sisingh & Vlieger 1930 nom. inv. prop. Theurillat, Aschimann, Küpfer & Spichiger 1995 | |
| 121 | Scots Pine wood of the carbonatic substrates | *Erico-Fraxinion orni* Horvat 1959 nom. inv. prop. Theurillat, Aeschimann, Küpfer & Spichiger 1995 | |
| 124 | Submontane Scots Pine wood of the silicatic substrates | *Dicrano undulati-Pinion sylvestris* (Libbert 1932) Matuszkiewicz 1962 | |
| 125 | Montane Scots Pine wood of the silicatic substrates | | |
| 130 | Scots Pine wood of the plain | *Quercion roboris* Malcuit 1929 | 9190 [Old acidophilous oak woods with *Quercus robur* on sandy plains] |
| 131 | Spruce-Beech wood of the carbonatic substrates | *Luzulo luzuloidis-Fagion sylvaticae* Lohmeyer & Tüxen in Tüxen 1954 | 9110 [*Luzulo-Fagetum* beech forests] |
| 133 | Spruce-Beech wood of the carbonatic substrates, *Larix decidua* variant | | |
| 134 | Spruce-Beech wood of the silicatic substrates | | |
| 136 | Spruce-Beech wood of the silicatic substrates, *Abies alba* variant | | |
| 137 | Spruce-Beech wood of the silicatic substrates, *Larix decidua* variant | | |
| 138 | Esalpic Silver Fir wood | *Abieti-Piceion* (Br.-Bl. in Br.-Bl et al. 1939) Soò 1964 | 9410 [Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio-Piceetea*)] |
| 139 | Silver Fir wood of the carbonatic substrates | | |
| 140 | Silver Fir wood of the mesic soils | *Vaccinio-Abietenion* Oberd. 1962 - *Abieti-Piceion* (Br.-Bl. in Br.-Bl et al. 1939) Soò 1964 | |
| 141 | Silver Fir wood of the silicatic substrates | *Vaccinio-Abietenion* Oberd. 1962 | |
| 142 | Silver Fir wood of the silicatic substrates with *Fagus sylvaticae* | | |
| 143 | High montane Spruce wood of the carbonatic substrates | *Abieti-Piceion* (Br.-Bl. in Br.-Bl et al. 1939) Soò 1964 | |
| 145 | Montane Spruce wood of the silicatic substrates and xeric soils | *Vaccinio-Piceenion* Oberd. 1957 - *Vaccinio-Abietenion* Oberd. 1962 | |
| 146 | Montane Spruce wood of the silicatic substrates and xeric soils, *Pinus sylvestris* variant | *Vaccinio-Abietenion* Oberd. 1962 | |
| 147 | Montane Spruce wood of the silicatic substrates and mesic soils | | |

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|---|---|---|---|
| 148 | High montane and subalpine Spruce wood of the silicatic substrates and xeric soils | *Vaccinio-Piceenion* Oberd. 1957 - *Vaccinio-Abietenion* Oberd. 1962 | |
| 149 | High montane and subalpine Spruce wood of the silicatic substrates and mesic soils | | |
| 153 | Secondary montane Spruce wood | | |
| 154 | Secondary montane Spruce wood, high montane variant | | |
| 159 | Primitive Larch wood | *Vaccinio-Abietenion* Oberd. 1962 | 9420 [Alpine *Larix decidua* and/or *Pinus cembra* forests] |
| 160 | Typical Larch wood | | |
| 165 | Sequentially Larch wood | | |
| 166 | Primitive Larch and Swiss pine wood | *Vaccinio-Piceenion* Oberd. 1957 - *Vaccinio-Abietenion* Oberd. 1962 | |
| 167 | Typical Larch and Swiss pine wood | | |
| 170 | Larch and Swiss pine wood with *Picea abies* | | |
| 171 | Swiss pine wood | *Vaccinio-Piceenion* Oberd. 1957 | |
| 172 | Black Alder wood of gulley | *Alnion glutinosae* Malcuit 1929 | 91E0* [Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*)] |
| 173 | Typical Black Alder wood | | |
| 174 | Black Alder wood of lake | *Alnenion glutinoso-incanae* Oberd. 1953 | |
| 175 | *Alnus incana* wood | | |
| 176 | *Alnus viridis* wood | *Alnion viridis* A. Schnyd. 1933 | Any connection with Habitat |
| 177 | Willow wood of bank | *Salicion albae* Soó 1930 | 91E0* [Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*)] |
| 178 | Willow wood of river bed | *Salicion incanae* Aichinger 1933 - *Salicion albae* Soó 1930 | |
| 179 | *Salix caprea* wood | *Sambuco racemosae-Salicion capreae* Tüxen & Neumann in Tüxen 1950 | Any connection with Habitat |
| 180 | *Salix cinerea* wood | *Salicion cinereae* Müller & Görs 1958 | |
| 183 | White Poplar formation | Any connection with syntaxa | |
| 186 | *Sorbus aucuparia* community | *Sambuco racemosae-Salicion capreae* Tüxen & Neumann in Tüxen 1950 | |
| 188 | Pure *Robinia pseudoacacia* wood | Any connection with syntaxa | |
| 189 | Mixed *Robinia pseudoacacia* wood | Any connection with syntaxa | |
| 190 | *Prunus serotina* community | Any connection with syntaxa | |

components, where the weights are the ratios between the areas of the forests and the area of the territory under investigation for the multiscale level m. The wider is the area occupied by a forest, the higher is its contribution to the global quality of the territory. Besides, its contribution is weighted by the values of the components (stratification, alien, and protected species). The $FSQ^m(j)$ value can range from 0 (no significant forests are present in the target territory) to a maximum of 9, which refers to the quite unrealistic situation of forests of very high quality (set of components ($s_i$, $a_i$, $p_i$) = (3, 3, 3)), which occupy the entire territory. However, the presence of forests on the entire considered territory is not a good situation from a conservation perspective, because this means that other habitats (such grasslands, shrublands, wet zones etc.) are not present. Thus, besides the computation of $FSQ^m$, we have defined a set of ranges of quality, to define a metric (Assini & Albanesi, 2015a). In the ongoing discussion, the first class ($0 \leq FSQ^m \leq 0.9$) is here further split in two subclasses, to highlight the special case of FSQ = 0 (i.e., no natural forests of area greater than 1 ha is present). Moreover, the suggested policies for each class of forest quality are discussed further in detail, together with the investigation about the opportunity to change or to maintain the metric according to the level of multiscale analysis. In Tab. 4, the metric for the $FSQ^m$ indicator is reported. This metric include the highest class 5 related to very high FSQ values (> 4.5), due not only to the components values, but also to high

Tab. 3 - The empirical *if-then-else* algorithm.

