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Assessment of soil protection to support forest planning: an experience in southern Italy

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Abstract

Aim of study: To support landscape planning when soil-erosion control and water cycle regulation represent relevant issues for forest management.

A methodological approach —based on simplified index— is proposed in order to assess the protective efficacy of forests on soils (indirect protection). This method is aimed at supporting technicians who are requested to define the most suitable management guidelines and silvicultural treatments.

Area of study: Southern Apennines (Alto Agri district —Basilicata Region— Italy), where a landscape planning experimentation was implemented.

Material and methods: The data to estimate the parameters used for the simplified index calculation are retrieved from a non aligned systematic forest inventory.

The method considers: 1) the tendency towards instability, 2) the protective action of forest cover and 3) different silvicultural options.

Main results: For the analysed forest categories, the results indicate the situations in which hydrogeological hazard is high. The cross-reading of these data with the values based on years of partial and total uncovering of the ground according to different silvicultural options (for each forest category in the reference period of 100 years) has supported the definition of silviculture treatments and management options suitable for the considered forest formations.

Research highlights The proposed method can effectively support technicians in the field by highlighting situations of major hazard risk. Thanks to the joined assessment of different silvicultural options for each forest category, a series of silvicultural treatments, capable of better protecting the soil, can be already defined in the field survey phase.

Key words: Alto Agri district (Italy); Forest Landscape Management Planning (FLMP); management; silvicultural treatment; protective function e soil erosion.

Introduction

In Europe, the protective role of forests was firstly acknowledged in the 3th Ministerial Conference for the Protection of Forests in Europe (MCPFE) held in Lisbon in June 1998. In this occasion, a distinction was made between indirect protection, which referred to the prevention of soil erosion and peak flows (Brag *et al*., 2006), and direct protection from natural damage which was focused on people and their activities (Motta and Haudemand, 2000). In addition, the 5th MCPFE, held in Warsaw in 2007, paid particular attention to water resources with special emphasis on coordination of forest and water resources management policies (Warsaw Resolution 2 "Forests and Water").

These important forest functions included: the protection of water quality and supply, the prevention of floods and landslides, the mitigation of drought effects and the struggle against soil erosion. Thus, it is proposed that an integrated forest-water-soil "vision" ought to be applied in order to orientate management toward sustainability, as was also stated at the Warsaw Conference.

The development of planning systems on a landscape scale appears to be the most appropriate tool to

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analyse all forest features and to define management guidelines in an integrated and ecosystemic approach which considers all the different components (Başkent and Yolasiğmaz, 2000; Cubbage *et al.,* 2007; Schmithüsen, 2007). Landscape planning addresses broad scale forest management, with special attention on land and environmental aspects (such as watersheds, biodiversity, hydrogeological protection, etc.) that cannot be properly considered by referring to a single forest management unit (*i.e.* single forest ownership) (Paletto *et al.,* 2012). Since this level of planning requires a complex series of parameters to evaluate the different functions, it is important that the extensive analysis of the forest as an ecosystem be coupled with a reduction of the costs in the field survey phase. Whereas several methods have already been codified for certain functions (*e.g.* productive function and landscape conservation), others lack the objective elements for an effective quantification. In particular, a gap was found in the definition of a quick method to assess the forest protection against hydrogeological risk.

The protection of the forests in preventing soil erosion is determined by a combination of factors (such as canopy density, dominant height, basal area, regeneration density, density of herb layer, volume and distribution of coarse woody debris, percentage of gap and tree species composition), resulting in effects which in many cases are non-separable (Bebi *et al*., 2001; Chauvin *et al*., 1994; Cosandey *et al*., 2005).

The equation of hydrologic balance constitutes the central thread to assess the influence of forests on hydrologic processes. This feature analyses a series of processes by which forests influence the water cycle (interception, infiltration and evapo-transpiration).

The hydrological cycle of watersheds is affected by canopy interception, which in some cases amounts to 10-30% of the rainfall, but which can even amount to 50% of the rainfall in certain areas (Calder, 1990; Chang, 2006; Waring and Running, 1998).

Interception varies greatly according to the precipitation characteristics (intensity and duration). Interception is greater for rainfall of a shorter duration and intensity (Crockford and Richardson, 1990; Hewlett, 1982). Furthermore, structural parameters of forests such as leaf area and shape, forest density and vertical structure also play a significant role (Chang, 2006). Interception represents an important component of the direct protection that forests provide for soils. The different layers, (tree, shrub, herbaceous, moss and leaf litter), prevent a part of the rainfall from directly hitting the ground, by dissipating most of the kinetic energy of the raindrops, thereby significantly softening the impact of the rain on the ground.

