The Use of the Forest Status Quality Indicator in Planning Policies for Biodiversity Conservation

Ten Case Studies on Forest Plantations in North Italy

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***Abstract*—This paper describes a new application of the previous defined Forest Status Quality Indicator in planning policies of forest conservation. Starting from previous analysis and conclusions about the importance of the forest plantations for ecological restoration, new case studies confirm the possibility of using this indicator to efficiently guide policy makers and planners to choose the best position and extensions of forest types/patches for restoration and connectivity. By considering the present situation of the forest quality, we propose a method to compute a predicted value of the indicator by considering, in addition, the contribution of plantations, once they will be naturalized in the territory under consideration. The new, predicted value of the Forest Status Quality Indicator is a function of the ecological components, which are at the basis of the naturalistic approach of its definition. The results are shown on ten important case studies of plantations in the West Po Plain (North Italy). The method of prediction can be used to measure the impact of plantations on the quality of the forests and to define under which hypothesis they can play an important role in biodiversity conservation.**

Keywords-biodiversity; environmental indicator; forest status quality; Geographic Information Systems; conservation policy.

I. Introduction

This paper is based on the authors' work [1] and reports the extension of their current research activity. Compared to [1], nine more case studies are added; moreover, the present paper provides the list of all the forest types found in the studied locations, which was not possible in the previous work. Finally, the theory about the ecological indicator, called Forest Status Quality (FSQ), already reported in [1], has been validated by showing a new application to the definition of policies for forest management and conservation.

The previous target, i.e., to propose and measure indicators related to some specific aspects of biodiversity, within a given territory, has been extended to show how an indicator can be used to assess the efficacy of a policy of forest conservation.

The naturalistic indicator FSQ has been introduced for the first time in literature with an investigation about its relationship with another ecological indicator, the land use Anthropentropy Factor [2][3]. However, the preliminary results were very promising in giving a realistic assessment of the situation of forests quality in a given territory.

For this reason, the research has been carried further along this direction. Here, we recall from the previous contribution [1] some important aspects of FSQ indicator, in order to appreciate the improvement of the ongoing researches.

In literature, the most common approach to define biodiversity indicators is to use separately the following primary attributes of biodiversity: (1) species/composition, (2) structure, and (3) function [4], or landscape metrics [5].

The main innovative feature of FSQ, with respect to literature, is the joined evaluation of species composition and structure and landscape metric. In fact, the biodiversity components are: the stratification, the percentage of alien species and the percentage of protected species. Stratification can be easily depicted in four layers: tree, high and low shrub, and herb layers (see Figure 1). Figure 2 shows some typical alien species in the territory under investigation. On the other hand, often protected species (see Figure 3) correspond to true forest species, such as *Anemone nemorosa*, *Campanula trachelium*, *Carex elongata*, *Convallaria majalis*, *Listera ovata*, *Neottia nidus-avis*, and *Primula vulgaris*. The three components characterize the different forest patches of the territory under investigation of the ten case studies.

Furthermore, the FSQ indicator takes into account also a landscape feature, i.e., the size of the forest patches. Consequently, only patches greater than 10.000 square meters are considered. In fact, patches smaller than 1 ha generally show low species richness [6] and a scarce floristic quality due to the edge effect which can increase the abundance of weedy and alien species [7]-[9]. The richness and floristic quality (due to true forest species) of the forest patches can be influenced not only by their size, but also by their shape. However, a correlation between the shape and the species richness of forest patches can be found when the patch size is sufficiently high. In fact, Dzwonko and Loster [10][11] found a negative correlation between the shape index of Patton [12] and the number of shrubs and forest species. In that case, they worked with a restricted dataset of only 27 forests, with varying patch size from 0.03 to 1.6 ha. With such small patch sizes, it is possible that the entire patch was subject to the edge effects [13]. Honnay et al. [13] analyzed 234 forest patches varying

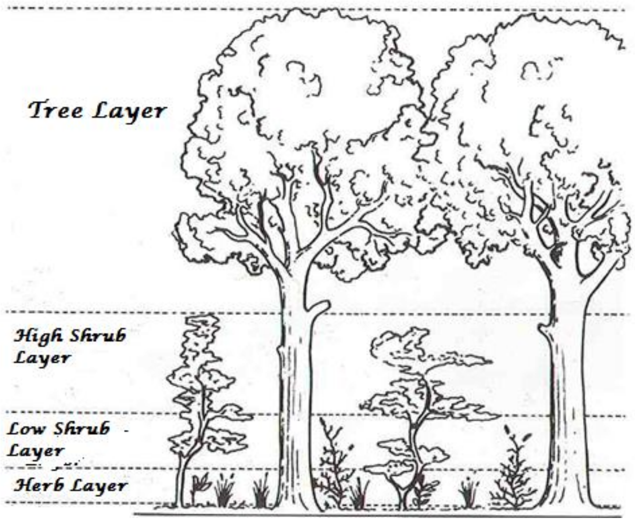

Figure 1. The layers of the stratification in a forest: tree, shrub (high and low), and herb layers.

Figure 2. Examples of some alien species in the territories under investigation: *Solidago gigantea*, *Robinia pseudoacaica*, and *Amorpha fruticosa*.

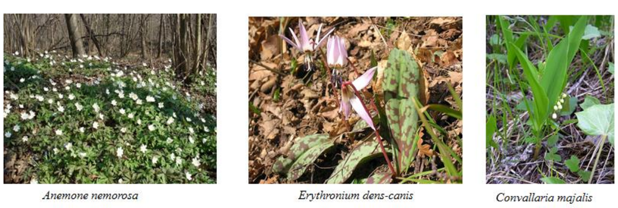

Figure 3. Examples of some protected species in the territories under investigation: *Anemone nemorosa, Erythronium dens-canis,* and *Convallaria majalis.*

in size between 0.5 and 5216 ha and found a correlation between the Patton shape index and the number of species in edges and clearings, the number of woody species and lianas and, as a consequence, with the total number of forest plant species. For these reasons, in a second improved definition of the FSQ indicator [1], also the shape of forest patches has been taken into account.