| **Conditions** | **Determination of parameters $s_i$, $a_i$, $p_i$, for each natural forest $T_i$** |
|---|---|
| For any altitude | If the number of layers = 2 then $s_i$ = 1 |
| | Else if number of layers = 3 then $s_i$ = 2 |
| | Else if number of layers = 4 then $s_i$ = 3 |
| For altitude <500 m | If the percentage of alien species is > 40 then $a_i$ = 0 |
| | Else if alien species range is (15-40] then $a_i$ = 1 |
| | Else if alien species range is (5-15] then $a_i$ = 2 |
| | Else if alien species range is [0-5] then $a_i$ = 3 |
| | If percentage of protected species range is (0.5-3] then $p_i$ = 1 |
| | Else if protected species range is (3-6.5] then $p_i$ = 2 |
| | Else if protected species range is > 6.5 then $p_i$ = 3 |
| For altitude ≥ 500 m | If the percentage of alien species is > 10 then $a_i$ = 0 |
| | Else if alien species range is (5-10] then $a_i$ = 1 |
| | Else if alien species range is (2-5] then $a_i$ = 2 |
| | Else if alien species range is [0-2] then $a_i$ = 3 |
| | If percentage of protected species range is (0.5-5] then $p_i$ = 1 |
| | Else if protected species range is (5-10] then $p_i$ = 2 |
| | Else if protected species range is > 10 then $p_i$ = 3 |

Tab. 4 - The metric on the multiscale $FSQ^m$ indicator of forest status quality (the index *m* identify the level of multiscale analysis). The term "overbalanced" for the class 5 indicates an excessive presence of forests at the expense of other habitats (such, for example, grasslands and/or shrublands).

| Class of forest quality | Intervals of $FSQ^m$ |
|---|---|
| 1 Unsatisfactory | $0 \leq FSQ^m \leq 0.9$ |
| 2 Satisfactory but improvable | $0.9 < FSQ^m \leq 1.8$ |
| 3 Good | $1.8 < FSQ^m \leq 3.6$ |
| 4 Optimum | $3.6 < FSQ^m \leq 4.5$ |
| 5 Overbalanced | $FSQ^m > 4.5$ |

surfaces (> 50% of the considered areas) occupied by forests at the expenses of other habitats. For this reason, the class 5 is defined "overbalanced".

## Results

### *Municipality level*

The first level of multiscale analysis consists of computing the $FSQ^1$ values for all 1544 municipalities of the region Lombardy. However, not all the municipalities host forests, which undergoes our *Constraint*. Particularly, only the 87.1% (i.e., 1375) has a $FSQ^1$ different from zero. Obviously, it is impossible to report here all the $FSQ^1$ values computed by our software. Therefore, some cumulative results will be given in a form suitable for the reader to appreciate them. In Fig. 3, the percentages of Municipalities with forest ($FSQ^1$ different from zero) is given. To give a significant, cumulative result, this percentage is reported for each Province. We remark that, however, this is done only to increase data readability and easiness of interpretation; as the $FSQ^1$ values are computed on the territories of each Municipality, these data still refer to the first level of the multiscale analysis.

However, Fig. 3 gives only a quantitative glance of the situation. In order to give a better description of the forest quality, the percentage of Municipalities falling into the five classes of forest quality, as defined in Tab. 4, is given (Fig. 4). As it can be seen, Municipalities of class 1 (unsatisfactory, with $FSQ^1$ in the range [0; 0.9]) are more prevalent in the Po Plain Provinces (Pavia, Monza-Brianza, Milano, Lodi, Cremona, and Mantova), while the other Provinces show a greater degree of variety of the $FSQ^1$ values, as indicated by the distributions of the $FSQ^1$ values (Fig. 5). Particularly, the Provinces of Lecco, Brescia and Bergamo are extremely variable, with a standard deviation higher than two, as it can be seen from Appendix II.

In Fig. 6A, a general overview of Lombardy is shown: it represents the results at the first level of our multiscale approach. Each Municipality is depicted in a colour identifying its class of forest quality. In the figure, class 1 is further split into two classes: class 0 (in white), where the $FSQ^1$ is equal to zero, to highlight the dramatic situation of the Municipalities without any forest, and class 1 (in light grey), where $0 < FSQ^1 \leq 0.9$, for unsatisfactory situations.

It is evident that the worst situation is localized in the Po Plain, then ameliorates towards the hilly areas and becomes the best in the mountain areas, where, however, many municipalities show an overbalanced situation (black), characterized by an excessive presence of forests. Furthermore, some alpine northernmost municipalities show particular low values of forest quality.

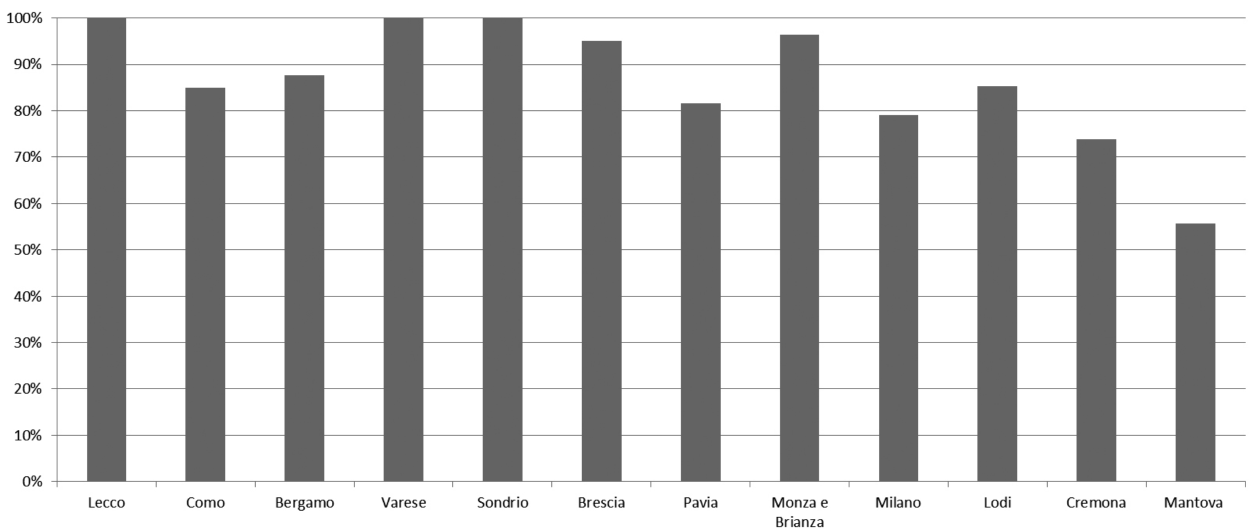


Fig. 3 - For each Province of Region Lombardy, the percentage of Municipalities with FSQ1 value different from zero is reported.

