A Naturalistic Indicator of the Forest Quality and its Relationship with the Land Use Anthropentropy Factor

Theory, Tools, and Results for an Italian Case Study

Silvia Assini
Dept. of Earth and Environment Sciences
University of Pavia
Pavia, Italy
e-mail: silviapaola.assini@unipv.it

Maria Grazia Albanesi
Dept. of Electrical, Computer and Biomedical Engineering
University of Pavia
Pavia, Italy
e-mail: mariagrazia.albanesi@unipv.it

***Abstract*— This paper describes a new indicator related to an important aspect of the forest landscape: the quality, expressed by the forest floristic composition, according to the phytosociological approach. Furthermore, the relationship with an existing land use indicator, the Anthropentropy Factor, is investigated. Another novelty of this research is its multidisciplinary approach: we combine the classical algorithms of computer vision systems to process the images from GIS (Geographic Information System) databases with the necessary expertise provided by the biological knowledge. The goal is to build a deep knowledge about some aspects of biodiversity preservation, by studying the impact of anthropic activities, both inside (urbanization) and outside (forests) the areas occupied by human settlements. We define two metrics to classify the levels of land use and forest quality status. The knowledge coming from the computation of the two indicators and the corresponding metrics can be used for policy actions, to guide local government decisions for biodiversity conservation in the landscape planning. The two indicators and the methodological approach are validated by presenting experimental results on a case study of a North-West area of Italy.**

Keywords- biodiversity; land use; environmental indicator; forest status; Anthropentropy Factor.

I. INTRODUCTION

Land use estimation is a key aspect for biodiversity preservation; in fact, the European Environment Agency considers land use and biodiversity in the same policy target and objective for the next decades [1]. The reason is the well-known significant loss of the territory, both for vegetal and animal species, due to the impact of anthropic activities on the environment. There are plenty of examples of human activities which lead to soil sealing and loss of wild nature: urban and rural expansion, new roads and communication lines, settlements for industries, tourism and services, and intensive farming.

If we consider the problem by a quantitative, absolute, point of view, the situation may not seem so dramatic: according to the most recent Corine Land Cover data [2] referring to the period 2000-2006, the artificial areas cover only the 4% of the land in Europe, as compared to a 34% of forests, a global value of 51% for activities to support the economic growth and food (agriculture, crops, pasture and semi-natural vegetation) and a 11% of bare soils, water and wet lands. However, if we consider the net change in land cover, expressed as a percentage of the initial year (2000), we observe a worrying value of +2.5% for the artificial areas, while other typologies of land cover have important decreases or slight increases (less than 0.5%).

Processes which cause land-use change are different in different parts of Europe [3]: the Boreal and Alpine regions are dominated by forest management; abandonment and intensification are mainly encountered in the Mediterranean; urbanization and drainage are more characteristic of the Continental and Atlantic regions. In Italy and, particularly, in the studied area, urbanization and agricultural intensification are the main drivers of biodiversity loss in the planar belt, while land abandonment and the consequent forest re-colonization cause biodiversity loss in the hilly-montane belt [4]-[6].

For all these reasons, a high challenging goal of the scientific community is to provide efficient ways to define, measure and correlate indicators which refer to some aspects of land use and biodiversity estimation, in order to help in defining policies to preserve environment and, in the same time, to assure a sustainable growth of our economies and societies. This ambitious goal is the main aspect of the research described in this paper, which is organized as follows. Section II describes the addressed problem and main novelties of our approach. Section III describes the state of the art, for what concerns the problem of defining efficient indicators for land use and forest status. Section IV addresses the problem of computing the new proposed Forest Status Quality Indicator (FSQ), and its relationship to a land use indicator, which has been recently proposed in literature, i.e., the Anthropentropy Factor, (AF). Section V describes the results of the computations of the new indicator on a real case on the Italian territory. Conclusion and considerations about future work close the article.

II. OUR MULTIDISCIPINARY APPROACH

One of the main novelties of the proposed study is its multidisciplinary approach, which bridges across two important fields of our modern scientific research: computer science and botany. Both of them have knowledge, tools and paradigms which are able to assess the impact of human activities for a sustainable future. In particular, we have chosen to address the problem of estimating land use and,

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among the different categories of land use, to pay attention to two main aspects:

- The estimation of the areas which are not influenced by anthropic activities and, potentially, could be occupied entirely by wild nature;
- Inside these areas, which parts are occupied by forests, and their *quality status*.