Patches with linear shapes are excluded, applying an ad hoc morphological operator on the image data set provided by the Geographic Information Systems (GIS) of the project (as explained in Section II.) Such linear patches, together with those smaller than 10.000 square meters, that can be considered as punctual patches, do not represent core areas hosting complex forest ecosystems (as the wide patches of compact shape where the edge effect is reduced) important for woody and herbaceous true forest species. However, they can represent critical elements to connect core areas and support the structure of a local/regional ecological network, and the evaluation of their quality should be better considered from the connectivity perspective. Therefore, only forest patches with similar geometric characteristics (wide size and compact shape) were considered, with the aim to evaluate more homogenous elements and to have a more realistic picture of the forest quality, which is useful for conservation purposes.

Besides embedding the geometric characteristics in the computation of the FSQ indicator, a second aspect has been considered [1]: the evaluation of the importance of forest plantations. This idea is at the basis of the new research activity here reported. In fact, in the first elaboration of the FSQ indicator [2][3], only natural forests were considered, while plantations were excluded from the evaluation. However, the Region Lombardy, in 2002, started and financed an important project aimed to create ten new plain forests, each of them with a size of about 40 ha and planted with native trees and shrubs [14][15].

Actually, such forests have not still developed a typical structure of mature wood and a typical nemoral herb layer, which will require at least 20-30 years. Anyway, because of their importance for the restoration of the Lombardy plain and conservation purposes, the initial idea of considering also such new forests give interesting preliminary results on a first case study in the Municipality of Travacò Siccomario (Province of Pavia).

After these preliminary results [1], in this paper we extend the analysis on other nine great forest plantations of the Region Lombardy, with an innovative approach to predict the efficacy of these plantations in their contribution to FSQ. This will be further explained in Section III. First, a brief description of preliminary researches on the theory about FSQ is given in Section II. Conclusion and future work end the paper in Section IV.

II. Preliminary Research activities

In this section, a brief summary of the theory of FSQ indicator is given. Moreover, preliminary results are reported with more details in [1], in order to appreciate how the research has been evolving to make improvements and new contributions with respect to the state of the art.

A. *Definition of the Forest Status Quality Indicator*

The FSQ expresses the forest quality status as the value of its ecological components, with particularly reference to the biodiversity conservation. A set of sub-regions occupied by natural forest F_i (i = 1, 2, n) was defined. Each of F_i may have one or more occurrences, denoted by the index k, in the territory (k = 1, 2, max(i)). The number of occurrences may vary from a minimum of 1 to a maximum, which depends on the forest type (max(i)). Each k-th occurrence is characterized 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 ERSAF Database "Map of the Forest Types of Lombardy" [16]. For each forest T_i, we found the correspondence with one or more phytosociological tables [17]. For each forest type T_i, we defined a set of the following indicator components (s_i, a_i, p_i): the stratification (number of layers) of a forest type $_i$ (s_i), the percentage frequency of alien species (a_i) in the corresponding phytosociological table/s, and the percentage frequency of protected species (p_i) (according to the Lombardy regional law, L.R. 10/2008) in the corresponding phytosociological table/s. The three components can assume only discrete values, from 0 to 3, according to an if – then – else algorithm described in [2] [3]. After determining the values of the set of components for stratification, alien and protected species, for each forest T_i, it is possible to compute the FSQ Indicator of a municipality of area S as

$$FSQ = \Sigma_i \ \Sigma_k (s_i + a_i + p_i)*A^k_i/S \qquad (1)$$

The FSQ definition is the weighted values of the components, where the weights are the ratios between the areas of the forest patches and the area of the territory under investigation. By using the primitives of the open source QGIS software [18], the values of A^k_i in the territory under investigation have been computed, in order to estimate the value of the FSQ indicator, according to (1), for all the municipality of our case studies. Obviously, according to (1), FSQ indicator is a real number in a limited range: the minimum value is 0, which corresponds to the dramatic situation where no forests are present in the territory with at least one occurrence of area greater than 10.000 square meters. The maximum possible value is 9, which is derived by considering the unrealistic situation of a municipality where no anthropic presence occurs, and the territory is entirely occupied ($\Sigma_\iota \ \Sigma_\kappa \ A^k_i = S$) by forests of very high quality (set of components (s_i, a_i, p_i) = (3,3,3)).

TABLE I. 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 requalification 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.
4 Optimum	3.6 < FSQ <= 4.5	The optimun situation, with a high quality of forests.
5 Overbalanced	FSQ > 4.5	The overbalanced situation, forests overcoming other ecosystems. A policy for shrubland and grassland biodiversity preservation is preferable.

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 I, the metric for the FSQ indicator and the suggested policy actions are shown.

B. *The Erosion Operator*

The introduction of the factor "shape" of the forest patches in the computation of the FSQ slightly modify the original definition in (1), where only the areas of forest patches are considered and weighted by the naturalistic components (s_i, a_i, p_i). The only limitation introduced on the geographic data is still a quantitative one (the 10.000 square meters as the minimum accepted size of the forest patch to be evaluated). However, we decided to take into consideration a characteristic that refers to the shape of a patch, i.e., to reduce the edge effect, which, in turn, reduces the floristic quality. This can be done by applying the standard mathematical morphology operator of Erosion [19], with a structural element of a circle of radius of 50 meters. In fact, Erosion is a typical image processing operator that allows to "erode" a connected area, starting from its perimeter and proceeding inside, of an extent that corresponds to the shape of the structural element. In our case, the structural element is a circle of a given radius, in order to reduce the areas of the forests to their real inner shape, by excluding the areas near the boundary. If we use a circle as structural element, the shape of the forest will be remodeled in a symmetric way, all along the boundaries. The diameter of the structural element determines the minimum distance that a forest patch must have from its center to all the points of its boundaries, in order to be considered in the FSQ computation.