The present paper proposes a methodological approach which is based on simplified index, in order to assess the protective efficacy of forests on soils (indirect protection) at the landscape level. This method is, therefore, aimed at supporting technicians who are requested to define the most suitable silvicultural and management guidelines. A case study, in the framework of a landscape planning in the Italian Southern Apennines, is presented.

Materials and methods

Study area

Alto Agri district, located in the Basilicata Region, southern Italy (40° 20’ 25” N; 15° 53’ 52” E), occupies a surface of 72,559 ha. Geographically, the territory is characterised by a valley, through which the Agri river flows. The basin is mainly a mountainous configuration with steep slopes and a few plains. The average altitude is 650 m a.s.l. and only 20% of the area is below 300 m a.s.l. The hydrogeological network is characterized by a irregular regime. The annual and monthly data on precipitation indicate a considerable amount of rain, with a mean annual precipitation between 767 mm and 1,168 mm. A typical Mediterranean trend is evident, with a minimum during summer and a maximum during winter and the rainfall pattern is highly variable.

The mean annual temperature is 12.6°C. The coldest month is February, with an average temperature of 3.8°C, whereas the hottest month is August, with an average of 22.6°C. The above mentioned features demonstrate the hydrogeological vulnerability of the territory. Hence forests are extremely important in protecting both the soil and water.

The forest surface area covers 42,367 ha, which is equal to 58.4% of the entire territory. The present research considers the main forest categories of the Alto Agri district (oak, beech and black pine forests), which cover a surface area equivalent to 83.3% of the forest surface.

Forest formations with a prevalence of oaks are: i) type with a prevalence of Downy Oak (*Quercus pubescens* Willd.), (37% of total forest surface); ii) type with a dominance of Turkey Oak (*Quercus cerris* L.)

(23% of total forest surface). Currently, around 70% of oak forests are managed as coppice. High forests are equally distributed among those with asexual origin, which were derived by the conversion of coppices, and from those with sexual origins.

Beech forests, consisting of a generally monospecific formation of *Fagus sylvatica* L., cover 11.6% of the forest surface. Of these, 80% are high forests originated from coppices. Presently, the management of these formations is less intensive than in the past, due to a lower demand for firewood.

The *Pinus nigra* subsp. laricio (Poir.) mountain forests were originally artificial plantations and presently occupy a total surface of 11.7%. These formations are monospecific and show a one-storey structure. The main function of these forests is the hydrogeological protection.

Methodological approach

The data for the statistical definition of the territory and the functions of different land uses are gathered with the aid of a non aligned systematic inventory, which is stratified according to the forest categories (Cantiani *et al*., 2010).

As a reference classification system for the basic cartography, the CORINE land cover (EEA, 2009) European classification until level III was adopted. A specific classification was assembled for the forests which was based on the use of a homogeneous cultivation subcategory. This feature was ranked as an intermediate between the forest category and the forest type, and took into account both the forest system and possible treatments of the wood (Agnoloni *et al*., 2009).

During the field survey the description of the forest focuses on collecting site data, analysing the condition of the soils, such as eventual geological instability, and studying the structure of the vegetation including the tree, shrub and herbaceous layers. A total of 307 circular sampling plots of 0.5 ha are classified. The information is then entered into a Geographical Information System (GIS), which is built on the regional forest map.

The data to estimate the parameters used for the simplified index calculation are retrieved from the non aligned systematic inventory database.

The method to assess the protective efficacy of forests on soils (indirect protection) considers three different aspects: 1) the tendency towards instability, which is the sum of the orographic features that may influence erosion, 2) the protective action of forest cover and 3) different silvicultural options.

Regarding the *tendency towards instability*, it depends on numerous factors, of which the mode of action and importance are only partially known. Slope is considered one of the most important morphologic variables for the stability of mountain sides, although the effect exerted by slope varies greatly according to the different substrate typologies (Carrara *et al*., 1992; Guida *et al*., 1979; Megahan, 1979). For these reasons, slope is used as a proxy. For each inventory plot, the forest slope is calculated with the aid of a Geographical Information System (GIS) and then ranked in a class soil erosion risk. According with the method proposed by Scrinzi *et al*. (2006), for the present research, six classes are distinguished as reported in Table 1.