We have chosen these two aspects because (a) the first is essential to estimate, for a given territory, which parts are yet available for wild habitats, and (b) the second takes into consideration the important presence of the forests which provide benefits for the human well-being (the so-called ecosystem services), such as flood prevention, erosion control, CO_2 absorption, climate regulation, *refugium* function for wild plants and animals, recreation, science and education. However, a simple counts of square kilometers is a too rough method to give hints on the real status of the environment for biodiversity preservation. In fact, others elements have to be taken into consideration, in order to describe the two aspects by indicators which have a real meaning, from an ecological point of view. In particular, we fixed these goals:

- The proposed indicators have to take into account not only the areas, but also their shapes, as fragmentation of habitats is a great problem for biodiversity preservation.
- The presence of a forest, inside a territory, has to be described not only by its relative area, but also by several aspects related to its quality, as the number of alien or protected species and the stratification.

Our multidisciplinary approach combines algorithms of computer-assisted image processing and remote sensing data analysis with the knowledge about forest typologies based on their floristic composition according to the phytosociological approach [7-10]. Besides the indicators, we propose two metrics to define ranges of increasing worrying status for biodiversity preservation. Such metrics may support policies for management and restoration of forests and landscape.

III. The State of the Art

A. Forest quality indicators

Quality means different things to different people. The assessment of forest quality differs according to the different components that can be evaluated (ecological, social and/or economic components associated to forests). In many assessment systems, environment has been relegated to a relatively unimportant element, if compared with other issues such as economic importance, although there are now also some specialized indicator sets relating to the environment, such as WWF (World Wide Fund For Nature) Living Planet Index [11]. Other examples include: the IUCN (International Union for the Conservation of Nature) well-being index [12], that divides indicators into two classes, the first relating to human well-being (socio-economic) and the second to the environment (ecological, environmental services etc.) and the Montreal Process criteria and indicators [13], for temperate and boreal species outside Europe, which uses seven criteria (and 67 indicators) including the conservation of biological diversity.

B. Land use indicators

All data provided by international projects [14] proves that our high-energy consumption lifestyles are exerting an increasing, destroying pressure on wildlife habitats. We have to consider not only the soil sealing phenomenon, i.e., thousands of hectares/year are covered by concrete, but also the fragmentation of territory and of habitats, a serious threat for most of endangered species in Europe. Therefore, conventional land use indicators based on the simple computation of area percentage are not able to express the gravity of the problem. For this reason, we have considered recent contributions in literature [15-16], which describe a new indicator, called Antropentropy Factor (AF). Here, we recall the basic definition and concepts which are essential to understand the relationship between this indicator and the Forest Status Quality Indicator here proposed (for details on the properties of the AF indicator and its application to Italian territory, see [15]).

Anthropentropy is a neologism, from the Greek term *Anthropos* (*Ἄνθρωπος*) = man, and *entropy*; in fact, the AF indicator wants to express the “disorder” introduced in natural ecosystems, by the presence and disturbance of human beings. The AF expresses in an absolute, continuous scale (from 0 to 1) the degree of anthropic human activities and the consequent land use. We think that this indicator is the closest one to a naturalistic evaluation of land use, because it does not only computed the percentage of land occupied by human activities and urban expansion, but also it takes into consideration the *shape* of the areas subtracted to nature, and their relative positions, thus incorporating an important aspect of fragmentation and its impact on biodiversity. This is possible because the computation is performed by using classical image processing morphological operator of dilation [17] on satellite GIS images of the territory on satellite maps of the territory.

In order to compute the AF indicator, we define the following entities: (a) the delimited part of a geographic territory under consideration, and its area S, in squared kilometers; (b) the Death Zone, as the union of all the anthropic regions of the territory, and its area DA, in square kilometers), and (c) the Neutral region as the part of the territory, if any, containing inland waters, (e.g., lakes or lagoons) and lands located more than 3,000 m above sea level, and its area NA (in square kilometers). The Anthropentropy Factor (AF) is defined [15] as the ratio:

$$AF = DA / (S - NA) \quad (1)$$

The AF expresses the land use as a fractional number, between 0 (completely uninhabited territory, DA = 0) and 1 (the Death Zone completely occupies the territory, but for the Neutral Zone (if any, because in the Neutral Zone human settlements are not possible.) In Table I, the corresponding metric on the AF indicator is described. For a reasoned treatment of the metric and its relationship with a possible policy making for a sustainable development, see [15-16].