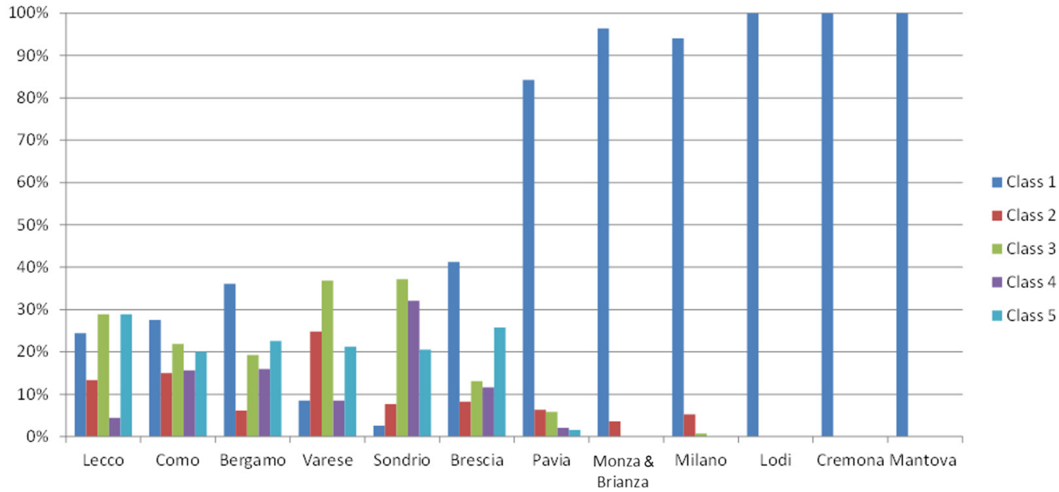


Fig. 4 - The percentage of Municipalities falling into each class of forest quality, as defined in Tab. 4, for each province.

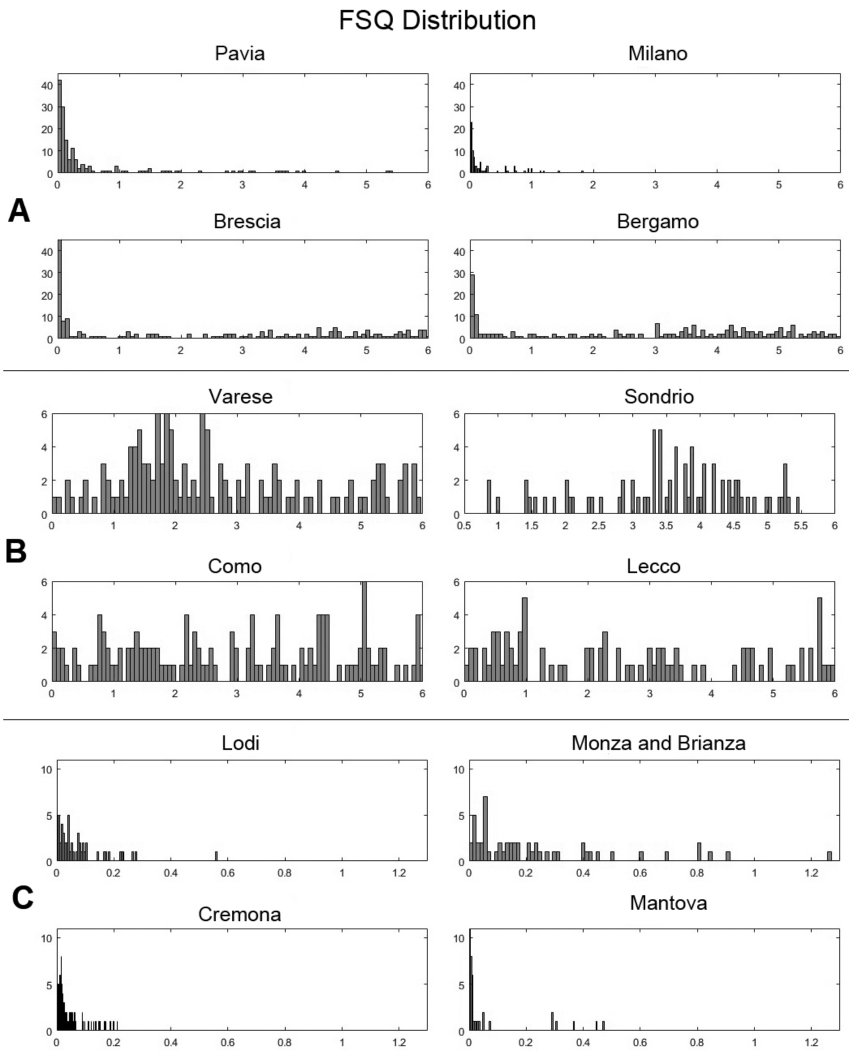


Fig. 5 - A) The statistical distributions of the FSQ[1] values, for the provinces Pavia, Milano, Brescia, and Bergamo; B) The statistical distributions of the FSQ[1] values, for the provinces Varese, Sondrio, Como, and Lecco; C) The statistical distributions of the FSQ[1] values, for the provinces Lodi, Monza and Brianza, Cremona, and Mantova.

***Province level***

In Tab. 5, the values of $FSQ^2$ are listed for each province, while in Fig. 6B, the class of forest quality for each Province is shown; it is the overview of the results at the second level of our multiscale approach. The Province with the highest $FSQ^2$ value is Lecco (FSQ > 3), followed by Como, Bergamo, Varese, Sondrio, and Brescia (FSQ comprised between 2.5 and 2.9). The Provinces of Pavia, Monza-Brianza, Milano, Lodi, Cremona, and Mantova show very low values of the FSQ (comprised between 0.03 and 0.7). Only two classes are reported and Lombardy results divided into two parts: a central-northern part showing a good quality of forests and a central-southern part showing an unsatisfactory quality.

In order to compare the results at the first two levels of multiscale approach, we computed the difference between the forest quality class of each Municipality and the forest quality class of the Province, which includes the Municipality itself. The results are shown in Fig. 7. The difference ranges from -3 to + 4. In the Provinces prevalently or exclusively localized in the Po Plain, only few Municipalities show classes of forest quality different from the class of the Province they belong to. Generally, this difference is due to values, at Municipality level, which are worse than those at Province level.

The only exception to this behaviour is the Province of Pavia (which include

Tab. 5 - The computed values of $FSQ^2$ for each province, listed according the descendent order.

| Province | $FSQ^2$ |
|---|---|
| Lecco | 3.437.291 |
| Como | 2.885.362 |
| Bergamo | 2.825.348 |
| Varese | 2.676.358 |
| Sondrio | 2.642.532 |
| Brescia | 2.515.929 |
| Pavia | 0.72789 |
| Monza & Brianza | 0.241556 |
| Milano | 0.17803 |
| Lodi | 0.068943 |
| Cremona | 0.034725 |
| Mantova | 0.033574 |

both plain and mountain areas): here we observe Municipalities with values better than the value at Province level. They are localized in the extreme southern part of region Lombardy, corresponding to the Apennine belts.

