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Review paper

Exploring forest infrastructures equipment through multivariate analysis: complementarities, gaps and overlaps in the Mediterranean basin

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Abstract - The countries of the Mediterranean basin face several challenges regarding the sustainability of forest ecosystems and the delivery of crucial goods and services that they provide in a context of rapid global changes. Advancing scientific knowledge and fostering innovation is essential to ensure the sustainable management of Mediterranean forests and maximize the potential role of their unique goods and services in building a knowledge-based bio-economy in the region. In this context, the European project FORESTERRA ("Enhancing FOrest RESearch in the MediTERRAnean through improved coordination and integration") aims at reinforcing the scientific cooperation on Mediterranean forests through an ambitious transnational framework in order to reduce the existing research fragmentation and maximize the effectiveness of forest research activities. Within the FORESTERRA project framework, this work analyzed the infrastructures equipment of the Mediterranean countries belonging to the project Consortium. According to the European Commission, research infrastructures are facilities, resources and services that are used by the scientific communities to conduct research and foster innovation. To the best of our knowledge, the equipment and availability of infrastructures, in terms of experimental sites, research facilities and databases, have only rarely been explored. The aim of this paper was hence to identify complementarities, gaps and overlaps among the different forest research institutions in order to create a scientific network, optimize the resources and trigger collaborations.

Keywords - FORESTERRA, infrastructures, multidimensional scaling, Mediterranean countries

Introduction

The countries of the Mediterranean basin, as well as those of other geographical areas with a Mediterranean climate, are facing problems regarding the sustainability of forest ecosystems and the provision of essential goods and services, in a context of rapid global change (Lindner 2010, Lafortezza et al. 2013).

The Mediterranean forest regions cover areas typically characterized by high intrinsic diversity in several inter-related aspects: ecological, environmental, cultural, economic, social and historical (Scarascia Mugnozza et al. 2000, Fabbio et al. 2003). For this reason it is important to advance scientific knowledge and promote innovation, which is essential to ensure the sustainable management of Mediterranean forests, maximizing the potential role of their goods and services in building a knowledge-based bio-economy of the region (Croitoru 2007, Merlo and Rojas 2000). The FP7 European Project FORESTERRA ("Enhancing FOrest RESearch in the MediTERRAnean through improved coordination and integration") has the objective to strengthen scientific cooperation on Mediterranean forest research through the integration and harmonization of research, infrastructure and existing databases through an ambitious transnational framework to reduce the fragmentation of existing forest research and maximize its impact (http://www.foresterra.eu/).

There are a number of regional organizations and research projects that collect data and compile information relevant to Mediterranean forests and related issues, such as FAO Silva Mediterranea Committee, AIMF, Biodiversity International, Blue Plan, CIHEAM, CIRCE of INGV, CMA and SEL of CRA, EFIMED, FOREST EUROPE, JRC (in particular EFFIS for forest fires), MMFN, OFME, UNECE, URFM of INRA, WWF, LFCC process, etc. (FAO 2011). Yet, each of these entities looks at this issue from different perspectives by collecting data in response to specific questions and needs or with a geographic focus which only embeds a part of the

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Mediterranean rim. The resulting evidence is that forest research in the Mediterranean is poorly exchanged and unequally developed (Saket 2002). In fact, while forest research is well developed in some European countries like France, Spain and Italy, its development is significantly lower in other countries where few resources are allocated to forest research (Palahi et al. 2008, Scarascia Mugnozza et al. 2000). Such gaps are particularly evident when dealing with infrastructures. In this perspective, the identification of Mediterranean countries whose level of forest research development and infrastructure equipment is different provides an opportunity to enhance the general level and to improve the quality of forest research in the area as a whole (Turner et al. 2003).

To the best of our knowledge, the equipment and availability of infrastructures, in terms of experimental sites, research facilities and databases, have only rarely been explored. Other scientific disciplines tried to analyze such issue (e.g. Kennedy et al. 2008), but no attention has been paid to forest research infrastructures so far.

According to the European Commission, research infrastructures are facilities, resources and services that are used by the scientific communities to conduct research and foster innovation (http://eurofed.stis.belspo.be/eurofed.asp?id=300;100;400&lang=en). They include: major scientific equipment (or sets of instruments); knowledge-based resources such as collections, archives or scientific data; e-infrastructures, such as data and computing systems and communication networks; and any other infrastructure of a unique nature essential to achieve excellence in research and innovation.

Research infrastructures play an increasing role in the advancement of knowledge and technology and of their exploitation (Archibugi and Pietrobelli 2003). Research infrastructures help structuring the scientific community and play a key role in the construction of an efficient research and innovation environment by offering high quality research services to users from different countries, by attracting young people to science and by networking facilities towards open, interconnected, data-driven and computer-intensive science and engineering.

In this perspective, within the framework of FORESTERRA project, the aim of this paper is twofold: (i) making a survey of the types of forest infrastructures available across the Mediterranean basin and (ii) identifying complementarities, overlaps and gaps among the different Mediterranean countries in terms of forest infrastructures, in order to create a scientific network, optimize the resources and trigger future collaborations.

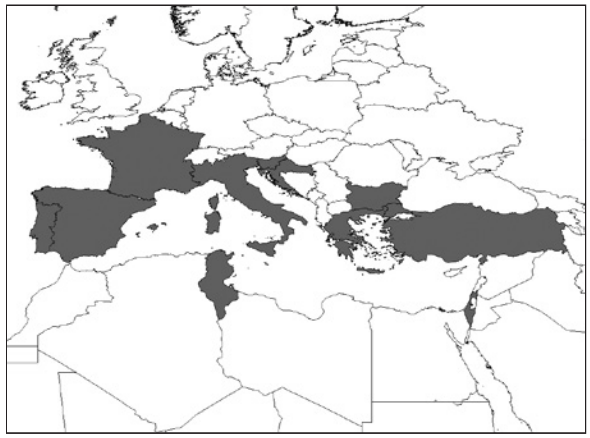

Figure 1 - Location of the FORESTERRA countries analyzed.

Study area

The Mediterranean basin extends for 3,800 km from east to west, starting from the head end of Portugal to the shores of Lebanon, and about 1,000 km from north to south, from Italy to Morocco and Libya. In the European Union, seven Member States are included in the Mediterranean region, some only partially (France, Portugal, Italy, Spain), wholly others (Greece, Malta, Cyprus).