TABLE I. THE METRIC ON THE AF INDICATOR FOR LAND USE.

Class of land use and map color	Evaluation of Land Use	
	Intervals of **AF**	***Meaning***
1 light green	0 <= AF <= 0.2	Very low level of anthropentropy, *ideal* situation for nature and human beings
2 green	0.2 < AF <= 0.4	A first worrying level of anthropentropy, but the situation is still *good*
3 yellow	0.4 < AF <= 0.6	A serious level of anthropentropy, with a beginning negative impact of anthopization on the environment.
4 red, light violet	0.6 < AF <= 0.8	A very serious level of anthropentropy, with a great negative impact of anthopization on the environment.
5 violet, black	0.8 < AF <= 1	The worst situation, with an irreversible environmental degradation.

In Figure 1, the map of the area of our case study (the territory of Pavia province) is shown: for each municipality, its territory is depicted in a color related to the class of land use, as specified in Table I (from green, yellow, red and black). Even if the AF indicator is able to take into considerations quantitative extensions, shapes and relative positions of the anthrophized areas of a territory, it expresses only the land use pressure on the environment (according to the DPSIR (Driving Forces, Pressures, States, Impacts, Responses) model [18] of the European Environment Agency); it does not give any hints on the state of the green areas *outside* the urbanized areas, which is the goal of the second and new indicator here described.

IV. THE FOREST STATUS QUALITY INDICATOR

For our purposes, we define the forest quality status as the value of its ecological components, with particularly reference to the biodiversity conservation. We have chosen the following components: the number of forest layers (more layers correspond to higher biodiversity), the presence of protected species according to the regional law (more protected species mean higher and better biodiversity) [L.R. 10/2008] and the presence of alien species (lesser alien species mean higher and better biodiversity). We considered only natural forests (plantations were not taken into consideration). Furthermore, we considered only forests occurring on areas greater than 10.000 square meters. In forest patches smaller than 1 ha, floristic richness is generally very low [19]. For a given territory of area S, we define a set of sub-regions occupied by natural forest F_i (i = 1, 2, n). Each of F_i may have one or more occurrences, denoted by the index k, in the territory (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 type of T_i, derived from the GIS Database "Map of the Forest Types of Lombardy" [20], which classifies 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.) [21].

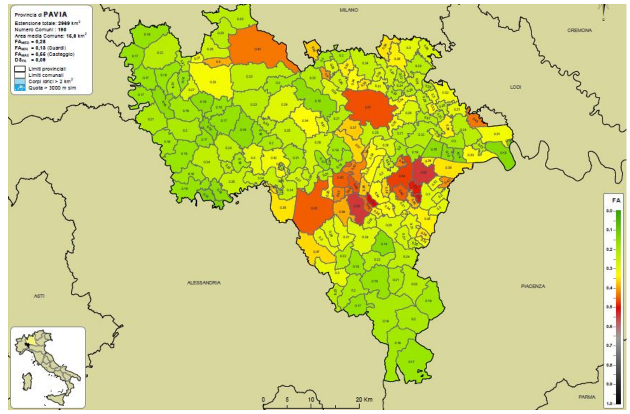

Figure 1. The visual map for the AF land use indicator for the municipalities of the target area of our case study (Pavia Province, Lombardia, North Western Italy).

In our target territory, we have 66 different forest types, but only 32 of them have occurrences whose areas are greater than 10.000 square meters. Therefore, in our case study, n= 32.

For each forest T_i, we found the correspondence with one or more phytosociological tables [22]. When this correspondence was not reported by the above mentioned authors, we used other bibliographic references or phytosociological relevés collected in the area where the forest type occurs. In Table II, a list of the types T_i and the relative reference *syntaxa*, for the territory under investigation, is provided. The Type Lab field in the Table is a label which refers to the database [20] used as input data source.

For each forest type T_i, which is described by one or more phytosociological tables, we defined a set of the three indicator components (s_i, a_i, p_i) above described:

- Stratification (number of layers) of a forest type i (s_i): this component analyzes 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 an abundance value equal to 2.
- Percentage frequency of alien species (a_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.
- Percentage frequency 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.