As a result of the Erosion, the forest patches with a linear shape (a thin stripe less than 100 meters of amplitude) disappear from the map, as it can be seen in the experimental results reported in Section II.E. All the other patches are reduced by the erosion, to minimize the "edge" effect. With the introduction of the Erosion operator, we applied to each area A^k_i the Erosion operator E[], thus leading to a new expression of FSQ, denoted by FSQ_e:

$$FSQ_e = \Sigma_i \ \Sigma_k (s_i + a_i + p_i)*E[A^k_i]/S \qquad (2)$$

The new operator FSQ_e takes into consideration both the quantitative (areas) and the qualitative (shapes) aspects of the forest patches.

C. *The hardware and software infrastructure*

In order to compute the values of FSQ in (1) and (2), we settled a software environment, capable of measuring the areas of the territories of the municipalities under investigation, the areas of the forest patches, and to implement the Erosion operator. The same hardware/software infrastructure has been used both for the previous results [1][2][3], and for the new research activity here presented.

The hardware resource is a standard Workstation with a 64 bit Intel® Core™ I7-3630QM microprocessor at 2.4 GHz, with 12 GB RAM with a Full HD resolution monitor, for easily displaying details of the maps, and Windows 10 operating system.

The software equipment is based on QGIS software [18], 2.14 version, for visualizing, managing and processing geospatial information. In fact, as in the previous contribution [1][2][3], we have used a GIS map database (ERSAF database), free available from the Region Lombardy [16], in order to derive the useful description about the distribution of the forest in the territory. In Figure 4, the visual map for a portion of the Municipality of the preliminary case study [1] is shown. Different colors refer to different types of forests. Particularly, the compact pink area refers to the forest plantation. The other colors refer to natural forests.

The second GIS map we used is provided by ISTAT, the Italian National Institute of Statistics, for the administrative boundaries of the municipalities [20]. By using the QGIS primitives, it is possible to compute on this map the area of the municipality under investigation, i.e., the value of S in (1) and (2). By combining information of the two GIS maps [16][20], it is possible to define exactly which of the Forests Types of the ERASAF Database belongs to each Municipality under investigation.

The Erosion operator (see Section II.B) has been implemented by using the primitives of morphological operators in Matlab environment [21] for image processing. Finally, some *ad hoc* software has been developed for the generation of the quantitative results of Section III and their storing and management in a typical relational database, to facilitate access and subsequent use in future researches.

D. *The Study Area*

The study area in the preliminary research [1] is the Municipality of Travacò Siccomario. It is located in the Lombardy plain at an average altitude above sea level of 66 meters, and is mainly characterized by agricultural fields and urban areas. Natural forest areas are localized along watercourses and channels, often as linear elements dominated by mixed woody species as *Salix alba*, *Populus alba*, *Quercus robur*, *Ulmus minor* and, very frequently, the invasive *Robinia pseudacacia*. Wide forest patches are limited and dominated by the woody species above mentioned. As we consider only forest types that have at least one occurrence in the territory of area greater than 1 ha, only three types of natural forests survive these requirements: the *Salix alba* communities, the *Populus alba* communities, and *Robinia pseudoacacia* communities.

Moreover, in this study we want to include also plantations in the FSQ computation. In 2003-2004, one of the great plain forests of the Lombardy Region was realized in this municipality. This project was entitled "The Great Forest between the Two Rivers", because it is at the join of Ticino with Po River (see Figure 5). In particular, meso-xerophilous and meso-igrophilous forest patches were realized on a surface of about 41 ha, planting native trees (such *Populus nigra*, *Ulmus minor*, *Acer campestre*, *Malus sylvestris*, *Carpinus betulus*, *Quercus robur*, *Salix alba*, *Alnus glutinosa*, *Populus alba*, *Prunus padus*) and native shrubs (such *Crataegus monogyna*, *Corylus avellana*, *Prunus spinosa*, *Sambucus nigra*, *Cornus sanguinea*, *Frangula alnus*, *Viburnum opulus*, *Salix cinerea*). Considering the woody floristic composition, the new forest can be considered as the forest type Oak-Elm wood (also including the Black Alder variant) [22]. The value set of components for stratification, alien and protected species is 3,2,2 for this plantation. In Table II, all the forest types, of area greater than 1 ha, for the case study of Travacò Siccomario are shown.

TABLE II. FOREST TYPES FOR THE PRELIMINARY CASE STUDY [1].

Naturalistic components (s_i, a_i, p_i)	**Description of forest types and relative reference *syntaxa***
(1,1,0)	Willow wood of bank
(3,1,0)	White Poplar formation
(2,1,0)	Pure *Robinia pseudoacacia* wood
(3,2,2)	Plantation (Oak-Elm wood, also including the Black Alder variant)

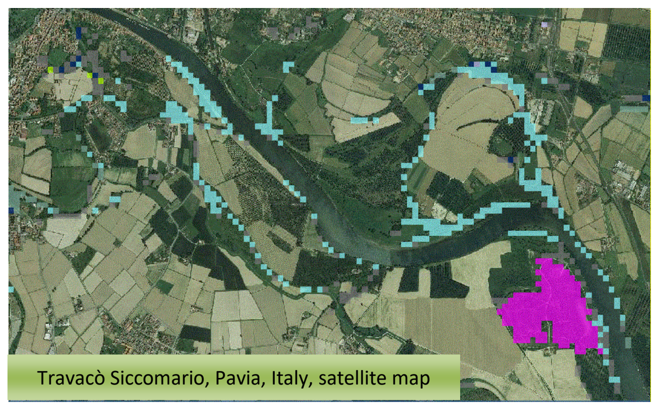

Figure 4. The territory under investigation (Municipality of Travacò Siccomario) in the preliminary case study [1]: the blocked colored areas superimposed on the geographic map show the presence of the natural forests (light greeen and light blue) and the plantation (pink).

Figure 5. The "Great Forest between the Two Rivers" forest plantation project: an overview of the territory where river Ticino joins the river Po.