Regarding the *protective action of forest cover*, similarly to what happens for slope, it depends on various aspects, of which the relevance is only partially known. In reason of the fact that the interception indicates to what extent the quantity of water hitting the soil is reduced, the interception is used as a proxy. The protective action of forest cover is estimated by a Synthetic Index of Protection (SIP), developed starting from the rainfall interception capacity of different forest layers. The specific composition of the stand is the first parameter considered. The interception values for each species, expressed as a percentage of total precipitation, are estimated in accordance with other studies conducted in the Mediterranean area. Forest formations, similar to the case study, in terms of climatic (rainfall regime and temperature) and dendrometric (stage of growth, density and basal area) characteristics are taken into account (Aboal *et al*., 2000; Scarascia Mugnozza *et al*., 2000; Cosandey *et al*., 2005; Llorens and Domingo, 2007). The average interception values for shrub, herbaceous and leaf litter

Table 1. Classes of slope

Slope%	**0-5**	**5-15**	**15-35**	**35-70**	**70-140**	**>140**
Class	Flat	Very gentle	Gentle	Intermediate	Steep	Very steep

Table 2. Mean interception percentages

Layer	Species	Interception % (I)
Tree	Black pine	52
	Beech	22
	Oaks	19
Shrubs	—	15
Herbs	—	15
Leaf litter	Broadleaved	3
	Conifers	5

layer are also derived from published data (Hewlett, 1982; Kenneth, 1996; Wang *et al*., 2005). Considering the above cited papers, in Table 2, the mean percentage interception values of tree, shrub, and herbaceous layers at full degree of coverage, as well as leaf litter presence, are reported. Regarding the tree layer, the three most representative categories (black pine, beech and oak dominant forests) are also considered.

Forest canopy cover can be defined as the percent forest area occupied by vertical projection of tree crowns (Korhonen *et al*., 2006). This parameter is an important variable in studies on natural hazards dynamics (Berger and Rey, 2004) and in models focused on assessing the forest protective function (Bebi *et al*., 2001).

In this research, the degree of canopy cover is surveyed by technicians in the field; for each layer (tree, shrub, herbaceous) and leaf litter it is assessed in order to build the Synthetic Index of Protection (SIP). In particular, tree canopy cover is estimated in each inventory plot by technicians using spherical densiometer (Lemmon 1956). The spherical densiometer is a specific instrument for estimating canopy comprising a convex or concave mirror etched with a grid of 24 squares, within each of which the observer scores canopy cover at four equally spaced points (Paletto and Tosi, 2009). The technician counts the number of dots up to a total of 96 (24 squares subdivided into 4 smaller squares). This number is multiplied by 1.04 in order to obtain the percent of overhead area not occupied by canopy (canopy openness). In the estimation of tree canopy cover, the technicians in the center of plot carried out 4 measurements in the direction of the 4 cardinal points (North, South, East and West) with the spherical densiometer place at the height of 1.3 m. This procedure has been taken in order to decrease the degree of subjectivity in the estimation of tree canopy cover.

For the other layers (shrub, herbaceous) and leaf litter the cover is estimated by technicians using point contact sampling, 21 points 8 meters spaced along a ortogonal cross over each circular sampling plot. The counted contact points are transformed in the degree of cover.

SIP is calculated using the following formula:

$$SIP = C_t \cdot I_t + C_s \cdot I_s + C_h \cdot I_h + C_l \cdot I_l$$

C = Degree of canopy cover/leaf litter cover.
I = Interception.
t = Tree.
s = Shrub.
h = Herbaceous.
l = Leaf litter.

SIP is expressed in classes on a scale of 10, where each class is represented by the central value, respectively.

Regarding *different silvicultural options*, a classification, which takes into account the number of years when the ground may be either partially or totally uncovered according to different silvicultural options, is developed for each forest category and silvicultural options. The usual management treatments and options adopted in the territory are considered (Table 3). A reference period of 100 years is assumed in order to evaluate the years of total/partial uncovering of the ground. This period includes more management cycles for coppices. Using table 3 each plot is classified considering the actual silvicultural treatment and the potential different silvicultural options.

By combining soil erosion risk (Table 1), different silvicultural options lenghts (Table 3) and the SIP index expressed in classes on a scale of 10 —where each class is represented by the central value, respectively — it is possible to choose for each plot the best silvicultural treatment able to ensure the protective function. The last step is to aggregate the results of each plot at the level of the main forest categories and the related forest system.