All areas of the Mediterranean region are home to site-specific wild animals and plants, with a large number of species not detectable anywhere else in the world. The rate of endemism is exceptionally high: over half of the 25,000 flowering plants identified to date in the region, equivalent to about 10% of all known plants on Earth, is made up of endemic species. Mediterranean is thus among the areas of the world with the highest biodiversity (Mittermeier et al. 2004, Underwood et al. 2009).

Data

The FORESTERRA questionnaires on infrastructures were generated by reviewing and amending similar initiatives carried out previously (e.g. ERANET-ARIMNET and JPI-FACCE). A Mediterranean forestry research framework database was hence generated from the information gathered from the questionnaires received from eleven Mediterranean countries of the FORESTERRA Consortium: Spain, France, Italy, Turkey, Portugal, Tunisia, Bulgaria, Slovenia, Croatia and Greece (Fig. 1).

We detected nine-teen types of infrastructures (Tab. 1) covering the forest research activities of the FORESTERRA countries analyzed. We excluded from further analysis the infrastructures common to all countries: Experimental plantation & Forest research site for long-term monitoring; Forest Genetics and Biotechnology Lab; Forest Nursery, Rhizo/

Table 1 - List of forest infrastructures recorded through the questionnaires.

INFRASTRUCTURES
1. Arboretum, Forest genetic trial, Seed bank & Seed lab
2. Biomass, Economics & Wood Technology labs
3. Botanical garden & Botany lab
4. Carbon flux towers
5. Eco-physiology lab
6. Environmental, GIS and Forest Geomatics labs
7. Experimental plantation & Forest research site for long-term monitoring
8. Fire ecology labs
9. Forest Biochemistry lab
10. Forest Genetics and Biotechnology lab
11. Forest Hydrology lab
12. Forest Nursery, Rhizo/Phytotrons & Micropropagation lab
13. Forest Protection lab (entomology and pathology)
14. Meteorological station, lab & field equipments for climate change studies
15. Mobile Lab Unit
16. Silviculture & Forest biometry lab
17. Soil lab
18. Stable isotopes & Chemistry labs
19. Wood harvesting, Mechanization, Trasportation & Ergonomics lab

Phytotrons & Micropropagation lab; Meteorological station, lab & field equipments for climate change studies; Stable isotopes & Chemistry labs.

Methodology

A data matrix X was created having dimension i, j where i is the number of different types of research infrastructure while j is the number of considered countries. The matrix element x_{ij} was set up to one if the j-th country owns the i-th infrastructure, or to zero when such infrastructure is not present in the country.

The row vector x_i represents the distribution of the i-th infrastructure i within countries. The column vector x_j represents the infrastructural endowment of the country. A country owning all (none) infrastructure would have a vector x_j having all "1" (or "0").

The analysis was carried out in three steps. In the first step we analyzed the simple ordering of countries by number of infrastructures owned and of infrastructures by number of countries in which it is distributed. Then, we analyzed the relationships between pairs of countries in terms of mutual complementarities of infrastructures. In the last step we made use of multidimensional scaling technique to determines groups of countries similar by infrastructural equipment (Salvati and Zitti 2009). This allows to highlight common patterns of specialization.

The simple ordering of countries and infrastructures (step 1) was obtained by respectively summing the elements of the correspondent column or row vectors:

$$C_j = {}_i\sum x_{ij} \qquad R_i = {}_j\sum x_{ij}$$

In the step 2, we created the square matrixes I having dimension jxj in which each element represents a relationship between a pair of countries. Such relationship is expressed by the mean of a complementarity index between the two countries $j1$ e $j2$. We created three matrixes that correspond to three different complementarity indices: a general complementarity index I^1, a specific complementarity index I^2 and a relative specific complementarity index I^3. The general complementarity index I^1 represents the number of different infrastructures that are owned by one and only one of the two countries divided by the total number of different infrastructures I:

$$I^1_{j1,j2} = [{}_i\sum |x_{ij1} - x_{ij2}|] / I$$

It takes maximum value 1 when the two countries are perfectly complementary without overlapping; it takes the minimum value of 0 when the countries own exactly the same kind of infrastructures. This index is symmetric (i.e. the value does not change inverting the two countries $j1$ and $j2$) and thus the matrix I^1 is symmetric. We can interpret this index as the overall result of a partnership between the two countries.

The specific complementarity index I^2 represents the number of infrastructures missing in the country J^1 and owned by the country J^2, divided by the total number of different infrastructures J:

$$I^2_{j1\,j2} = [{}_i\sum (1-x_{ij1})\, x_{ij2}] / I$$

It takes the maximum value 1 when the country j^1 has no infrastructure while country J^2 has all the kind of infrastructures considered; it assumes the minimum value 0 when the countries have the same kind of infrastructures. It can be considered as a proxy for the effect of the partnership between the two countries from the point of view of country $j1$.

The relative specific complementarity index I^3 represents the number of infrastructure missing in the country J^1 and owned by the country J^2, divided by the number of infrastructures missing to the country J^1:

$$I^3_{j1,j2} = [{}_i\sum (1-x_{ij1})\, x_{ij2}] / [{}_i\sum (1-x_{ij1})]$$

It takes the maximum value 1 when the country J^2 has all the infrastructures missing to the country J^1. It takes the minimum value 0 when the country J^2 has none of the infrastructures missing in country J^1. It can be considered as the relative effect of the partnership between the two countries from the point of view of country J^1.

Finally, to determine a two-dimensional clas-

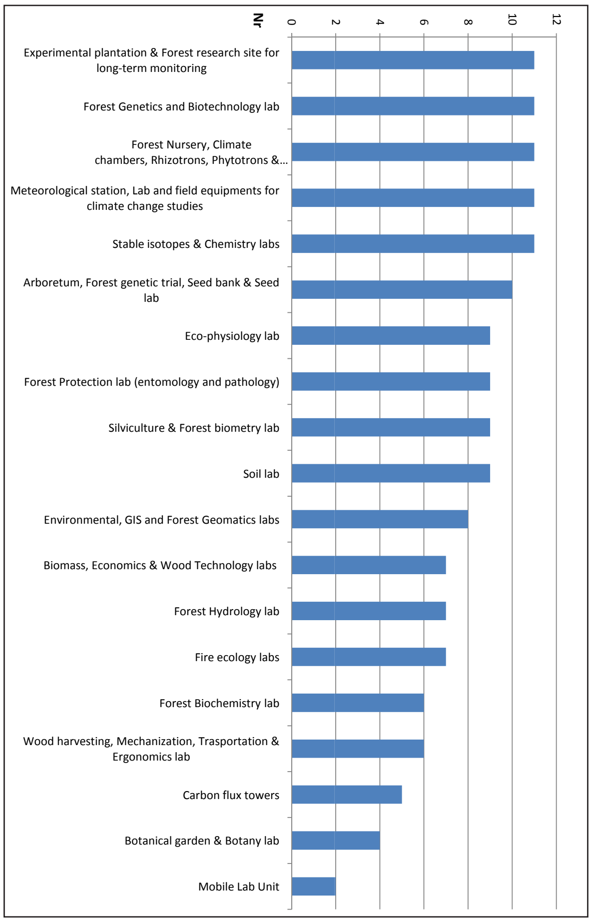

Figure 2 - Frequency graph of the infrastructures belonging to the forest research institutes of the FORESTERRA countries.