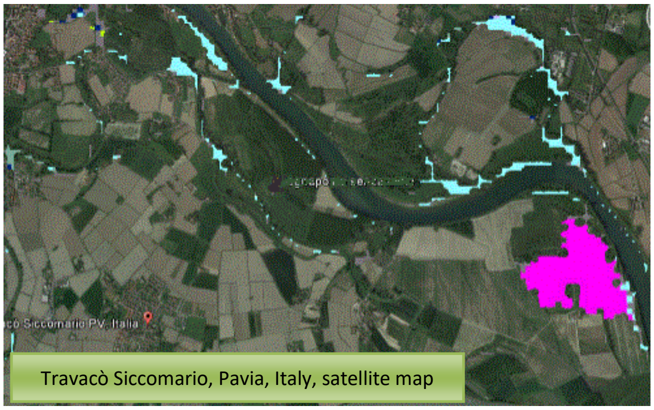

Figure 6. The territory under investigation after the Erosion operator applied to all the forest patches.

E. Preliminary Experimental Results

By applying the erosion operator to compute the FSQ_e, according to (2), we can compare the effect of the Erosion on each forest types of Table II. Clearly, the erosion has reduced the areas of the forest patch. However, the loss of the areas is not equal for all the four forest types. In fact, the loss is determined by the shapes of the patches, which are quite different in the territory under examination. The loss percentages are the following: 3.6% for the plantation, 35.2% for the *Salix alba* communities, 51.3% for the *Populus alba* communities, and 61.2% for the *Robinia pseudoacacia* communities. It is interesting to note that the plantation is the forest type with the lowest loss; this means that in the project the plantation patch has a shape, which is very close to an ideal core area. Moreover, the *Robinia pseudoacacia* communities have the highest loss, and it is a positive aspect, because of the very low floristic quality, due to the dominance of alien species in linear and fragmented patches. In Figure 6, the map of the territory after the erosion is shown. The reduction of the colored areas of the forests types is evident, by comparing Figure 6 to Figure 4. In Figure 7, the areas of the forests (Y axis) before and after the erosion are plot, for each forest type of Table II.

III. Planning Conservation Policies using the FSQ Indicator

In the preliminary study [1], we have evaluated the naturalistic components of the plantation in the municipality of Travacò Siccomario. This initial idea can be further investigated by directly explaining the contribution of plantations in the definition of the FSQ indicator. This operation is computed starting from the original formula (1) of FSQ, without the erosion operator, because, according to the results reported in Section II, the Erosion operator is quite irrelevant on the plantations (Figure 7), due to their compact shapes.

Suppose that, in a given municipality under investigation, there is a plantation of area A_p, with its naturalistic components (s_p, a_p, p_p). For simplicity, we show the discussion in the case of a single plantation, but the theory can be easily extended to the case of more than one patches. By reconsidering formula (1), we can separate the contribution to the global value of FSQ in two distinct parts: the first is due to the natural forest patches in the territory, the second is due to the plantation only. A new definition of FSQ is possible, which considers also the plantation contribution. We denote this "new" FSQ with the symbols FSQ', and (1) becomes:

$$FSQ' = \Sigma_i \ \Sigma_k \ (s_i + a_i + p_i)*A^k_i/S + \ (s_p + a_p + p_p)*A_p/S \quad (3)$$

Usually, a plantation have not still developed a typical structure of mature wood; moreover its naturalistic component can be only estimated, in its actual value of the triplet (as in the first case study of Travacò Siccomario, where (s_p, a_p, p_p) has been set to (3,2,2)), but we have no assurance that these values will be the same after 20-30 years, when the plantation will become, presumably, a new mature and "natural" forest. For this reason, it is interesting to study the variation of FSQ' in (3), for each possible values of the triplet (s_p, a_p, p_p). This analyses can express the strength of the naturalistic components in rising (or lowering) the FSQ' indicator. By analyzing (3), we can observe that the sum of the three naturalistic components (s_p, a_p, p_p) is a linear, multiplicative coefficient of the second term. In order to reduce the complexity of the study (actually, in (3) there are four independent variables, i.e., the area of the plantation A_p and the three components (s_p, a_p, p_p), we can substitute in (3) one variable x defined as

$$x = s_p + a_p + p_p \quad (4)$$

where x can assume only discrete values, in the range [1,9]. By observing that in (3) the first term corresponds to the FSQ value, computed without plantations according to (1), by substituting the value of FSQ (1) and x (4) in (3), we can write

$$FSQ' = FSQ + x*A_p/S \quad (5)$$

where FSQ' is the new value of the FSQ indicator, which includes plantations too, FSQ is the original value, which excludes plantation, according to the initial hypothesis [2], [3], x is the independent variable and A_p is the area of the plantation. The new definition of FSQ' can be used to reach two different goals: (a) if the plantation is already present in the territory, by varying x, we can compute the minimum and maximum gain of the FSQ value; (b) if the plantation is not still present, but it is the object of a planned, future project of a policy for forest conservation, it is possible to study as the indicator can improve, from its actual value of FSQ to the new value, i.e., FSQ', and consequently we can also determine to what extent the class of forest quality of