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TABLE II. FOREST TYPES FOR THE PROVINCE OF PAVIA (ITALY)

Type Lab[a]	Description of forest types T_i and relative reference *syntaxa*
1	T_1: Oak-Hornbeam wood of the lowlands *Syntaxa: Polygonato multiflori-Quercetum roboris* subass. *carpinetosum* and *anemonetosum* Sartori 1984; *Quercus robur*, *Carpinus betulus* and *Physospermum cornubiense* community; *Quercus robur*, *Carpinus betulus* and *Holcus mollis* community
12	T_2: Oak wood of inland sand dunes ("dossi") *Syntaxa: Quercus robur* community
13	T_3: Oak wood of stony river beds *Syntaxa: Quercus robur* and *Brachypodium rupestre* community
14-15	T_4, T_5: Oak-Elm wood (also including the Black Alder variant) *Syntaxa: Polygonato multiflori-Quercetum roboris* subass. *ulmetosum* Sartori 1984
20, 23	T_6, T_7: *Quercus pubescens* wood of the carbonatic substrates (also including the Chestnut variant) *Syntaxa: Quercus pubescens*, *Euphorbia cyparissias* and *Epipactis helleborine* community
26, 27	T_8, T_9: *Quercus petraea* wood of the carbonatic substrates and mesic soils (also including the Chestnut variant) *Syntaxa: Physospermo cornubiensis-Quercetum petraeae* Oberd. et Hofm. 1967
28	T_{10}: *Quercus cerris* wood *Syntaxa: Quercus cerris, Cruciata glabra* and *Anemone trifolia* community
45, 48, 49, 50, 57	T_{11}, T_{12}, T_{13}, T_{14}, and T_{15}: Chestnut wood on drift; Chestnut wood of the carbonatic substrates (mesic soils, meso-xeric soils, xeric soils); Chestnut wood of the siliceous substrates and mesic soils *Syntaxa: Physospermo cornubiensis-Quercetum petraeae* Oberd.et Hofm. 1967*; Castanea sativa* and *Corylus avellana* community
63, 64, 65	T_{16}, T_{17}, and T_{18} *Ostrya carpinifolia* and *Fraxinus ornus* wood (of layer, of cliff, typical) *Syntaxa: Knautio drymeiae-Ostryetum* Mondino et al. 1993
84	T_{19}: Birch wood *Syntaxa: Betula pendula* community
88	T_{20}: Primitive Beech wood *Syntaxa: Trochiscantho-Fagetum* Gentile 1974; *Fagus sylvatica* and *Acer opulifolium* community
89, 96, 97, 105	T_{21}, T_{22}, T_{23}, and T_{24}: Beech wood of the carbonatic substrates (high-montane, montane, montane of xeric soils, submontane) *Syntaxa: Trochiscantho-Fagetum* Gentile 1974; *Fagus sylvatica* and *Acer opulifolium* community
99	T_{25}: Beech wood of the siliceous substrates *Syntaxa: Trochiscantho-Fagetum* Gentile 1974; *Fagus sylvatica* and *Acer opulifolium* community
172	T_{26}: Black Alder wood of gulley *Syntaxa: Alnus glutinosa, Populus alba* and *Ulmus minor* community
173	T_{27}: Typical Black Alder wood *Syntaxa: Osmundo regalis-Alnetum glutinosae* Vanden Berghen 1971; *Carici elongatae-Alnetum glutinosae* W. Koch 1926 et R. Tx. 1931; *Carici acutiformis-Alnetum glutinosae* Scamoni 1935
177	T_{28}: Willow wood of bank *Syntaxa: Salix alba* community*; Salicetum albae* Issler 1926
180	T_{29}: *Salix cinerea* wood *Syntaxa: Salicetum cinereae* Zolyomi 1931
183	T_{30}: White Poplar formation *Syntaxa: Populus alba* community
188	T_{31}: Pure *Robinia pseudoacacia* wood *Syntaxa: Robinia pseudoacacia* community
189	T_{32}: Mixed *Robinia pseudoacacia* wood *Syntaxa:Robinia pseudoacacia*, *Quercus robur* and *Ulmus minor* community

a. According to ERSAF database [20]

The three components can assume only discrete values, from 0 to 3. While the definition of quality of stratification is independent on the altitude of the forest, the definition of values related to the percentages of alien and protected species is different, according to 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, reported in Figure 2.