sification of the infrastructural systems among the different countries, we performed a Multi-Dimensional Scaling (MDS) analysis. MDS is a means of visualizing the level of similarity of individual cases of a dataset. It refers to a set of related ordination techniques used in information visualization, in particular to display the information contained in a distance matrix. An MDS algorithm aims to place each object in N-dimensional space such that the between-object distances are preserved as well as possible. Each object is then assigned coordinates in each of the N dimensions. The number of dimensions of an MDS plot N can exceed 2 and is specified a priori. Choosing N=2 optimizes the object locations for a two-dimensional scatterplot (Borg and Groenen 2005, Honarkhah and Caers 2010).

Starting from the matrix X, we set up the square matrix of scalar products $P=X^TX$ having dimension JxJ (which corresponds to the matrix of the indices I^1 multiplied by J). We decided to apply an Euclidean metric to the matrix of distances between countries.

We applied to this matrix the dimensional reduction by finding sequentially the vectors that minimize a loss function of the distances from the points d.

Results and Discussion

The analysis allowed to identify the geographical distribution of the forest infrastructures across Mediterranean countries, identifying the most and the less common infrastructure (Fig. 2) and the most and less endowed country (Tab. 2).

Table 2 - Ranking of countries by endowment of infrastructures.

FORESTERRA countries	Nr. of infrastructures
Italy	18
Turkey	17
Spain	17
France	17
Greece	16
Slovenia	15
Israel	14
Portugal	13
Croatia	11
Tunisia	9
Bulgaria	6

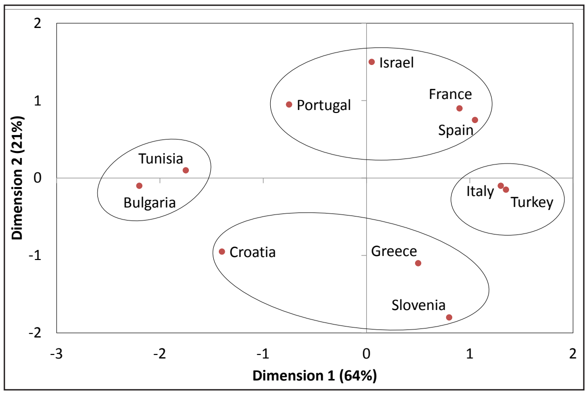

Figure 3 - Scatter plot of the MDS analysis.

The MDS analysis in two dimensions had a data fitting of about 85% (depending on Mardia's Fit Measure) with 64% in the first dimension and 21% of the second, respectively (Fig. 3). The first dimension summarizes the infrastructure that are substantially more common (greater weight to more variables present). Essentially, it repeats the ranking by number of infrastructure. While Turkey and Italy are almost overlapping and are well represented by the first dimension, the second dimension shows two models of specification in the countries immediately following in the list: on the one hand, Slovenia, Greece and Croatia, on the other Israel, Portugal , France and Spain. Bulgaria and Tunisia are confirmed to be poorly endowed by general infrastructure, and not equipped of specific infrastructure. The intermediate position on this dimension of the countries most endowed is compatible with the presence in these countries of both types of specializations.

Looking at the original data (not shown here), it is possible to identify the specific infrastructures that characterize the groups of countries classified by the second dimension: Carbon Flux Towers; Forest Biochemistry lab; Forest Nursery, Rhizo/Phytotrons & Micropropagation lab; Stable isotopes & Chemistry labs, for the countries at the top of the figure; Botanical garden & Botany lab; Eco-physiology lab; Arboretum, Forest genetic trial, Seed

Table 3 - Matrix of indices of general complementarity (number of complementary infrastructures on total infrastructure).

	Italy	Turkey	Spain	France	Greece	Slovenia	Israel	Portugal	Croatia	Tunisia
Turkey	15%	-								
Spain	20%	15%	-							
France	30%	25%	10%	-						
Greece	40%	25%	40%	40%	-					
Slovenia	35%	30%	45%	55%	45%	-				
Israel	40%	35%	20%	20%	60%	65%	-			
Portugal	45%	40%	35%	35%	55%	60%	25%	-		
Croatia	65%	70%	55%	55%	55%	50%	55%	50%	-	
Tunisia	65%	60%	55%	55%	55%	60%	45%	20%	40%	-
Bulgaria	80%	75%	70%	70%	60%	75%	50%	35%	35%	25%

Table 4 - Matrix of indices of specific complementarity (number of infrastructures obtained in the partnership by the row country on total infrastructure).

	Italy	Turkey	Spain	France	Greece	Slovenia	Israel	Portugal	Croatia	Tunisia	Bulgaria
Italy	-	5%	10%	5%	10%	5%	5%	0%	5%	0%	0%
Turkey	10%	-	10%	5%	5%	5%	5%	0%	10%	0%	0%
Spain	20%	15%	-	5%	15%	20%	0%	0%	5%	0%	0%
France	15%	10%	5%	-	15%	15%	0%	0%	5%	0%	0%
Greece	30%	20%	25%	25%	-	20%	25%	15%	10%	5%	0%
Slovenia	30%	25%	35%	30%	25%	-	30%	20%	10%	10%	10%
Israel	35%	30%	20%	20%	35%	35%	-	5%	15%	5%	0%
Portugal	45%	40%	35%	35%	40%	40%	20%	-	20%	0%	0%
Croatia	60%	60%	50%	50%	45%	40%	40%	30%	-	15%	5%
Tunisia	65%	60%	55%	55%	50%	50%	40%	20%	25%	-	5%
Bulgaria	80%	75%	70%	70%	60%	65%	50%	35%	30%	20%	-

Table 5 - Matrix of indices of relative specific complementarity (number of infrastructures obtained in the partnership by the row country on total infrastructure missing to the same country).