In the Provinces localized both in the Po Plain and Alpine belts (Mountain and/or Hilly), the values at the Municipality level are very different and variable (in some cases better, but in some cases worse) when compared with the value at Province level.

***Phytogeographical belt level***

At the third level, the entire Region is analyzed according to the five Phytogeographical belts, previously defined. The values of the $FSQ^3$ are shown in Appendix III. The Po Plain belt shows the lowest value, while the hilly belts show low values, with the Alpine Hill slightly better than the Apennine Hill. The highest values belong to the mountain areas, with the Apennine Mountain better than the Alpine Mountain.

In Fig. 6C, the results at the third and last level of our multiscale approach are depicted, using the same convention of the previous levels: the class of forest quality of each belt is shown, according the metric of Tab. 4. The Apennine Mountain belt shows the best class of forest quality (4), followed by the Alpine Mountain belt (3). The Hilly belts (Alpine and Apennine) show the same class of forest quality (2). The Po Plain belt shows the worst class of forest quality (1).

The difference between the class of forest quality at Municipality level and the class of forest quality at Phytogeographical level, which includes the Municipality itself, is shown in Appendix IV in order to compare the lowest and the highest level of resolution of the multiscale analysis.

In the Apennine belts (Hilly and Mountain), the deviations from the value of the belts are limited to one point (+ or – 1). In the Po Plain belt, some Municipalities show deviation of -1. Only in the north-western part of the belt, deviation of +1 or +2 are observed. In the Hilly Alpine belt, the deviations are very variable. In the Mountain Alpine belt, the positive deviations prevail, with exceptions in two extreme northern Municipalities. A possible interpretation of the meaning of these results are carefully sounded in the Discussion.

**Discussion**

Our results highlight that the study of the $FSQ^m$ at the several scale m can give different global perspectives to assess the quality of forests, whose significance depends also on the level itself.

At the finest scale of resolution, the municipality le-

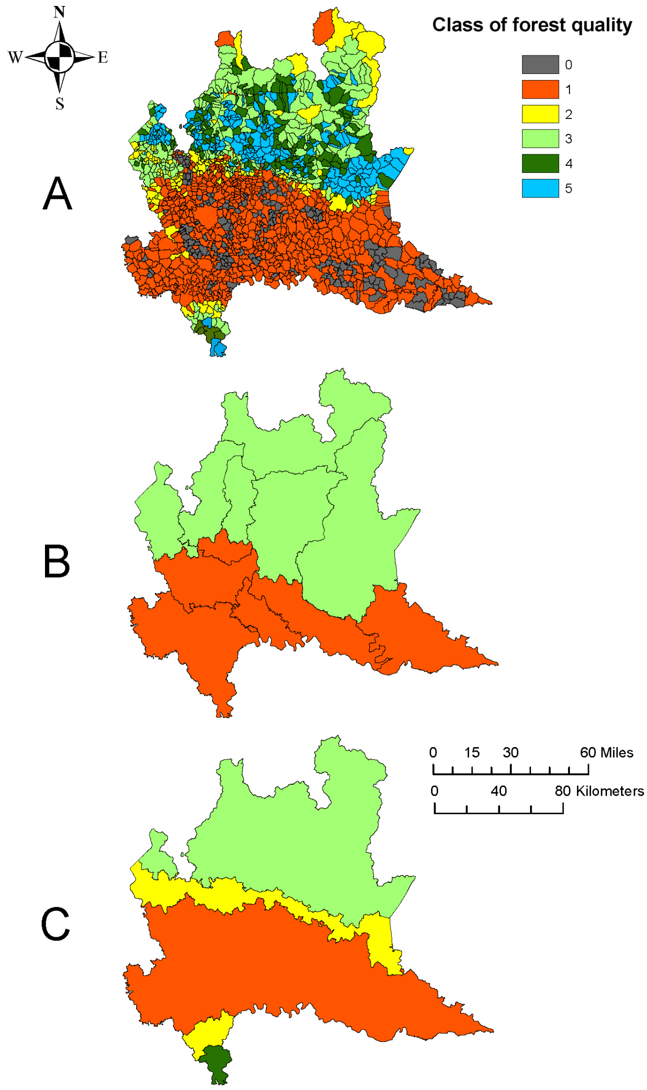


Fig. 6 - A global view of Region Lombardyat the three levels of multiscale analysis, according to a class of forest quality, identified by its $FSQ^1$ value. Class 0 means absence of forests, Classes 1-5 are the same of the metric in Tab. 4 (1 = Unsatisfactory; 2 = Satisfactory but improvable; 3 = Good; 4 =Optimum; 5 = Overbalanced). A = Municipality level, B = Province level, C = Phytogeographical level.

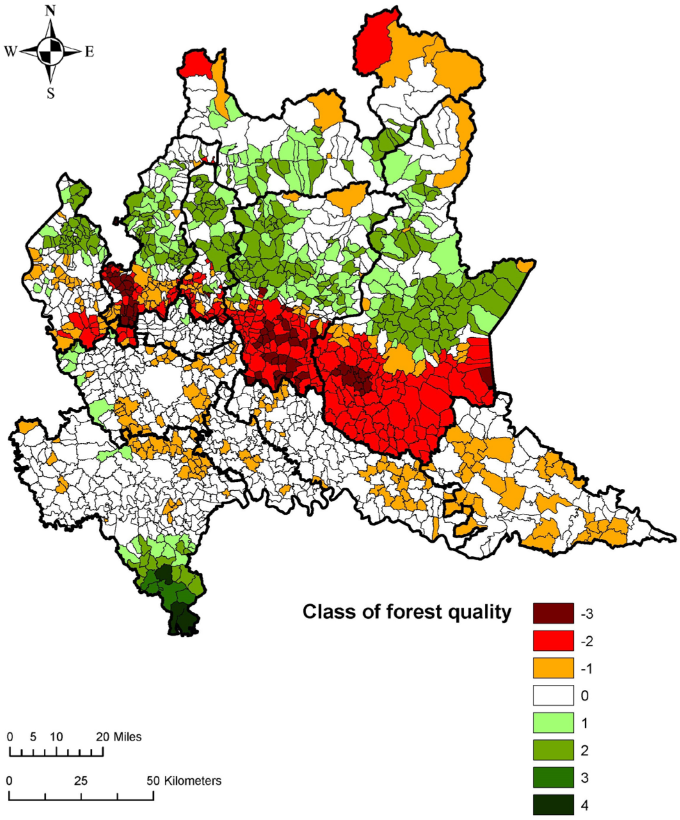


Fig. 7 - The difference between the forest quality class of each Municipality and the forest quality class of the Province, which includes the Municipality itself.

vel, we have a detailed information, and, in some cases, the forest quality of a Municipality can be also very different from the one of near municipalities. At this level, all the five classes of forest quality were obtained, with a very good differentiation among municipalities. The particular low values shown by some alpine northernmost municipalities seem due to the occurring of some areas above the altitudinal limit of forests and a high human impact for ski tourism. At the coarsest scale of resolution, the regional phytogeographical level, we have information expressing a global forest quality for a wide territory, but with still a good differentiation among belts (4 classes of forest quality were obtained). The lower value of the Alpine montane belt respect to the Apennine montane belt seems also here due to the occurring of some areas above the altitudinal forest limit and to the ski tourism impact. At province level, we have too generic information, with a very little difference among provinces (only 2 classes of forest quality were obtained). Furthermore, at this level, the differences of the forest quality classes of the Municipalities are more accentuated than at the regional phytogeographical level, indicating that the quality expresses by the indicator at province level is not representative of the real situation.