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 $p_i = 3$

Figure 2. The computation algorithm of the three indicator components.

For each of the forest type i of Table II, we computed the relative value set of (s_i, a_i, p_i), according to the algorithm of Figure 2 and the phytosociological tables and/or relevés: the complete value set is reported in Table III.

TABLE III. THE VALUE SET OF COMPONENTS FOR STRATIFICATION, ALIEN AND PROTECTED SPECIES, FOR EACH FOREST TYPE.

Type Lab	Components (s_i, a_i, p_i)
1	3,2,3
12	2,2,1
13	3,3,3
14-15	3,2,2
20, 23	3,3,1
26, 27	2,3,3
28	3,3,2
45, 48, 49, 50, 57	2,3,3
63, 64, 65	3,3,2
84	1,3,0
88	3,3,3
89, 96, 97, 105	3,3,3
99	3,3,3
172	3,3,1
173	2,3,2
177	1,1,0
180	2,2,0
183	3,1,0
188	2,1,0
189	3,2,0

After determining the values of the set of components for stratification, alien and protected species, it is now possible to define the Forest Status Quality Indicator (FSQ) of a given territory as:

$$FSQ = \Sigma_i \ \Sigma_k (s_i + a_i + p_i)*A^k_i/S \qquad (2)$$

for i= 1, 2,.., n, k = 1,2,… max(i) where i is one of the n the significant forest type (at least one occurrence of the forest has A^k_i >= 10.000 square meters) which is present in the territory under investigation, A^k_i is the area of the k-th occurrence of forest type i, and S is the area of the territory. The number of occurrences may vary, from a minimum of 1 to a maximum, which depends of the forest type (max(i)).

The FSQ definition is the weighted values of the components, where the weights are the ratios between the areas of the forests and the area of the territory under investigation. 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 related to the values of the components (stratification, alien, and protected species) as described in the if-then-else algorithm. The summation in (2) is for all the forest types of the territory under investigation, and for all the occurrences of the forests.

The FSQ value can range from 0 (no forests are present in the territory with at least one occurrence of A^1_i> 10.000) to a maximum of 9, which is derived by considering the “perfect”, quite unrealistic, situation of a forest of very high quality (set of components (s_i, a_i, p_i) =(3,3,3)), and where the areas of all the occurrences are equal to the area of the entire territory ($\Sigma_\iota \ \Sigma_\kappa \ A^k_i = S$).

By using an approach similar to the AF metric, we have defined a set of ranges for the FSQ indicator, starting from an unsatisfactory forest quality, a satisfactory but improvable situation, a good, an optimum situation and overbalanced situation. In Table IV, the metric for the FSQ indicator and the suggested policy actions are shown.

TABLE IV. THE METRIC ON THE FSQ INDICATOR FOR FOREST QUALITY.

Class of forest quality	Evaluation of Forest quality and policy	
	Intervals of FSQ	*Suggested policy*
1 Unsatisfactory	0 <= FSQ <= 0.9	Very low level forest quality. A high-impact policy of restoration and/or requalitication of forest is mandatory.
2 Satisfactory but improvable	0.9 < FSQ <= 1.8	Sufficient forest quality but improvable. A policy for forest biodiversity preservation is preferable.
3 Good	1.8 < FSQ <= 3.6	Good forest quality, the first level of satisfactory situation. A policy for the conservation of existing forests is suggested.
4 Optimum	3.6 < FSQ <= 4.5	The optimun situation, with a high quality of forests. A policy for the conservation of existing forests is suggested. Anyway, if shrublands and grasslands are scarse or absent, a policy for their biodiversity preservation has to be considered.
5 Overbalanced	FSQ > 4.5	The overbalanced situation, forests have overcome other ecosystems. A policy for shrubland and grassland biodiversity preservation is highly suggested.