	Italy	Turkey	Spain	France	Greece	Slovenia	Israel	Portugal	Croatia	Tunisia	Bulgaria
Italy	-	50%	100%	50%	100%	50%	50%	0%	50%	0%	0%
Turkey	67%	-	67%	33%	33%	33%	33%	0%	67%	0%	0%
Spain	100%	75%	-	25%	75%	100%	0%	0%	25%	0%	0%
France	75%	50%	25%	-	75%	75%	0%	0%	25%	0%	0%
Greece	100%	67%	83%	83%	-	67%	83%	50%	33%	17%	0%
Slovenia	86%	71%	100%	86%	71%	-	86%	57%	29%	29%	29%
Israel	88%	75%	50%	50%	88%	88%	-	13%	38%	13%	0%
Portugal	82%	73%	64%	64%	73%	73%	36%	-	36%	0%	0%
Croatia	92%	92%	77%	77%	69%	62%	62%	46%	-	23%	8%
Tunisia	87%	80%	73%	73%	67%	67%	53%	27%	33%	-	7%
Bulgaria	89%	83%	78%	78%	67%	72%	56%	39%	33%	22%	-

bank & Seed lab for the countries in the lower part.

In conclusion, we can classify the forest research infrastructures equipment of the analyzed countries in four groups:

1) countries characterized by the presence of nearly all the infrastructure, consisting on Italy and Turkey;
2) countries with only a few general infrastructure (Tunisia and Bulgaria);
3) a "West Europe and Israel" model with large occurrence of Carbon Flux Towers, Forest Biochemistry lab, Stable isotopes and Microscopy Lab & Chemistry labs, composed of Israel, which is the most characteristic country of the group, and three Western Mediterranean countries (Portugal, France and Spain);
4) a "Balkan" model with large occurrence of Botanical garden & Botany lab, Eco-physiology lab and Arboretum, Forest genetic trial, Seed bank & Seed lab, composed of Slovenia, Greece and Croatia (which has less infrastructure but more specific than group 2).

Consequently, as also suggested by the complementarity indices analysis (Tab. 3, Tab. 4 and Tab. 5), while for the group 2 is necessary to develop agreements with most endowed countries (group 1 but also some in groups 3 and 4), bilateral partnerships could be fruitful in particular for groups 3 and 4 considering the different pattern of specialization. The unique bilateral partnership that allows full coverage are those integrating Italy (which also has the specific infrastructure of the two specialized models) with France or Greece. Agreements among more than two countries should include members of all the four groups.

Conclusions

In a framework of scientific and technical forest research, this study may help to: (i) foster coordination and integration of forest research activities at European level; (ii) endorse the multidisciplinary approach to address new research challenges through closer cooperation between different research fields (silviculture, ecology, physiology, climatology, molecular biology, pathology, wood technology, etc.); (iii) increase scientific and technical excellence; (iv) make easier the access to complementary research facilities and expertise between national and international institutions, optimizing the use of technical resources; (v) create support studies on the multifunctionality of the European forests.

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Research paper

Empirical modelling of chestnut coppice yield for Cimini and Vicani mountains (Central Italy)

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Abstract - The prescription of stand rotation according to site conditions and economic targets requires yield information that expresses stand productivity under different site-classes. This is particularly relevant for the optimal management of chestnut coppices allowing the production of timber assortments sized differently. This paper reports a new yield model built for chestnut coppices of the Cimini and Vicani mountains (Central Italy), according to three site index classes. The model focuses on the development of stands after an intense thinning carried out at the ages of 13-14 years. The model is compared with two previous yield tables built for chestnut coppice forests living in the same area and including one site index class only. The study stresses the high productivity of chestnut coppices growing on the volcanic soils of Cimini and Vicani mountains and shows how the growth course following intense thinning allows to get stems with large mean volume at the end of rotation. In the light of the most recent studies on the causes of ring shake, i.e. the most relevant defect of chestnut wood, the negative consequences on timber quality originating from the current thinning regime are also outlined.

Keywords - forest management, yield table, thinning, rotation length

Introduction

Coppice is a silvicultural system extensively applied in Italy and in other Mediterranean countries to get quite exclusively firewood under relatively short rotations. Coppice management is based on cultivation techniques that generally result in the simplification of forest composition and structure to the benefit of wood production (Ciancio and Nocentini 2004).

According to the National Forest Inventory (Gasparini and Tabacchi 2011), coppices cover about 35% (i.e. 3.7 million hectares) of the forest area. Within the coppice area, chestnut (*Castanea sativa* Mill.) coppices are a case apart because this fast-growing species produces a wide range of easily marketable and quality assortments for agriculture, constructions, furniture and leather tanning industry.

In Italy, chestnut forests cover an area of 0.8 million hectares (Gasparini and Tabacchi 2011): 70% are managed as coppices with standards and the remaining 30% as orchards for fruit production. In the early fifties of the last century, the relationship between the two forms of cultivation was reversed compared to nowadays and it has been turning over time following the socio-economical changes affecting the rural areas and the spread of two destructive fungi causing, respectively, the chestnut blight (*Cryphonectria parasitica*) and the ink disease (*Phytophthora cambivora*). The domestic production of chestnut wood barely exceeds 0.9 Mm^3 per year, 63% being represented by timber assortments (ISTAT 2002). The current annual increment of chestnut stands is 5 Mm^3 (Gasparini and Tabacchi 2011): that means that the harvested volume could be significantly increased.

The rising demand of renewable resources, the versatility of the raw material also supported by technological innovation by the wood industry, and the need to diversify the productive activities in rural areas, are all together favourable factors to increase domestic chestnut wood yield. This perspective might be however hindered by the fragmentation of private forest land ownership and the inadequate organization of wood supply chain that makes difficult to guarantee the continuity in the supply and the quality of available products, as well (Pettenella 2001).

In the past, timber assortments from chestnut coppices were frequently characterized by relatively low economic value, mainly because of the small average size of the shoots at the end of cutting cycle, since relatively short rotations (16 to 20 years) were adopted, usually without any thinning. By contrast, in recent years, new management schemes based on longer rotations and selective thinnings, accord-

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ing to site condition and socio-economic context, have been experimentally developed to increase the timber value (Amorini and Manetti 2002, Lemaire 2009a). Research trials showed that gradual thinnings are being able to promote regular and moderate growth of tree rings, thus reducing the occurrence of ring shake, a chestnut wood defect that can significantly lower its commercial value (Fonti et al. 2002, Cosseau and Lemaire 2009).

The improvement of the quality of chestnut timber from coppices should take into duly account rotation lengths suited to growth potential under various site conditions. This asks for effective tools to assess the growth potential of chestnut coppice stands with respect to a given site.