Results

In the specific of the Alto Agri landscape planning, considering data surveyed from the 307 plots for the tree main forest categories and the related forest system (beech coppices, beech high forests, oak coppices, oak high forests and black pine forests), 3 tables (Tables 4, 5 and 6) have been constructed. The tables indicate the

Table 3. Years of partial and total uncovering of the ground according to different silvicultural options for each forest category in the reference period of 100 years

Forest category	Silvicultural system	Silvicultural option	Treatment	Years of partial uncovering of the ground	Years of total uncovering of the ground
Beech	Coppice	1	Coppice with standards (rotation 35 years)	30	0
	Coppice	2	Coppice selection system	0	0
	Coppice	3	Conversion to high forest with shelterwood felling (rotation 100 years)	30	0
	Coppice	4	Conversion and treatment for permanent renovation	0	0
	Coppice	5	Abandonment of management (no treatment)	25	0
	High forest	1	Shelterwood felling (rotation 100 years)	30	0
	High forest	2	Treatment for permanent renovation	0	0
	High forest	3	Abandonment of management (no treatment)	25	0
Oak	Coppice	1	Abandonment of management (no treatment)	25	0
	Coppice	2	Coppice with standards (rotation 35 years)	18	0
	Coppice	3	Conversion to high forest and treatment with natural renovation (rotation 90 years)	5	0
	High forest	1	Abandonment of management (no treatment)	25	0
	High forest	2	Shelterwood felling (rotation 100 years), with natural renovation (rotation 90 years)	5	0
Black Pine	High forest	1	Treatments for natural renovation of pine —edge felling shelterwood felling— (rotation 90 years)	10	0
	High forest	2	Treatments for natural substitution of species (rotation 90 years)	20	0
	High forest	3	Clear felling with artificial renovation (pine or other species afforestations)	0	10
	High forest	4	Abandonment of management (no treatment)	20	0

Table 4. Slope/SIP for Beech forests category (percentage of sampling for each combination)

SIP	Slope				
	0-5	5-15	15-35	35-70	Total
Coppices					
20	7.7	7.7	23.1	15.4	53.8
30	15.4	15.4	0.0	7.7	38.5
40	0.0	0.0	0.0	7.7	7.7
Total	23.1	23.1	23.1	30.8	100.0
High forests					
20	1.9	1.9	25.9	22.2	51.9
30	3.7	7.4	24.1	13.0	48.1
40	0.0	0.0	0.0	0.0	0.0
Total	5.6	9.3	50.0	35.2	100.0

Table 5. Slope/SIP for Turkey Oak forests category (percentage of sampling for each combination)

SIP	Slope					
	0-5	5-15	15-35	35-70	70-140	Total
Coppices						
10	—	2.3	5.3	1.5	—	9.1
20	1.5	6.8	12.8	9.0	—	30.1
30	8.3	13.5	21.8	14.3	—	57.9
40	0.8	0.8	0.8	0.8	—	3.0
Total	10.5	23.3	40.6	25.6	—	100.0
High forests						
10	—	—	—	—	—	—
20	1.8	8.8	7.0	3.5	—	21.1
30	1.8	17.5	35.1	14.0	1.8	70.2
40	—	3.5	3.5	1.8	—	8.8
Total	3.5	29.8	45.6	19.3	1.8	100.0

Table 6. Slope/SIP for Black Pine forests category (percentage of sampling for each combination)

SIP	Slope					
	0-5	5-15	15-35	35-70	70-140	Total
30	—	—	—	4.0	—	4.0
40	—	—	10.0	8.0	—	18.0
50	—	8.0	20.0	24.0	4.0	56.0
60	—	4.0	14.0	4.0	—	22.0
Total	—	12.0	44.0	40.0	4.0	100.0

situations in which hydrogeological hazard is high (where steep slopes are associated with low values of SIP). The cross-reading of these data with the values of table 3 (which takes into account the years when the ground may be uncovered) has supported the definition of silviculture treatments and management options suitable for the forest formations of the study area.

Beech forests

The Table 4 shows that about 35% of beech high forests are located in areas where steep slopes are associated with low values of protection. Hence, this condition may highlight a high degree of instability. As a matter of fact, about 23% of beech coppices are in this situation; in this forests the coppice selection system (option 2 in Table 3) is chosen as a silvicultural treatment. This treatment, which consists of a periodic partial uptake of coppice shoots on the stump where individuals of different ages grow together (Perrin, 1954), provides permanent ground cover. On the other hand, intensive management is required, thereby rendering it economically unsuitable for the local owners. In other areas, the conversion to high stands with a permanent renovation treatment (option 4) is selected in order to favour an uneven structure. This treatment guarantees a permanent ground cover (Bastien *et al*., 2005) although is fairly expensive. Similarly, high forests located in areas with high degree of instability, 35% of the sample, are decided to apply a permanent renovation treatment.