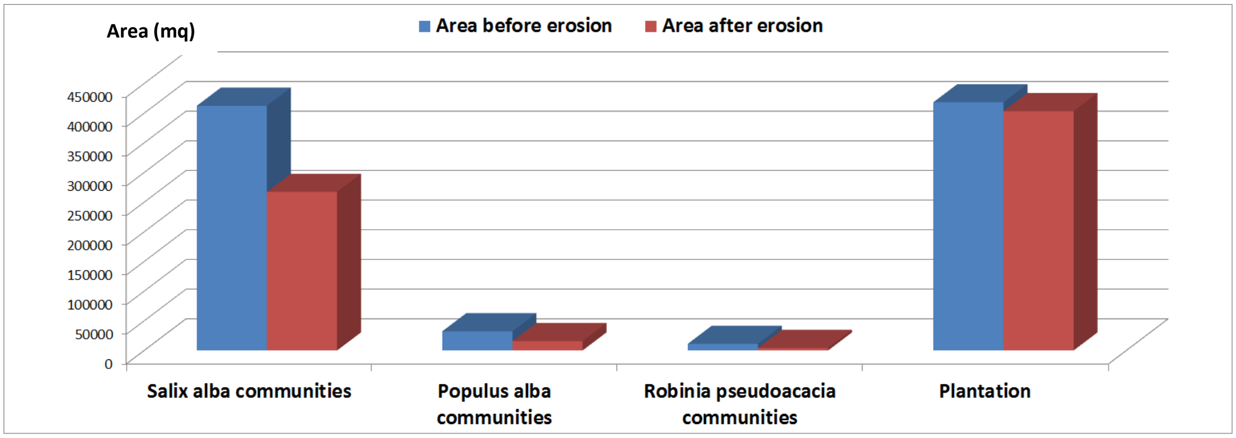

Figure 7. The areas (in square meters, on Y-axis) for each the forest types (on the X-axis), before and after the Erosion.

the territory may improve (according to Table I). The two cases will be analysed in details in Section III.A and Section III.B, respectively.

A. *Ten case studies of existing plantations*

We consider ten case studies, which are part of the project, "Ten Great Forests for the Plain", in Region Lombardy, in the North part of Italy (Figure 8). The project is the result of two years of intensive work toward a goal strongly shared by Regions, Provinces, Municipalities, ERSAF "Regional Agency for Services to Agriculture and Forests" and several other organizations and associations in the area. At present, eight forests have been funded, and seven have been completed. By careful analysing the ERSAF GIS database [16], we have identified further three great plantations in Region Lombardy. Therefore, we consider ten case studies, listed in Table III. Their positions in Region Lombardy are depicted in Figure 9. For completeness, in Table IV, a list of the natural forest types located in the territories of the ten case studies is provided, together with their reference *syntaxa* and the values of the triplets of naturalistic components. The *Type Lab* field in the Table is a label, which refers to the ERSAF database [16] used as input data source, and it is reported to help any comparative analysis and reference to the database. Moreover, in Table V, the membership of each forest type to each case study is reported.

By using the primitives of the open source QGIS software [18] on the GIS ERSAF data set [16], for each municipality of the ten case studies, we have computed the following values:

- the FSQ value (according to (1)) ;
- the areas of all the plantations (the term A_p in (5)).

At this point of the analysis, we can obtain a first important set of results: for each case study, it is possible to plot FSQ', according to (5), as a function of x (see(4)), i.e., as a function of the forest quality of the plantation, expressed in terms of its naturalistic components of stratification, alien and protected species.

Figure 8. The geographic position of Region Lombardy in the North West part of Italy.

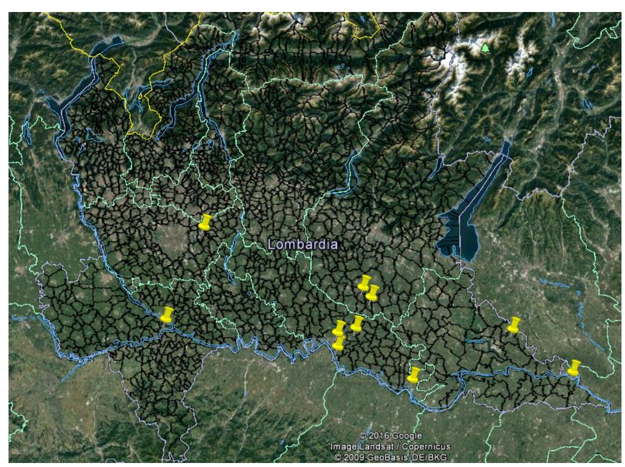

Figure 9. The ten case studies in the Region Lombardy.

TABLE III. THE TEN CASE STUDIES OF EXISTING PLANTATIONS: DENOMINATION AND GEOGRAPHICAL COORDINATES.

Case study	Name of the Municipality	Geographic Position	
		Latitude	Longitude
1	Travacò Siccomario	45° 9'7.58"N	9° 9'42.82"E
2	San Gervasio Bresciano	45°18'22.41"N	10° 8'54.31"E
3	Milzano	45°16'22.29"N	10°11'29.93"E
4	Cremona	45° 8'25.53"N	10° 1'55.86"E
5	Gadesco-Pieve Delmona	45° 9'38.92"N	10° 7'19.31"E
6	Gerre De' Caprioli	45° 5'26.18"N	10° 2'7.59"E
7	Casalmaggiore	44°59'17.91"N	10°25'10.63"E
8	Bigarello	45°10'55.20"N	10°54'44.63"E
9	Carbonara di Po	45° 2'16.78"N	11°13'26.36"E
10	Pioltello	45°29'22.90"N	9°19'34.25"E

TABLE IV. FOREST TYPES IN THE TEN CASE STUDIES: REFERENCE SYNTAXA AND NATURALISTIC COMPONENTS.

Type Lab[a]	Naturalistic components (s_i, a_i, p_i)	Description of forest types and relative reference *syntaxa*
1	3,2,3	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
14-15	3,2,2	Oak-Elm wood (also including the Black Alder variant) *Syntaxa: Polygonato multiflori-Quercetum roboris* subass. *ulmetosum* Sartori 1984
172	3,3,1	Black Alder wood of gulley *Syntaxa: Alnus glutinosa*, *Populus alba* and *Ulmus minor* community
173	2,3,2	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	1,1,0	Willow wood of bank *Syntaxa: Salix alba* community; *Salicetum albae* Issler 1926
183	3,1,0	White Poplar formation *Syntaxa: Populus alba* community
188	2,1,0	Pure *Robinia pseudoacacia* wood *Syntaxa: Robinia pseudoacacia* community
189	3,2,0	Mixed *Robinia pseudoacacia* wood *Syntaxa:Robinia pseudoacacia, Quercus robur* and *Ulmus minor* community

a. According to ERSAF database [16]

The fundamental question is: what is the improvement of the forest quality due to the presence of the plantation, expressed by the indicator FSQ', if compared to the situation where plantations are not present or considered (FSQ value)?