In Italy, the available yield tables show the high productivity as well as the variability of chestnut coppices in terms of mean volume increment, it varying between 9 and 21 m^3 per hectare per year (Corona et al. 2002). However, most of the available yield tables are not framed by site-classes, thus limiting their use as operative support to silvicultural and management decision processes. This is the case of chestnut coppices on the Cimini and Vicani mountains in Central Italy, growing under a suitable environment for chestnut but variable as to ground slope, aspect and soil conditions. Two yield tables are available for these coppices: the first one is referred to the entire area of the Cimini and Vicani mountains (Cantiani 1965), whilst the second one is referred to coppices growing on the North-West slopes of these mountains (Lamani 1993); both tables are established with reference to an unique site-class and take into account rotations and thinning regimes no longer applied.

In the light of these considerations, the objectives of this study are to: a) building up a new empirical yield model for chestnut coppices of the Cimini and Vicani mountains, framed by site-classes and based on the most common thinning regime currently applied; b) comparing the new model with the preexisting ones to integrate knowledge about chestnut coppices in the studied woodland.

Study area

The Cimini and Vicani mountains are located in the north of Latium region. Pyroclastic rocks and lavas form the geological substrate of the relieves (Chiocchini 2006); soils, classified as andisols and identified as “black soils”, are fertile, deep and loose with acid pH (Bernetti 1959). Mean annual temperature is 12.8°C. The hottest month is July with an average temperature of 22°C, and January is the coldest one (4.2°C). The minimum temperature is just below zero (-2.1°C). Annual rainfall ranges between 1,250 mm and 1,550 mm; summer drought is not actually recorded thanks to the humid air coming from the Thyrrenian Sea and the nearby Vico Lake, although a sub-arid period between July and August may occur (Blasi 1994).

The forest area is about 220 km^2, mostly covered by oak and chestnut coppices. Turkey oak (*Quercus cerris* L.) and beech (*Fagus sylvatica* L.) high forests characterize the flat top of Mount Cimino (1,053 m a.s.l.) and the west side of the Vico Lake valley. Public forest estates (mostly municipal) extend for several hundred hectares whilst the private ownership is very fragmented. Chestnut coppices grow in monospecific stands on about 8,000 hectares, between 550 m and 950 m a.s.l.. Their monospecificity is due either to the applied silvicultural practices and to the environmental conditions (distinctively, the volcanic soils where chestnut finds its optimal growth conditions).

An average of about 200 hectares of chestnut coppices are harvested or thinned per year. Rotation length ranges between 16 and 20 years (19 years, on average) under private properties and between 18 and 25 years (23 years, on average) under public properties. Chestnut coppices are usually thinned once at ages of 13-14 years. In a few public estates a second thinning is occasionally carried out 3-5 years before the end of the rotation. This study is focused on modelling coppice growth after the unique thinning usually applied.

Materials and methods

Three forest estates where chestnut coppices are prevailing were considered: the municipal property of Soriano nel Cimino along the slopes of Mount Cimino; the regional property near the village of San Martino al Cimino; the Mount Palanzana, where many small privately-owned stands are located. In each forest estate, five thinned stands of various ages (from 14 to 31 years) were selected. The boundaries of the selected stands were identified on colour ADS40 2008 aerial orthophotos (nominal geometric resolution: 1 m).

Three circular sample plots with 10-m radius were established in each stand, for a total of 45 plots. The location of plot center was randomly selected and reached in the field by GPS with sub-metric accuracy. In each sample plot the following attributes were measured: diameter at breast height (dbh) of live and dead shoots and standards, height of a sample of 15 shoots and the age of shoots, assessed by a tree corer on the stems of average dbh.

The following stand parameters were calculated: number of shoots (live and dead) per hectare, number of standards per hectare, mean and dominant dbh of shoot and standard layer, mean and top height of shoots, wood volume of shoots and of standards. Top height was calculated as the regression height of the shoots with quadratic mean diameter of the 100 thickest shoots per hectare (Van Laar and Akca 2008). The wood volume was calculated through the volume tables by Castellani et al. (1984), the same used by Lamani (1993).

The collected data were used to establish a model predicting the top height of shoots (TH, in meters) as a function of stand age (A, in years). The anamorphic model proposed by Schumacher (1939) was adopted, as suggested by von Gadow and Hui (1999):

$$TH = b_0 \cdot \exp\cdot(-b_1 \cdot \frac{1}{A}) \qquad [1]$$

From this relationship, the site-index curve was derived (Sharma et al. 2002, Skovsgaard and Vanclay 2008), that is the predictor of site index (SI) from TH measured at a given age. SI is a standardized indicator of stand productivity, i.e. the stand top height at a selected index age. In this case, the age of 20 was chosen as index, since this is the average age of the sampled stands:

$$SI = TH * (\exp\cdot(9.777 / A) / 1.63044) \qquad [2]$$

Then, regressions were established to model the stand growing stock (V, in m^3 per hectare) and the number of shoots per hectare (N) as a function of A and SI under a bio-mathematically sound perspective (Corona 1995):

$$\hat{V} = SI^{c_1} * \exp(-\frac{c_2}{SI * A^2}) \qquad [3]$$

$$\hat{N} = m_0 + m_1 / \sqrt{A} + m_2 * SI \qquad [4]$$

where c_1, c_2, m_0, m_1 and m_2 are the model coefficients to be estimated.

From V and N the mean volume of a single shoot ($\hat{v}$, in m^3) can be calculated:

$$\hat{v} = \hat{V} / \hat{N} \qquad [5]$$

Since number of standards proved to be no-correlated with A (r = -0.08) and with SI (r = -0.1), it was deemed suitable to keep constant this stand parameter, i.e. equal to the average number of standards found in sample plots.

The total volume of standards is equal to their number times the mean volume of a single standard ($\hat{v}_{st}$, in m^3), which, in turn, was predicted as a function of SI and A under a bio-mathematically sound perspective:

$$\hat{v}_{st} = SI^{f_1} * \exp(-\frac{f_2}{SI * \sqrt{A}}) \qquad [6]$$

where f_1 and f_2 are the model coefficients to be estimated.

Results

Tab. 1 shows the statistical parameters of [1]-[3]-[4] and [6] models; all the model coefficients are characterized by p<0.01. Tab. 2 reports the resulting yield for chestnut coppices of the Cimini and Vicani mountains according to SI values equal to 14 m, 17 m and 20 m, corresponding to the site index range in the studied area (Fig. 1).