This is due to the ecological (climate, substrate, phytogeography) heterogeneity of the Region Lombardy and to the fact that provinces are administrative units (and not environmental units). Thus, we have many provinces, which include territories with different environmental characteristics and forest quality. Our indicator does not allow to appreciate the differences among the forests (which, on the contrary, are flatten) occurring at province level. The municipality is also an administrative unit, but of reduced surface and generally included in an ecologically homogenous territory, which is only planar or hilly or mountainous. Thus, our indicator allows to appreciate the differences among the forest quality occurring at municipality level. The regional phytogeographical belts are environmental units and thus our indicator is able to express the differences between the forest quality occurring in them. From these results, we conclude that the lowest and highest level of our multiscale analysis are the most representative and show a high efficacy in assessing the forest quality. This is because our indicator evaluates the forest quality prevalently on the basis of their floristic composition (two components of the defined value sets depend on it: protected and alien species), which is expression of the ecological features of the sites where they occur. Consequently, if the territorial units derived from the multiscale approach are ecologically homogenous, our indicator well represent their forest quality. On the contrary, if territorial units derived from the multiscale approach are ecologically heterogeneous, our indicator is not completely functional.

Some forest types, as indicated in Appendix I, show that the scores of the components can be different in different provinces. This could seem a weakness of the applied method indicating that forest types are not stable units. On the contrary, this is a strength of the applied method because allows to the indicator to capture the natural floristic variability (in terms of herbs and shrubs) of forests dominated by the same trees, but occurring in sites characterized by different ecology and phytogeography as the provinces are in region Lombardy. Furthermore, the satisfactory results seem to confirm the validity of choosing the scale [0-3] of discrete values for the components.

A further point to highlight in this discussion is the capability of the FSQ indicator to identify which forest types obtain the best evaluation, with the maximum value sets (3, 3, 3) for the considered components (stratification, protected species, alien species), and thus considered of high conservation interest. We call these forest type “Top Forests”. The number of the Top Forests are the 27% of the total number of assessed forest types (34 over 126).

The Top Forests include: 3 types (9%) typical of the plain (Oak-Hornbeam wood of the lowland, eastern variant, Oak wood of stony river beds, and Oak-Elm wood, shrubby variant), 13 types (38%) typical of the hills, and 18 types (53%) typical of the mountains.

Particularly interesting are those types, which obtained the best evaluation only in part of their distribution, such for example *Quercus petraea* (Matt.) Liebl. wood of carbonatic substrates, *Quercus cerris* L. wood, and *Ostrya carpinifolia* Scop. and *Fraxinus ornus* L. wood, which are of better quality in the provinces of Bergamo, Brescia, Como, Lecco, Sondrio, and Varese than in the province of Pavia. On the contrary, submontane Beech wood of carbonatic substrates and montane Beech wood of silicatic substrates are of better quality in the province of Pavia than in the provinces of Bergamo, Brescia, Como, Lecco, Sondrio, and Varese. As already stressed, this indicates that the forest quality depends on the entire floristic composition of the forest, and assessments, which do not consider such composition, can fail.

Another point to investigate is how it is possible to use the $FSQ^m$ indicator to understand the importance of protected areas in preserving the best forest. At this purpose, we here report the distribution of Natura 2000 network (based on the Habitat Directive and representing the most important conservation network in Europe) and other protected areas, and compare it to the localization of the Top Forests in region Lombardy (Fig. 8). Stretching over 18 % of the EU's land area and almost 6 % of its marine territory, Natura 2000 is the largest coordinated network of protected areas in

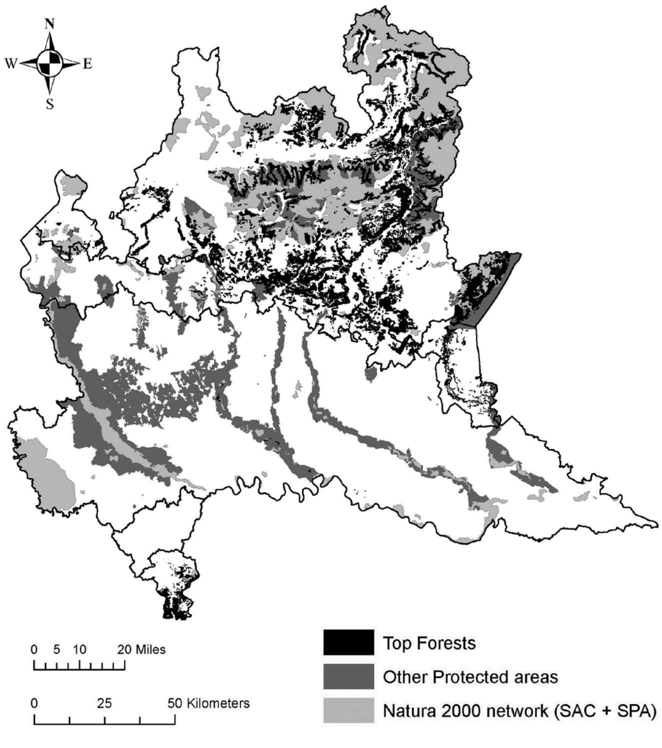


Fig. 8 - Localization of the best forests (Top Forests), Natura 2000 network and other protected areas in Region Lombardy.

the world. It offers a haven to Europe's most valuable and threatened species and habitats (European Commission, Natura 2000, 2017).

It is very interesting to observe that, in the Apennine Mountain belt, the most of the areas occupied by the Top Forests are outside the considered protected areas, while in the Alpine Mountain belt, a part of the Top Forests is included in protected areas, but also here, a great part is outside the protected areas. A possible interpretation is that criteria used by policy makers to delimit and establish protected areas included, not only the presence of forests, but also other communities (heathlands, grasslands, wet habitats) and areas attended by animals of conservation concern. Furthermore, we must not forget that in Mountain belts, despite the best quality of forests, we have many municipalities showing the value 5 of forest quality classes, indicating an unbalanced situation.