To find the answer, it is convenient to plot the absolute gain of FSQ' over FSQ, as a function of x. By considering (5), we can express the absolute gain as

$$FSQ'/FSQ = 1 + x * A_p/[S*FSQ] \quad (6)$$

In Figures 10 and 11, the absolute gain in (6), expressed as a percentage, is plot as a function of x, for the ten case studies. They are grouped in two sets: the first one (Figure 10) refers to the municipalities that show a modest increment of the FSQ' (*low increasing cases*), if compared to FSQ (less than 5%). The second set shows very interesting gains (*high increasing cases*), up to 90%. Obviously, Equation (6) is a straight line, where the slope is directly proportional to the area of the plantation (A_p) and inversely proportional to the area of the municipality. For this reason, case studies where the area of the plantation is considerably less that the area of the municipality show less values of gain.

The case study #8, Bigarello, suggests important considerations about policy of forest conservation. In fact, as it can be inferred from Table V, in the municipality of case study # 8 there are not natural forests of areas greater than 1 ha; therefore, the value of FSQ is zero. For this reason, this case study does not appear in Figure 10 and 11, because the absolute gain is numerically, equal to infinite (FSQ = 0 in (6)).

The plots of Figures 10 and 11 are very interesting because they show a potential very impressive gain in the Forest Status quality Indicator, if we choose carefully the area of the plantation and also the forest types involved, i.e., their naturalistic components, expressed by the cumulative variable x.

For this reason, we have analysed the projects of the plantations and, considering the planted species, we have defined the corresponding forest types (see Table VI) with their current value of the triplet (s_p, a_p, p_p) for each case study, as follows:

Case Study #1: $s_p = 3; a_p = 2; p_p = 2$
Case Study #2: $s_p = 3; a_p = 3; p_p = 3$
Case Study #3: $s_p = 3; a_p = 3; p_p = 3$
Case Study #4: $s_p = 3; a_p = 2; p_p = 2$
Case Study #5: $s_p = 3; a_p = 2; p_p = 2$
Case Study #6: $s_p = 3; a_p = 2; p_p = 2$
Case Study #7: $s_p = 3; a_p = 2; p_p = 2$
Case Study #8: $s_p = 3; a_p = 3; p_p = 3$
Case Study #9: $s_p = 3; a_p = 3; p_p = 3$
Case Study #10: $s_p = 3; a_p = 2; p_p = 3$ (7)

By substituting (4) and (7) in (6), we can obtain the absolute gain of the forest plantation, for each case study. The final results are summarized in Table VII. Some of them are noteworthy: for example case study # 8 goes from an initial dramatic situation (FSQ = 0, i. e., no forests) to a limited but interesting little improvement (FSQ' = 0.13).

Furthermore, in the case study #6, thanks to the new plantation, the municipality is able to improve its class of forest quality, from class 1 (FSQ = 0,014784877, thus < 0.9, See Table I), to class 2 (FSQ' = 0,925521). In the other cases, the increasing in the FSQ' is not sufficient to determine also an improving in the forest quality class. However, the absolute gain (expressed in percentage in Table VII) can be relevant, as in the case studies #2, #7, and #10 and, presumably, an enlargement of the plantation will be sufficient to improve the forest quality class.

Moreover, the enlargement is the only option, because the forest types corresponding to the plantations are coherent with the natural potentiality of the territories and cannot be changed.

TABLE V. FOREST TYPES IN THE TEN CASE STUDIES.

Type Lab[a]	Forest Types	Case Study									
		1	2	3	4	5	6	7	8	9	10
1	Oak-Hornbeam wood of the lowlands			*							
14-15	Oak-Elm wood (also including the Black Alder variant)				*			*			
172	Black Alder wood of gulley			*							
173	Typical Black Alder wood		*		*						
177	Willow wood of bank	*		*	*			*		*	
183	White Poplar formation	*									
188	Pure *Robinia pseudoacacia* wood	*	*	*	*						
189	Mixed *Robinia pseudoacacia* wood		*	*	*	*	*	*			*

a. According to ERSAF database [16]

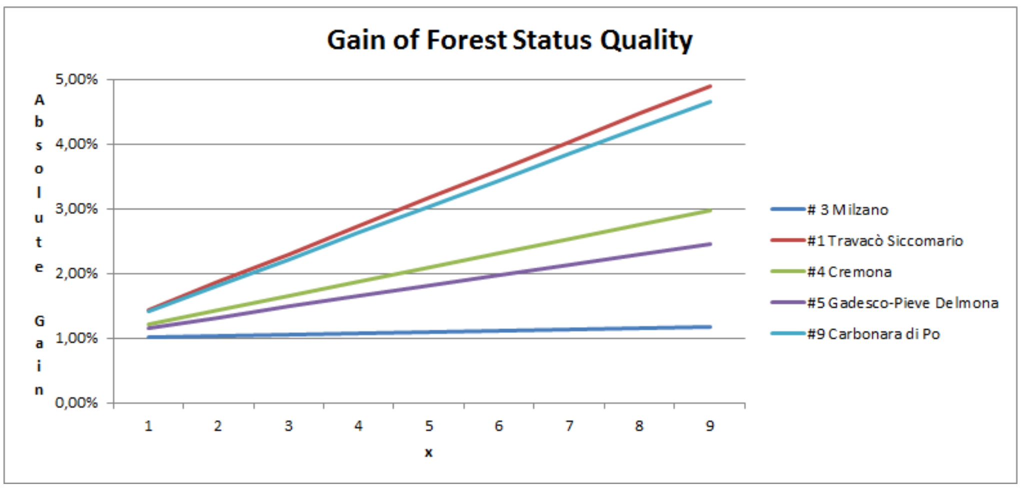

Figure 10. The absolute gain of FSQ' over FSQ, for low-increasing cases.