Site-index stresses the positive effect of thinning on stand volume and, especially, on mean volume of a single shoot, which doubles at age of 30 years moving from a site class to the upper one (Fig. 2). Mean increment culminates between 18 (SI=20) and 22 (SI=14) years, ranging from 7.2 to 13 m^3 per hectare per year. In the yield table of Lamani (1993) mean increment culminates at the age of 21 with 13.8 m^3 per hectare per year and the curve of top height as a function of age overlaps quite well the same relationship in our new yield model with SI=17.

The comparison with the yield table of Cantiani (1965) is difficult because height values are lacking here; then, the Eichhorn's rule (Eichhorn 1902, in Skovsgaard and Vanclay 2008) was applied. According to this rule, total production of wood volume at a given stand height is independent of age and site for a given site and species. It was used to attribute a SI value: in the Cantiani yield table the total volume at the age of 18 is 367 m^3 per hectare; in the yield table of Lamani this volume corresponds to an age of 21-22 and to a top height of about 17 m. In our new model top height of 17 m and age of 18 are equivalent to a SI between 17 and 20 m. This result is in agreement with data sampling in the most productive chestnut forests only, as for the yield table by Cantiani (1965).

Table 1 - Statistical parameters of yield models established for chestnut coppices of the Cimini and Vicani mountains.

Model	Coefficients	Value	Stand. Err.	R^2
[1]	b_0	27.333	2.280	0.458
	b_1	-9.777	1.589	
[3]	c_1	2.103	0.021	0.743
	c_2	3269.445	388.500	
[4]	m_0	2564.157	978.050	0.412
	m_1	11599.748	3277.014	
	m_2	-197.046	41.359	
[6]	f_1	0.663	0.169	0.375
	f_2	186.192	40.640	

What most distinguishes the three yield models is the curve describing the development of shoot number as a function of age, which highlights the difference in the rotation length and thinning occurrence (Fig. 3). The yield table by Cantiani stipulates

Table 2 - Yield predictions for chestnut coppices of the Cimini and Vicani mountains with reference to site-indexes of 14, 17 and 20 m (TH = top height; *V* = standing volume; N = number of shoots; v = mean volume; MAI = mean annual increment of standing volume).

	Site Index = 14						
	SHOOTS					STANDARDS	
age (years)	TH (m)	V (m^3ha^{-1})	N (nha^{-1})	*v* (m^3)	MAI ($m^3ha^{-1}year^{-1}$)	*V* (m^3ha^{-1})	MAI ($m^3ha^{-1}year^{-1}$)
15	11.9	91	2801	0.033	6.1	6.3	0.4
16	12.4	103	2705	0.038	6.5	7.0	0.4
17	12.8	115	2619	0.044	6.7	7.8	0.5
18	13.3	125	2540	0.050	7.0	8.5	0.5
19	13.6	135	2467	0.055	7.1	9.3	0.5
20	14.0	143	2399	0.060	7.2	10.0	0.5
21	14.3	151	2337	0.065	7.2	10.7	0.5
22	14.6	159	2279	0.070	7.2	11.5	0.5
23	14.9	165	2224	0.074	7.2	12.2	0.5
24	15.2	171	2173	0.079	7.2	13.0	0.5
25	15.4	177	2125	0.083	7.1	13.7	0.6
26	15.7	182	2080	0.088	7.0	14.4	0.6
27	15.9	187	2038	0.092	6.9	15.1	0.6
28	16.1	191	1998	0.096	6.8	15.8	0.6
29	16.3	195	1960	0.100	6.7	16.6	0.6
30	16.5	198	1923	0.103	6.6	17.3	0.6

	Site Index = 17						
	SHOOTS					STANDARDS	
age (years)	TH (m)	V (m^3ha^{-1})	N (nha^{-1})	*v* (m^3)	MAI ($m^3ha^{-1}year^{-1}$)	*V* (m^3ha^{-1})	MAI ($m^3ha^{-1}year^{-1}$)
15	14.4	165	2209	0.075	11.0	13.2	0.9
16	15.0	183	2114	0.087	11.4	14.4	0.9
17	15.6	199	2028	0.098	11.7	15.6	0.9
18	16.1	214	1948	0.110	11.9	16.8	0.9
19	16.6	227	1876	0.121	12.0	18.0	1.0
20	17.0	239	1808	0.132	12.0	19.2	1.0
21	17.4	250	1746	0.143	11.9	20.4	1.0
22	17.8	260	1687	0.154	11.8	21.5	1.0
23	18.1	269	1633	0.165	11.7	22.7	1.0
24	18.4	277	1582	0.175	11.6	23.8	1.0
25	18.7	284	1534	0.185	11.4	24.9	1.0
26	19.0	291	1489	0.196	11.2	25.9	1.0
27	19.3	297	1447	0.205	11.0	27.0	1.0
28	19.5	303	1407	0.215	10.8	28.1	1.0
29	19.8	308	1368	0.225	10.6	29.1	1.0
30	20.0	312	1332	0.234	10.4	30.1	1.0

	Site Index = 20						
	SHOOTS					STANDARDS	
age (years)	TH (m)	V (m^3ha^{-1})	N (nha^{-1})	*v* (m^3)	MAI ($m^3ha^{-1}year^{-1}$)	*V* (m^3ha^{-1})	MAI ($m^3ha^{-1}year^{-1}$)
15	17.0	187	1618	0.116	12.5	22.4	1.5
16	17.7	204	1523	0.134	12.8	24.2	1.5
17	18.3	220	1437	0.153	12.9	25.9	1.5
18	18.9	234	1357	0.172	13.0	27.6	1.5
19	19.5	246	1284	0.192	13.0	29.3	1.5
20	20.0	257	1217	0.211	12.9	30.9	1.6
21	20.5	267	1155	0.231	12.7	32.5	1.6
22	20.9	276	1096	0.252	12.6	34.0	1.6
23	21.3	284	1042	0.273	12.4	35.6	1.6
24	21.7	291	991	0.293	12.1	37.0	1.5
25	22.1	298	943	0.316	12.0	38.5	1.5
26	22.4	304	898	0.339	11.7	39.9	1.5
27	22.7	309	856	0.361	11.5	41.3	1.5
28	23.0	314	815	0.386	11.2	42.7	1.5
29	23.3	319	777	0.411	11.0	44.0	1.5
30	23.5	323	741	0.436	10.8	45.3	1.5