Such results generate some considerations. In mountain and high hilly areas, with some exceptions, forests are well conserved and widely distributed, showing good values of the FSQ. Here, the abandonment of traditional agro-pastoral activities has caused the forest colonization of open habitats with a consequent loss of biodiversity (Falcucci *et al*., 2007; Assini *et al*., 2014a; Assini *et al*., 2014b; Malavasi *et al*., 2018). Thus, the major efforts in the management of protected areas should be directed to the conservation of ecosystems different from forests.

On the contrary, in the plain and low hilly areas, urbanization and agricultural intensification have been the major drivers of biodiversity loss and pollution. Thus, a particular attention should be dedicated to the restoration of forests, which can provide important ecosystem services (such $CO_2/O_2$ exchange, protection from flooding, erosion and landslide) to a larger extent (due to their greater biomass) than open habitats.

***Validating of the indicator performance***

To judge the effectiveness of the indicator, we considered the variability of quality classes captured by it. In fact, such variability is strictly related to the variability of the ecological/phytogeographical conditions of the forests, and consequently to their floristic composition.

As explained in the methods, the floristic composition reported in the phytosociological tables is the base for the calculation of the values of the components combined in our indicator.

To better judge the effectiveness of the indicator, we should collect a statistically significant number of new phytosociological relevès of forests in municipalities of different provinces and with different values of the indicator resulted by our application. We should re-calculated the indicator on these new relevès and then compare it with the value resulted by our application. However, this is, obviously, very much time and cost expensive, and could be the goal of a further future work.

Anyway, we believe that the effectiveness of our indicator is inherent and due to the robust data set used to formulate it, consisting in 81 phytosociological tables composed by 484 phytosociological relevés distributed in 278 localities and 10 provinces of the region Lombardy.

## Conclusions

In conclusion, on the basis of the obtained results on the entire Region Lombardy, which are thus more robust than the preliminary results obtained in the previous work (Assini & Albanesi, 2015a), we suggested more detailed policies in relation to the different classes of forest quality (Tab. 6).

The classes 1 and 2 indicate low quality of forests and the necessity of forest restoration, which is mandatory for class 1 and preferable for class 2. The classes 3 and 4 indicate good and optimum forest quality, respectively, and the maintenance of the occurring forests is suggested. Particularly for class 4, no forest restoration is necessary, but, on the contrary, if shrublands and/or grasslands are scarcely represented, a policy for their conservation/restoration is highly suggested. Finally, the class 5 indicates an excessive presence of forests and, thus, a policy aimed to the restoration of grasslands and shrublands is mandatory.

The proposed multiscale $FSQ^m$ indicator is coherent with Dudley *et al*. (2006), which suggest the use of existing database, indigenous knowledge and possibly some field research as methods for data collection in order to evaluate the biodiversity conservation. Furthermore, they also suggest basic biological knowledge (in our case, phytosociology) as necessary expertise.

According to our results, the $FSQ^m$ indicator can be applied at local (m = 1) or regional scale (m = 3), but is not useful at intermediate territorial level. Maybe, different metrics should be formulated for such levels. However, we think that this is not a good approach because a metric should be of general validity, and thus the same for all the levels of the multiscale analysis. A better solution could be to refine the intermediate level by introducing the phytogeographical approach, particularly for those provinces that include areas with different environmental characteristics.

Finally, a further application of the FSQ indicator could be considered in the monitoring of forest habitats (according the Habitat Directive) in the SCIs of the Natura 2000 network. Probably, some adaptations will be necessary in relation to protected species, which vary according different regions and/or European countries, and taking in consideration Directive Species. The harmonization of management and monitoring activities in the SCIs is an important challenge for local managers even though it still needs much effort (Devictor

Tab. 6 - For each class of forest quality, according to the proposed metric (Tab. 4), the explanation of the suggested policies for conservation management.

| Class of forest quality | Suggested policy |
|---|---|
| 1<br>Unsatisfactory | Very low level of forest quality. A high-impact policy of restoration and/or requalification of forests is mandatory. |
| 2<br>Satisfactory but improvable | Sufficient forest quality, but improvable. A policy for the conservation of forest biodiversity is preferable, also considering forest restoration and /or requalification actions. |
| 3<br>Good | Good forest quality, the first level of satisfactory situation. A policy for the conservation of existing forests is suggested. |
| 4<br>Optimum | The optimun situation, with a high quality of forests. A policy for the conservation of existing forests is suggested. No forest restorations and/or requalifications actions are necessary. If shrublands and/or grasslands are scarse or absent, a policy for their conservation (including eventually restorations) is highly suggested. |
| 5<br>Overbalanced | The overbalanced situation, forests have overcome other ecosystems. A policy for shrubland and grassland conservation, including restorations and requalifications, is mandatory. |

*et al*., 2007). Particularly, Habitat Directive focuses on monitoring of the conservation status of habitats and species (Chiarucci *et al*., 2008). In fact, Article 17 of the Habitats Directive requires Member States to report every six years about the progress made with the implementation of the Habitats Directive. As the main focus of the directive is on maintaining and/or restoring a favourable conservation status for habitat types and species of community interest, monitoring and reporting under the directive is focusing on that (European Commission, Natura 2000, 2017). Thus, the FSQ indicator could be very useful in the assessment of the forest conservation status. Moreover, the recently published Handbook for the monitoring of habitat of community interest in Italy (Angelini *et al*., 2016; Gigante *et al*., 2016) suggests the collection of data about the vegetation layers (cover and height), alien species, landscape metrics and phytosociological relevés in the forest habitats. Therefore, all the information necessary to compute the FSQ will have to be collected and will be available when the monitoring will start.

Anyway, two questions related to the data used to compute the indicator are still open: 1) is the used ERSAF (2011) database still actual in representing the distribution of the Forest Types? 2) Have the forest patches been validated/tested on field when the Map of the Forest Types of Lombardy was realized?

These questions, of course, do not influence the multiscale formulation of the proposed FSQ indicator. However, they could influence the efficacy in using the values/results here obtained in future activity of management policies. As they are open questions that go beyond the scope of this work, they will be investigated in future work.