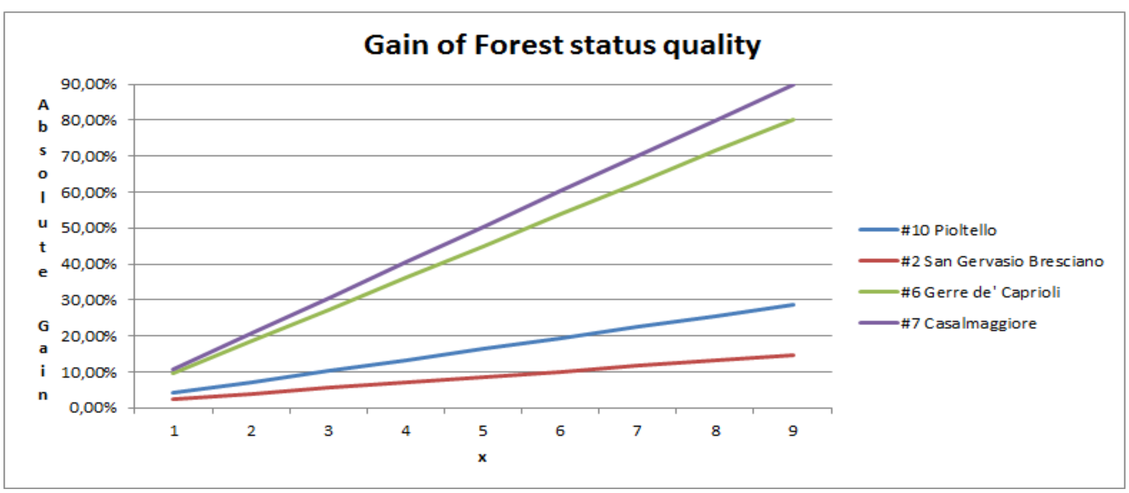

Figure 11. The absolute gain of FSQ' over FSQ, for high-increasing cases.

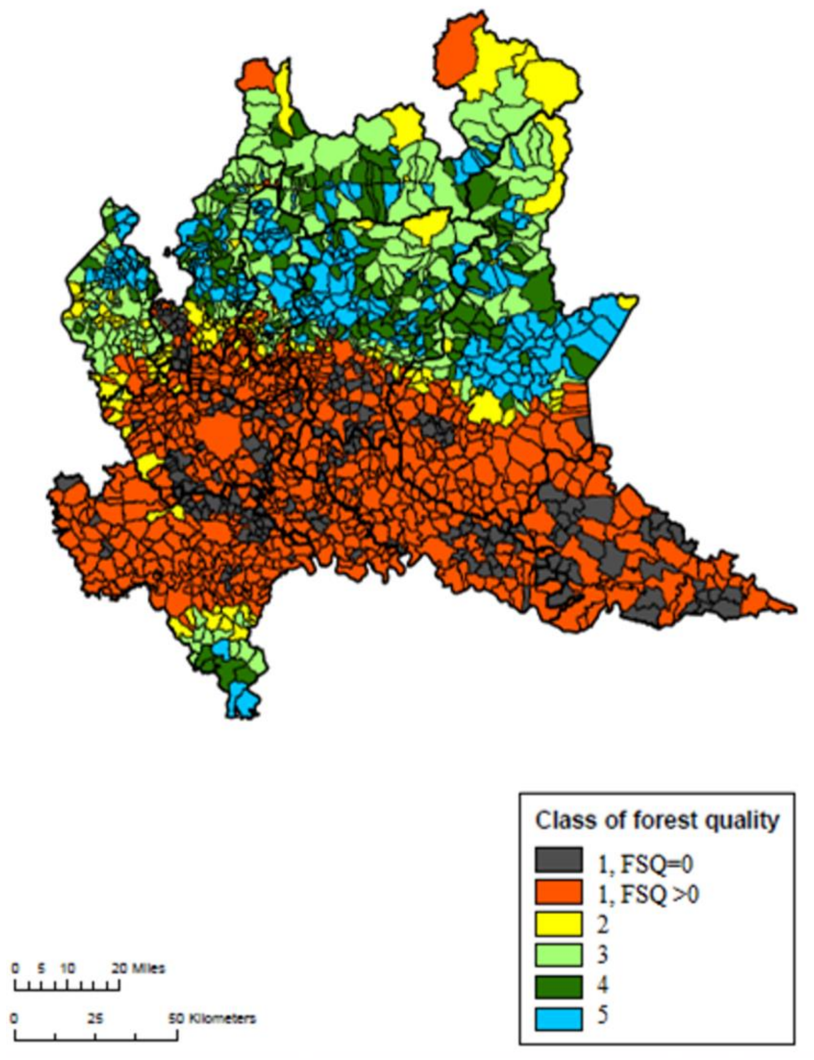

Figure 12. The map of the FSQ indicator on the Region Lombardy.

B. *The use of FSQ'indicator for conservation policies*

Developing biodiversity conservation planning tools is a big challenge for scientists [23][24]. The two main points a conservation policy should focus on are [25]:

- to identify what are the sites where a *quantitative* target for biodiversity conservation has to be achieved and
- to measure the contribution that these sites make to biodiversity conservation.

We think that the new formulation of the Forest Status Quality Indicator, i.e., the expression of FSQ' (according to (3)) can be a valid help in the achievement of these goals. First of all, the term *quantitative target* is well expressed by an indicator of type B [26], or performance indicator, such as the FSQ' is. In fact, the FSQ' indicator, compares the current conditions of the forest status quality to a specific set of reference conditions (the metric of Table I, which is the same for the original definition of FSQ and for FSQ').

In order to identify the sites where high-impact policy of restoration and/or requalification of forest are preferable, we can use the value of FSQ in order to identify the municipality, i.e., the sites, where the project and realization of plantation can be a valid response to conservation issues. For this purpose, we can consider the municipalities whose FSQ value (according to (1)) is in the class 1 (unsatisfactory, see Table I), i.e., the FSQ value is less than the first range threshold of 0.9. We have computed the values of FSQ for all the 1544 municipalities of Region Lombardy (we recall that this value is computed without the plantation contribution, only natural forest are considered.)