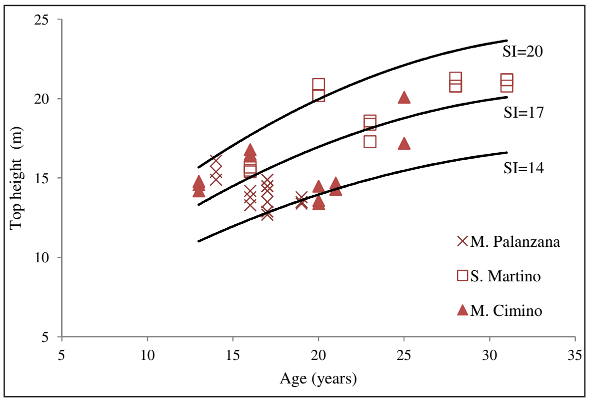

Figure 1 - Top height as a function of age and site-index in chestnut coppices of the Cimini and Vicani mountains. Values measured in the sample plots are also showed.

two thinnings: at 6 years 25% of shoots is harvested, whereas a second thinning at the age of 12 years reduces further stem number of 30%. The model by Lamani stipulates only one thinning at 13 years, with a removal of 37%. In the management practice of the last period, the intensity of the only thinning at the age of 13-14 years has further increased to get a higher stumpage value, and this condition is present in the new model here established. It is noteworthy that, even following the heavy thinning currently applied, tree mortality in coppice stands remains high: from 31% (SI=14) to 51% (SI=20) of the shoots become suppressed from the age of 15 years to the age of 30 years.

The number of standards is relatively low and it does not significantly affect stand volume: forest owners attribute to such trees, grown relatively isolated, a low economic value because of the epicormic branches and of the high probability of ring shake occurrence.

Discussion and conclusions

The interest of the new yield model presented here for chestnut coppices of the Cimini and Vicani mountains relies upon the high potential productivity of these stands in terms of woody mass and average size of the shoots at the end of rotation, as well.

Stand growth is largely influenced by site-class. The top height-age curves corresponding to SI=14, SI=17 and SI=20 overlap the first three site-classes of chestnut yield tables established by Lemaire (2009b) in France characterizing stands managed to produce high value timber assortments. This is an interesting evidence since many small woodworking companies located in the nearby of the Cimini and Vicani mountains import a lot of chestnut timber from France, neglecting local production because of an alleged low quality.

The economic value of chestnut stands does not only depend on wood productivity. The technologi-

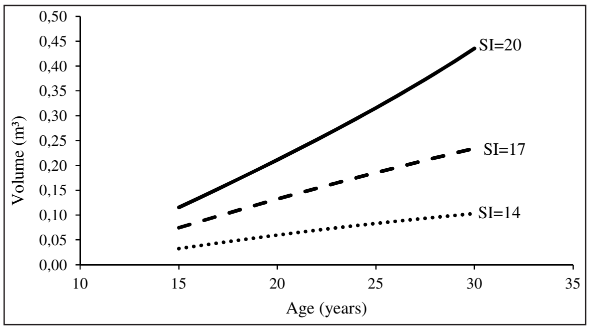

Figure 2 - Mean wood volume of shoots as a function of stand age and site index in chestnut coppices of the Cimini and Vicani mountains.

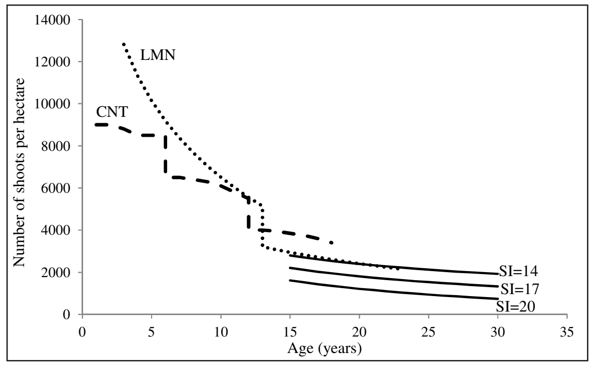

Figure 3 - Chestnut coppices of the Cimini and Vicani mountains: number of shoots per hectare as a function of stand age and site-index predicted by the new yield model (solid line) compared with the yield tables by Cantiani (CNT; dashed line; two thinnings) and by Lamani (LMN; dotted line; one thinning).

cal quality of timber influence greatly the income of forest owner, as well. Spina and Romagnoli (2010) observed that chestnut wood from the coppices of the Cimini and Vicani mountains is more affected by ring shake than wood coming from other chestnut coppice areas in Italy. This defect limits the use of chestnut wood for the most valuable assortments, especially those used as structural elements of buildings and furniture. Several interacting factors affect the phenomenon of ring shake under a single basic principle: an imbalance between the tensions being activated in the wood and the opposing cohesion forces (Fonti et al. 2002). Silvicultural practices can be very effective in preventing the defect or in reducing its incidence. Various studies conducted in different countries showed that abrupt changes in radial growth favour the ring shake occurrence (Cousseau and Lemaire 2009). Thus, it is essential to keep the diameter annual increment sustained and regular, e.g. to apply thinning before the growth rate declines because of competition (Cousseau and Lemaire 2009). For shoots growing in unthinned chestnut coppice stands in Central Italy, a critical age for ring shake establishment proves generally to be between the age of 12 and 14 years (Spina and Romagnoli 2010). Becagli et al. (2006) highlight the importance of anticipating the age of thinning to counteract ring shake occurrence. On the other hand, too intense thinnings may affect negatively chestnut wood quality: if ring width exceeds 6 mm, wood density and its own properties, tend to decrease (Fioravanti 1999).

The new yield model presented here points out that a unique intense thinning allows to get on average large-sized stems, but this might result in a lower quality of the final product. The intense resprouting after clearcutting, the soil fertility that speeds up self-thinning process and the incidence of diseases emphasize an early shoots' mortality. Thus, the regular reduction of interindividual competition would allow both the increase of stem quality and the decrease of deadwood accumulation and fire risk (Agee and Skinner 2005).

The new yield model integrates well the previous models developed by Cantiani (1965) and by Lamani (1993), while taking into account site-index. It improves the knowledge on chestnut coppices and provides to the forest owners of the Cimini and Vicani mountains an useful tool for making decisions about optimal rotation. It may be helpful in introducing innovation in chestnut coppice silviculture and supporting the enhancement of timber supply to gain more attention even from the most demanding woodworking companies.