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**Appendix I. Values of the considered indicator components for each forest type, and the provinces of occurrence**

| Type Label | Components $s_i$ | $a_i$ | $p_i$ | Province(s) |
|---|---|---|---|---|
| **1** | **3** | **2** | **0** | **Lodi, Pavia** |
| **1** | **3** | **2** | **3** | **Bergamo, Brescia, Como, Cremona, Milano** |
| 2 | 3 | 3 | 3 | Cremona, Mantova |
| 3 | 2 | 2 | 3 | Bergamo, Brescia, Como, Lecco, Milano, Monza & Brianza, Sondrio, Varese |
| 4 | 2 | 2 | 3 | Milano, Monza & Brianza, Varese |
| 5 | 3 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Milano, Monza & Brianza, Sondrio, Varese |
| 6 | 3 | 3 | 3 | Bergamo, Brescia, Lecco, Varese |
| 9 | 3 | 3 | 2 | Bergamo, Como, Monza & Brianza, Varese |
| 10 | 3 | 2 | 1 | Bergamo, Como, Lecco, Milano, Monza & Brianza, Varese |
| 11 | 3 | 2 | 1 | Monza & Brianza |
| 12 | 2 | 2 | 1 | Mantova, Milano, Pavia |
| 13 | 2 | 2 | 2 | Mantova, Milano, Varese |
| 13 | 3 | 3 | 3 | Brescia, Lodi, Pavia |
| 14 | 3 | 2 | 2 | Bergamo, Brescia, Como, Cremona, Lodi, Mantova, Milano, Monza & Brianza, Pavia, Varese |
| 15 | 3 | 2 | 2 | Bergamo, Cremona, Lodi, Pavia |
| 16 | 3 | 3 | 3 | Cremona |
| 17 | 2 | 3 | 3 | Brescia, Lecco |
| 18 | 2 | 3 | 3 | Bergamo, Brescia, Mantova |
| 20 | 3 | 3 | 1 | Pavia |
| 20 | 3 | 3 | 3 | Bergamo, Brescia, Como, Lecco, Mantova, Sondrio, Varese |
| 21 | 3 | 3 | 3 | Bergamo |
| 22 | 3 | 3 | 3 | Bergamo |
| 23 | 3 | 3 | 3 | Bergamo |
| 24 | 3 | 3 | 3 | Mantova |
| **26** | **2** | **3** | **3** | **Pavia** |
| **26** | **3** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **27** | **2** | **3** | **3** | **Pavia** |
| **27** | **3** | **3** | **3** | **Bergamo, Brescia** |
| **28** | **3** | **3** | **2** | **Pavia** |
| **28** | **3** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| 32 | 3 | 3 | 3 | Brescia, Mantova |
| 33 | 3 | 3 | 1 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 34 | 3 | 3 | 1 | Brescia |
| 38 | 2 | 3 | 0 | Brescia |
| 39 | 3 | 3 | 1 | Brescia |
| 40 | 2 | 3 | 1 | Brescia |
| 41 | 3 | 3 | 1 | Brescia |
| 42 | 3 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 45 | 2 | 3 | 3 | Pavia |
| 46 | 3 | 3 | 2 | Bergamo, Como, Lecco, Milano, Monza & Brianza, Varese |
| 47 | 2 | 2 | 3 | Como |
| **48** | **2** | **3** | **3** | **Pavia** |
| **48** | **3** | **3** | **2** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **49** | **2** | **3** | **3** | **Pavia** |
| **49** | **3** | **3** | **2** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **50** | **2** | **3** | **3** | **Pavia** |
| **50** | **3** | **3** | **2** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| 52 | 3 | 3 | 1 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 53 | 3 | 3 | 1 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 54 | 2 | 3 | 0 | Brescia |
| 55 | 2 | 3 | 0 | Brescia |
| 56 | 3 | 3 | 1 | Brescia |
| **57** | **2** | **3** | **3** | **Pavia** |
| **57** | **3** | **3** | **2** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| 61 | 3 | 3 | 2 | Brescia |

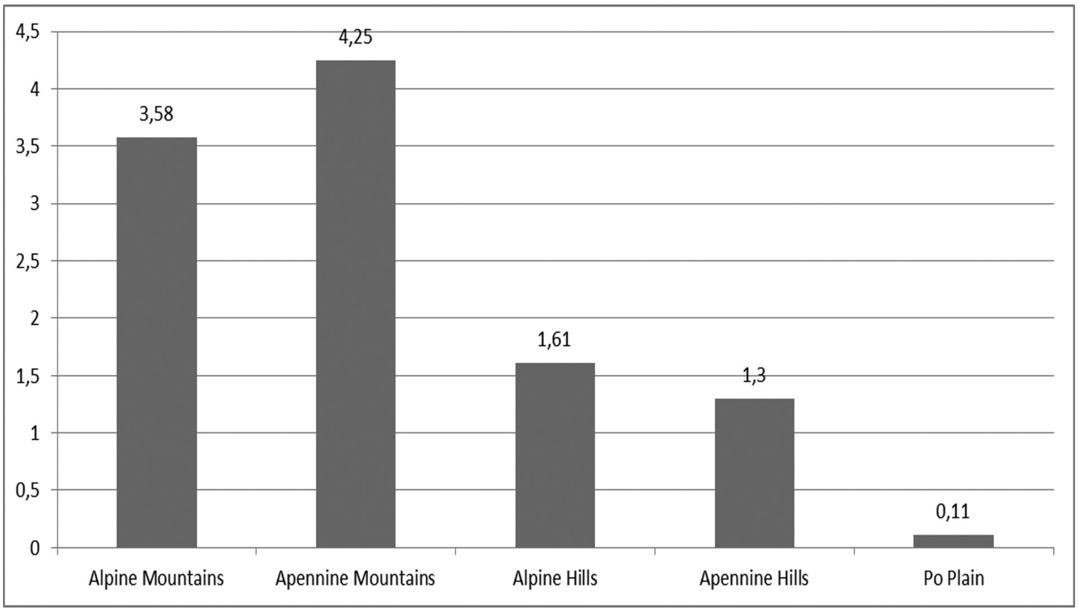
| Type Label | Components $s_i$ | $a_i$ | $p_i$ | Province(s) |
|---|---|---|---|---|
| 62 | 2 | 3 | 3 | Bergamo, Brescia, Como, Lecco, Varese |
| **63** | **2** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Varese** |
| **63** | **3** | **3** | **2** | **Pavia** |
| **64** | **2** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Varese** |
| **64** | **3** | **3** | **2** | **Pavia** |
| **65** | **3** | **3** | **2** | **Pavia** |
| **65** | **3** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Mantova, Sondrio, Varese** |
| 66 | 2 | 3 | 3 | Brescia |
| 67 | 3 | 3 | 2 | Bergamo, Brescia, Mantova |
| 68 | 1 | 3 | 3 | Bergamo, Brescia, Como, Lecco |
| 69 | 3 | 3 | 3 | Bergamo, Brescia |
| 70 | 3 | 3 | 3 | Bergamo, Brescia |
| 72 | 2 | 3 | 3 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 73 | 1 | 3 | 3 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| **75** | **1** | **3** | **3** | **Bergamo** |
| **75** | **2** | **3** | **2** | **Sondrio** |
| 77 | 3 | 3 | 3 | Bergamo |
| 78 | 1 | 3 | 3 | Brescia |
| **79** | **1** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **79** | **1** | **3** | **3** | **Brescia** |
| 81 | 1 | 3 | 3 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 82 | 2 | 3 | 3 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 83 | 1 | 3 | 1 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| **84** | **1** | **3** | **0** | **Pavia** |
| **84** | **2** | **3** | **1** | **Bergamo, Brescia, Como, Lecco, Monza & Brianza, Sondrio, Varese** |
| **88** | **1** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **88** | **3** | **3** | **3** | **Pavia** |
| **89** | **1** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **89** | **3** | **3** | **3** | **Pavia** |
| 91 | 1 | 3 | 3 | Brescia |
| 93 | 1 | 3 | 3 | Bergamo, Brescia, Lecco, Varese |
| 94 | 2 | 3 | 1 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| **96** | **1** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **96** | **3** | **3** | **3** | **Pavia** |
| **97** | **2** | **3** | **3** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **97** | **3** | **3** | **3** | **Pavia** |
| 98 | 2 | 3 | 3 | Bergamo, Brescia |
| **99** | **2** | **3** | **1** | **Bergamo, Brescia, Como, Lecco, Sondrio, Varese** |
| **99** | **3** | **3** | **3** | **Pavia** |
| 100 | 2 | 3 | 1 | Brescia |
| 102 | 2 | 3 | 1 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| **105** | **2** | **3** | **3** | **Bergamo, Brescia, Como, Lecco** |
| **105** | **3** | **3** | **3** | **Pavia** |
| 110 | 2 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 111 | 2 | 3 | 3 | Bergamo, Brescia, Lecco, Sondrio |
| 112 | 2 | 3 | 3 | Bergamo, Brescia, Lecco, Sondrio |
| **115** | **2** | **3** | **3** | **Sondrio** |
| **115** | **3** | **3** | **3** | **Bergamo, Brescia, Como, Lecco** |
| 117 | 2 | 3 | 3 | Bergamo, Brescia, Lecco, Sondrio |
| 119 | 3 | 3 | 3 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 120 | 3 | 3 | 3 | Bergamo, Brescia, Sondrio |
| 121 | 3 | 3 | 3 | Bergamo, Brescia, Como, Sondrio, Varese |
| 124 | 3 | 3 | 1 | Bergamo, Brescia, Sondrio, Varese |
| 125 | 3 | 3 | 1 | Bergamo, Brescia, Como, Sondrio |
| 130 | 3 | 2 | 1 | Como, Monza & Brianza, Varese |
| 131 | 2 | 3 | 1 | Bergamo, Brescia |
| 133 | 2 | 3 | 1 | Brescia |