In Figure 12, we have shown the visual map of Region Lombardy; besides the five classes, the first class is split in two colors: in black, to highlight the municipalities of class 1 with FSQ = 0, and in red, the municipalities of class 1 but FSQ > 0. By looking to the map, conservation policy maker should best individuate sites for plantation restoration. The situation in Lombardy is very worrying: a percentage of 54,3% of the municipalities are of class 1, with almost 13% of the municipalities has a FSQ value equal to zero. The distributions of the municipalities for each class of forest quality (according to Table I) is shown in Figure 13.

TABLE VI. THE FOREST TYPES FOR THE TEN CASE STUDIES.

Case study	Forest type corresponding to the plantation	Area of the forest plantation (in ha)
1	Oak-Elm wood	42
2	Mix between Oak-Elm wood, Oak-Hornbeam wood of the lowland, eastern variant, and Oak-El wood, variant with shrubs	37
3	Mix between Oak-Elm wood, Oak-Hornbeam wood, eastern variant, and Oak-El wood, shrubby variant	3
4	Oak-Elm wood	93
5	Oak-Elm wood	4
6	Oak-Elm wood	100
7	Oak-Elm wood	246
8	Oak-Hornbeam wood of the lowland, eastern variant	40
9	Oak-Hornbeam wood of the lowland, eastern variant	15
10	Oak-Hornbeam of the lowland	14

TABLE VII. THE GAIN OF THE PLANTATION, FOR EACH CASE STUDY.

Case study	FSQ (without plantation)	FSQ' (with plantation)	Absolute gain (formula (6))
1	0.056634801	0.228433	4.03%
2	0,022777227	0,336234	14.8%
3	0,138502546	0,163295	1.18%
4	0,060074294	0,151868	2.53%
5	0,011700202	0,02501	2.14%
6	0,014784877	0,925521	62.6%
7	0,003876087	0,271513	70.05%
8	0	0,135032936	NaN
9	0,024306075	0,113267	4.66%
10	0.003438496	0.0775	22.54%

Once we have individuated the sites where conservation policy should be realized, we can measure the effect of the gain of the forest status quality due to new plantations by computing the corresponding value of FSQ', exactly as we have shown for the ten case studies. The absolute gain according to (6) is a good indicator of the efficacy of the conservation policy, as it expresses the improvement of forest quality due to the new plantation realized in the territory under investigation.

Suppose, for example, that a municipality has a current value of FSQ below the first threshold, and we want to reach at least the class number 2. By applying the definition of the metric, this means that FSQ' must be at least greater than 0.9. Supposing to choose a high quality forest for plantation, namely a forest showing the highest value for the naturalistic components (3,3,3), by substituting FSQ' = 0.9 and x = 9 in (6):

$$0.9/FSQ = 1 + 9 * A_p/[S*FSQ] \qquad (8)$$

we can derive the minimum area of the forest plantation A_p to reach the goal:

$$A_p = S * (0.9 - FSQ)/9 \qquad (9)$$

In this way, we can use the naturalistic components, the FSQ and FSQ' indicators to help policy makers to determine *where* and *how* perform a possible policy of forest requalification by new plantation settlements. However, the choice of the forest type in the area of plantation cannot primarily follow the criterion of the highest value for the triplet of the naturalistic components, but the one of the *coherence* of the forest type with the natural potentiality and ecological conditions of such area. Subsequently, the area of the plantation sufficient to reach our goal will be calculated, as in (9). To better understand this concept of *coherence*, we can consider the example of the plain rivers, where forests will not reach the highest values for the naturalistic component, due to the human and natural disturbance. For this reason, policy makers have to be aware of the necessity of choosing wide areas for the plantations.

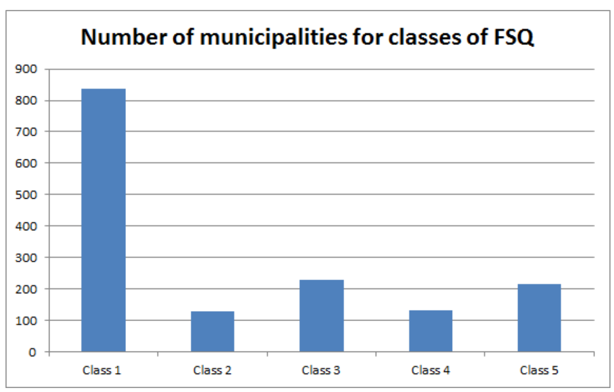

Figure 13. The distribution of all the municipalities of Region Lombardy, in each class of forest quality, according to the metric (See Table I).

IV. Conclusion and Future Work

In this paper, an application of the innovative indicator for forest quality assessment has been proposed with the aim to support planning policies for forest conservation. Despite the fact that it is an experimental research model, the results suggest that it could be used in real world purposes and cases. Actually, the analysed case studies confirm that our methodological approach is realistic in evaluating the forest quality. Moreover, it can give useful information about (a) the choice of forest types to enhance and (b) the surfaces necessary to plantations, if at least a satisfactory level of forest quality is pursued. The computation of such indicator on the territory of Region Lombardy is particularly challenging due to the following features: Region Lombardy ranks first in Italy for the population and for the number of local municipalities, second for population density, and fourth for area. It is also the most invaded Region by non-native species, which represent the 16.9% of the total vascular flora [27]. Furthermore, in Lombardy more than 800 municipalities show an unsatisfactory level of forest quality, and they are more concentrated in the Po Plain. Such Plain is a very polluted area, with values of PM2.5 (mg/cubic meter) between 26 and 35, and its greatest city, Milan, showing values between 36 and 69 [28]. Here, we firmly believe that serious policies of forest restoration are crucial, not only for biodiversity conservation, but also for the human health, due to the important role of forests in pollution control [29].

The present application of the FSQ, together with the previous contributions on the same topic [1][2][3], highlights the strength of the synergy between the botanical and computer science competences in addressing problems about environmental topics and in providing indicator based solutions for policy makers and planners.

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