V. EXPERIMENTAL RESULTS

A. Data Sets and computer-based processing

The case study is the province of Pavia (Figure 1), which is located around its chief town, Pavia (latitude, longitude: 45°11'7"44 N, 09°9'45"00 E), in the North-Western part of Italy. The province consists of 190 Municipalities, with the altitude (meters above sea level) in the range [53-951]. In order to compute the value of FSQ in (2), it is necessary to have a description of the territory in terms of administrative boundaries and area, the geo referential coordinates of the occurrences of the forest, and their relative types and areas. We have used two GIS databases in order to derive the useful data: (a) the database of the Italian administrative boundaries provided by Istat [23], where we can compute the exact boundaries of the municipalities of the case study and their relative areas (the term S in (1) and (2)), and (b) the ERSAF (Ente Regionale Servizi Agricoltura e Foreste, i.e., Regional Agency for Agriculture and Forest Services) database [20]. By superimposing the two data sets we can obtain a visual map of the territory, where, for each municipality, we can compute, with a standard primitives of GIS software, the areas of each k-th occurrence of each forest type i (the value A^k_i. in (2)).

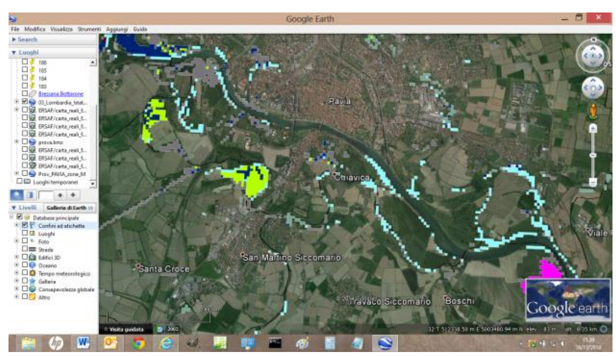

Figure 3. The visual map of the input data [20]: different colors refers to the forest types of Table II (a detail of the province of Pavia, Italy).

In Figure 3, the visual map for a limited zone of the studied area is shown in the standard Google Earth interface. Different colors refer to different types of forests.

B. Results on the case study and discussion

The values of AF and FSQ computed, according to (1) and (2), for each municipality are shown in Figure 4. The correlation between the two sets of values is very low (correlation coefficient: -0,197651). The dispersion plot

(FSQ v. AF) of Figure 5 also shows that the two indicators are quite independent and this is a positive result, because it expresses the fact that the two indicators are related to independent and different pressures on the environment: land use and forest quality. Figure 5 also shows that all the Municipalities with serious levels of AF (> 0.4) have very low levels of forest quality (FSQ < 0.9). This underlines a worrying trend to neglect the ecological compensations to mitigate the impact for increasing urbanization. On the other side, some Municipalities of high altitude show very low levels of AF (< 0.2), but overbalanced levels of FSQ (> 4.5), underling a worrying trend to neglect the forest re-colonization caused by land abandonment. All the results indicate how environment and biodiversity loss are scarcely considered in the land use policies of the study area.

VI. Conclusion and Future Work

In this paper, an innovative indicator for forest quality has been proposed and its relationship with the land use anthropentropy factor has been investigated. The forest quality indicator is coherent with literature indications [13] 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.

Current and future developments of this work include: a wider study area (Lombardy Region) and a shape parameter related to forest occurrences. An interesting analysis is to investigate how to combine FSQ and AF in a "super-indicator".