Oak forests

Almost 20% of the Alto Agri oak high forests grows on areas in which the protective function is prominent than other functions (Table 5). Besides, about 25% of

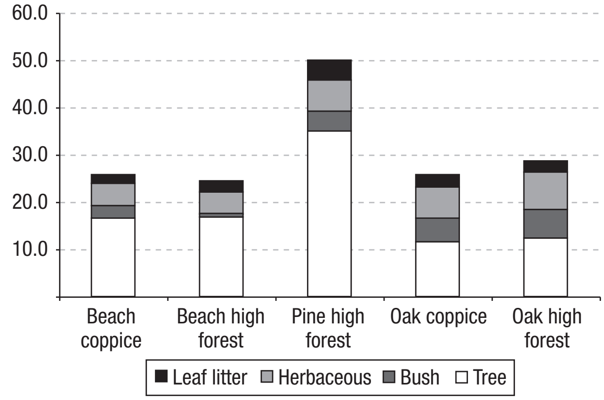

Figure 1. Average value of interception per type of cover, species and silvicultural system.

oak coppices enters into the protective function category. The most of oak coppices are under conversion to high forests managed under shelterwood system. The crucial phase of this treatment is during the period of renovation since the ground becomes partially bare for a relatively long period. Nonetheless, the rapid growth of the shrub and herbaceous cover in the years following felling should counter-balance the effects resulting from the opening of the canopy cover (Fig. 1); careful management practices in all phases of the treatment is, therefore, required. In the other oak coppices, the productive function is reported to be particularly important and the continuity of this management system is chosen as the best option. A correct treatment, in this case, is provided by a limited release of standards with a canopy cover not exceeding 5%, which is equal to about 50 standards per hectare. In this manner, the development of coppice shoots after felling is rapid and the ground is completely covered after 6 years (Cantiani *et al*., 2006; Cutini, 2006).

Black pine forests

The Table 6 shows that 44% of the samples possess a medium to high risk of instability in relation to the slope. Nonetheless, the index of canopy protection is high, since 78% of the samples fall within the class 50 and 60. The points where the protective function is a priority (intermediate slopes are associated with low values of protection, whereas high values of protection are associated with steep slopes), comprise 16% of the total. In these cases, treatments with a natural type of renovation that requires, to certain extent, a long period of total/partial uncovering of the ground, should not be chosen. In addition, the renovation of pine formations requires intense treatments due to the high demand for radiation of this species in the first years (Malcolm *et al.,* 2001). Thus, clear felling on small surfaces (few hectares) with an artificial renovation is considered as the best option. Regarding the species to be replanted, those with canopies having high degree of rainfall interception and, preferably, with persistent crowns are chosen.

Discussion and conclusion

The method applied in the Alto Agri allowed for the main forest categories to highlight the situations of higher risk of instability in relation to slope and to the index of canopy protection. Consequently, it was possible to define the most suitable silvicultural treatments for the different forest categories. In particular, we were able to highlight in which areas traditional silvicultural treatments could be applied. Moreover it was possible to evidence in which areas are most needed silvicultural treatments which provide a continuous canopy cover, ensuring an higher ground protection.

The results of the research are related to the specific forest formations of the Alto Agri and connected to the specific silvicultural treatments of the territory. Nevertheless the method can be adopted in diverse situations, adapting the mean interception values and evaluating the years of uncovering of the ground according to the silvicultural options for the various forest categories.

The present research attempts to provide a preliminary contribution for the most objective evaluation possible of the protective function. In this sense, the present method may represent a useful support structure, in the framework of the assessment of overall multifunctionality, by providing a synthetic and rapid evaluation of how different categories of forests are able to fulfil a protective function. The attributes to be used for this investigation are easily assessable in the field survey phase and no extra data is required, besides that which are already currently collected in order to describe the forest. These features, such as micro-site and structural data, can be effectively acquired only through a direct description, measurement and evaluation of the forest rather than cartographic and remote sensing-based analyses.

Besides, it is important to highlight that this method can be particularly useful in the Mediterranean context where some of the effects of the climate changes (desertification and drought) are going to increase interesting also forest areas and intensify the problem connected to soil protection (De Dios *et al*., 2007; Planinşek *et al*., 2011).

The authors are aware that the proposed method presents some limits, as: a general lack of knowledge concerning this topic in the scientific and technical literature, the complex water-forest-soil relationships are only partially taken into account, the uncertainties linked to the values of mean interception percentages of the different layers (Table 2) and the necessity to consider exposure.

Nevertheless, this method may effectively support technicians in the field by highlighting situations of major risk. Thanks to the joined assessment of different silvicultural options for each forest category, a series of silvicultural treatments, capable of better protecting the soil, can be already defined in the field survey phase.

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