| Type Label | Components $s_i$ | $a_i$ | $p_i$ | Province(s) |
|---|---|---|---|---|
| 134 | 2 | 3 | 1 | Bergamo, Brescia, Lecco, Sondrio |
| 136 | 2 | 3 | 1 | Brescia |
| 137 | 2 | 3 | 1 | Brescia |
| 138 | 2 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Sondrio |
| 139 | 1 | 3 | 3 | Bergamo, Brescia, Lecco, Sondrio |
| 140 | 2 | 3 | 3 | Bergamo, Brescia, Lecco, Sondrio, Varese |
| 141 | 3 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Sondrio |
| 142 | 3 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Sondrio |
| 143 | 2 | 3 | 2 | Bergamo, Brescia, Sondrio |
| 145 | 1 | 3 | 2 | Bergamo, Brescia, Lecco, Sondrio |
| 146 | 1 | 3 | 2 | Sondrio |
| 147 | 1 | 3 | 2 | Bergamo, Brescia, Lecco, Sondrio, Varese |
| 148 | 2 | 3 | 3 | Bergamo, Brescia, Sondrio |
| **149** | **3** | **3** | **2** | **Bergamo, Brescia, Lecco** |
| **149** | **3** | **3** | **3** | **Sondrio** |
| 153 | 1 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Sondrio |
| 154 | 2 | 3 | 3 | Bergamo |
| 159 | 3 | 3 | 3 | Bergamo, Brescia, Lecco, Sondrio |
| 160 | 3 | 3 | 3 | Bergamo, Brescia, Lecco, Sondrio, Varese |
| 165 | 3 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Sondrio, Varese |
| 166 | 3 | 3 | 3 | Bergamo, Brescia, Sondrio |
| 167 | 3 | 3 | 3 | Bergamo, Brescia, Sondrio |
| 170 | 3 | 3 | 3 | Bergamo, Brescia, Sondrio |
| 171 | 3 | 3 | 3 | Sondrio |
| 172 | 3 | 3 | 1 | Bergamo, Brescia, Como, Cremona, Lecco, Mantova, Milano, Monza & Brianza, Pavia, Sondrio, Varese |
| 173 | 2 | 3 | 2 | Bergamo, Brescia, Como, Cremona, Lecco, Lodi, Mantova, Milano, Monza & Brianza, Pavia, Sondrio, Varese |
| 174 | 3 | 3 | 1 | Como, Lecco, Varese |
| 175 | 3 | 3 | 3 | Bergamo, Brescia, Como, Lecco, Sondrio |
| 176 | 2 | 3 | 2 | Bergamo, Brescia, Como, Lecco, Sondrio |
| 177 | 1 | 1 | 0 | Bergamo, Brescia, Como, Cremona, Lecco, Lodi, Mantova, Milano, Monza & Brianza, Pavia, Sondrio, Varese |
| 178 | 1 | 3 | 1 | Bergamo, Brescia, Como, Sondrio, Varese |
| 179 | 2 | 3 | 1 | Bergamo, Brescia, Lecco, Sondrio |
| 180 | 2 | 2 | 0 | Lodi, Mantova, Pavia, Varese |
| 183 | 3 | 1 | 0 | Bergamo, Cremona, Lecco, Mantova, Milano, Pavia |
| 186 | 2 | 3 | 2 | Brescia, Como, Lecco, Sondrio |
| 188 | 2 | 1 | 0 | Bergamo. Brescia, Como, Cremona, Lecco, Lodi, Mantova, Milano, Pavia, Sondrio, Varese |
| 189 | 3 | 2 | 0 | Bergamo, Brescia, Como, Cremona, Lecco, Lodi, Mantova, Milano, Monza & Brianza, Pavia, Sondrio, Varese |
| 190 | 3 | 0 | 0 | Como, Lecco, Milano, Monza & Brianza, Varese |

## Appendix II: The average and standard deviation values of the FSQ[1] indicator, for each province

| Province | Average Value | Std. Deviation |
|---|---|---|
| Pavia | 0.61057 | 11.158 |
| Milano | 0.22153 | 0.35874 |
| Brescia | 25.451 | 22.607 |
| Bergamo | 28.670 | 20.178 |
| Varese | 28.143 | 16.996 |
| Sondrio | 35.261 | 11.411 |
| Como | 30.442 | 18.202 |
| Lecco | 28.454 | 20.524 |
| Lodi | 0.082188 | 0.098675 |
| Monza e Brianza | 0.024716 | 0.27679 |
| Cremona | 0.044583 | 0.050124 |
| Mantova | 0.067434 | 0.13149 |

**Appendix III: The results of the computation of FSQ³, for each belt, at the third level of the multiscale analysis**




**Appendix IV: The difference between the class of forest quality at Municipality level and the class of forest quality at Phytogeographical level, which includes the Municipality itself**