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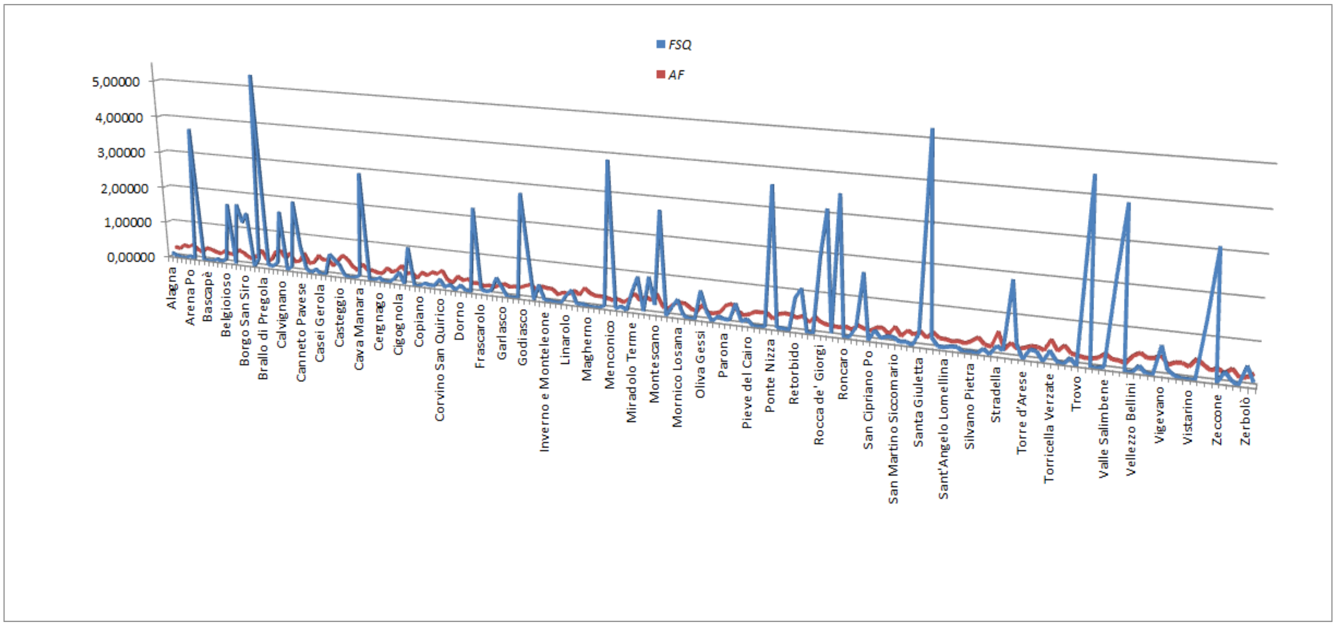

Figure 4. The two indicators Anthropentropy Factor (AF) and Forest Status Quality (FSQ), for all the municipalities of the province of Pavia.

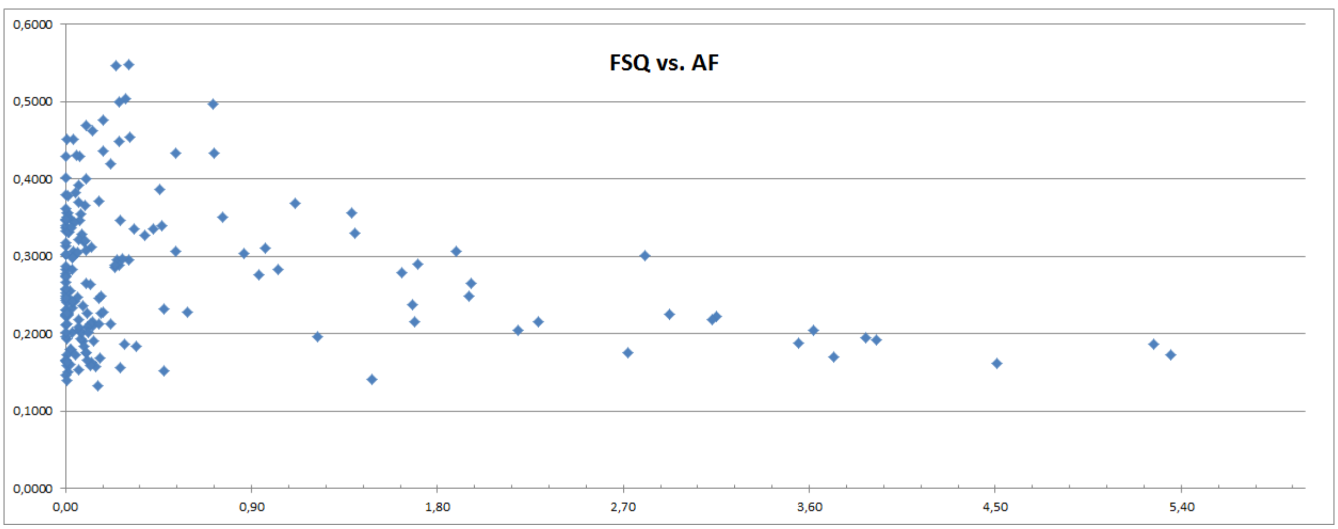

Figure 5. The relationship between the two indicators for land use and forest quality: dispersion plot of FSQ vs. AF, for all the municipalities of the province of Pavia.