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Research paper

Comparing growth rate in a mixed plantation (walnut, poplar and nurse trees) with different planting designs: results from an experimental plantation in northern Italy

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Abstract - Results of a mixed plantation with poplar, walnut and nurse trees established in winter 2003 in Northern Italy, are reported. Main tree species (poplar and walnut) were planted according to a rectangular design (10 x 11m), with different spacings and alternate lines. The experimental trial was carried out to verify the following working hypotheses: (i) possibility to combine main trees with different growth levels (common walnut, hybrid walnut, and different poplar clones) and test two different poplar and walnut spacings (5.0 and 7.4 m) in the same plantation; (ii) opportunity to reduce cultivation's workload, in comparison with poplar monoculture, using mixtures with different poplar clones and N-fixing nurse trees; (iii) verifying the growth pattern of two new poplar clones in comparison with the traditional clones cultivated for different purposes in Italy. The use of different valuable crop trees' mixtures intercropped with nurse trees and shrubs (including N-fixing trees) allows to decrease the cultivation's workload. In fact, a heavy reduction of cultural practices - fertilizers, weed control, irrigation and pesticides applications (-61%) are the main concurrent, supplementary benefits. The best growth performances (DBH and tree height), associated with the higher competition towards walnuts, were recorded with the new clones Lena and Neva in comparison with the I214 and Villafranca. The closer spacing (5 m between poplar and walnut trees) was found to be unsuited to get merchantable poplars sized 30 cm without developing a heavy competition towards walnut trees. The wider spacing (7.4 m) resulted vice versa suitable to get poplar trees sized as requested by veneer factories and to maintain an acceptable competitive level with walnut. Within this plantation design, a shorter rotation (8 yrs) is needed for Lena and Neva clones in comparison with I214 and Villafranca (10 yrs). Walnut intercropped with poplar showed cone-shaped crowns, light branching and a good stem quality in comparison with walnut grown in pure plantations. This model of mixed plantation can become an interesting optional choice to walnut's and poplar's monoculture with notable advantages both for farm economics, landscape quality and environment preservation.

Keywords - common walnut, hybrid walnut, mixed plantation, poplar clones, sustainable tree farming

Introduction

Poplar cultivation is the main internal source for timber industry, producing about 50% of the whole roundwood volume (Facciotto et al. 2003) in Italy. Since the early nineties, poplar cultivation is suffering a heavy reduction from 90,000 to 61,381 hectares (Gasparini e Tabacchi 2011, Coaloa et al. 2012) due to several factors: (i) the weak farmers' contractual position when selling a poplar plantation, (ii) the lack of any industry planning useful for programming planting investments, (iii) the wider use by poplar industry of semi-finished timber products imported from other European and extra-European countries, (iv) the increasing production costs, i.e. petrol, pesticides, fertilizers, etc. (Nervo et al. 2007). This condition enhanced research efforts for the innovation of poplar cultivation systems towards less energy-consuming plantations (Coaloa and Vietto 2005) or plantations able to produce, within the same rotation, larger-sized trees, along with reducing production's costs (Buresti and Mori 2006).

Another tree species, traditionally cultivated in Italy for valuable timber production, is common walnut (*Juglans regia* L.). In the past, this species was generally cultivated as a single tree or in linear plantations, intercropped to agricultural crops, both for nuts and timber production (Minotta 1990, 1992). More recently, this twofold production has been replaced by specialized pure plantations for timber production, using a square spacing of 5 to 6 m, or walnut seed orchards (Giannini and Mercurio 1997).

Over the last decades in Europe, under the financial support of EU rules 2080/92 and of Rural Development Plan, many mixed plantations were established with walnut and other valuable broadleaved and nurse trees (Becquey 1997, Becquey and Vidal 2006, Buresti and Mori 2006, Kelty 2006, Tani et al. 2006, Clark et al. 2008, Mohni et al. 2009). Recently in Italy, France, and North America, mixed

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plantations with walnut and poplar clones have been tested both in plantation forestry (Zsuffa et al. 1977, Buresti et al. 2008a, Vidal e Becquey 2008a, Paquette et al. 2008) and in agro-forestry systems (Balandier and Dupraz 1999, Rivest et al. 2010). These experiences pointed out the opportunity of testing the simultaneous cultivation of both species, characterized by different rotations (short poplar, medium-long walnut).

In this type of plantation, named in Italy *polycyclical plantation* (after Buresti et al. 2008b and Buresti and Mori 2012), the main crop trees with the same rotation are spaced at a definitive distance, to reach the merchantable size requested by industry within a shorter cycle. The reciprocal distance between main walnut and poplar trees must allow each tree to complete its rotation without the establishment of any heavy interspecific competition. Furthermore, when interplanting distance is correct, a positive competition can arise and the fast growing tree species can influence in a beneficial way the shape of lower growth and shade tolerant trees because of their low-covering crown (Schütz 2001, Pommerening and Murphy 2004, Kelty 2006, Buresti et al. 2008a, Buresti et al. 2008b, Vidal and Becquey 2008a).

A further benefit arising from this type of plantation is economical, by allowing a better distribution of income, poplar being harvested within 8-10 years and walnut within 20-30 years (Vidal and Becquey 2008b).

Results obtained in a poplar and walnut *polycyclical plantation*, aged 9 years, are here reported. The plantation has been carried out to verify the following hypotheses:

1) opportunity to get poplars sized 30 cm DBH testing two different distances from walnut (5 and 7.4 m) without heavy interspecific competition;
2) possibility of poplar cultivation at lower costs as compared with the traditional technique, reducing tending operations, using more than one poplar clone and mixtures with N-fixing trees;
3) test poplar clones different from the I214 traditionally planted in Italy, to verify their own productivity and ability to be competitive on the wood market;
4) opportunity of harvesting additional valuable trees established as nurse trees.

Materials and Methods

Site description and plantation management

Planting operations started in February 2003 in a flood plain of the Oglio river in the Mantua Province (San Matteo alle Chiaviche). The area is characterized by a good site-index, deep, silty-sandy and moderately alkaline soils, subjected to periodical flooding. A sub-continental climate with cold winters and hot wet summers characterizes the area (mean annual temperature 13.6° C., mean annual precipitation 790 mm with maximum in autumn and minimum in winter; mean rainfall reaches 145 mm in summer with a dry period of one month only).

This mixed plantation, extended over 14 hectares, is characterized by the following main crop trees: four poplar clones (Lena, Neva, I214 e Villafranca), common walnut (*Juglans regia* L.) and hybrid walnut (*Juglans x intermedia* MJ209) (Tab. 1). The common walnut's trees have been planted initially in pairs, each tree being located at 1 m, in order to select shortly the best tree of each couple. In this way, the chance to get a good quality tree in the expected position increases (Buresti et al. 2001, 2003). Walnut and poplar main trees are planted according to a rectangular design (10 x 11 m) using alternate lines. In all, 90 poplars, 45 hybrid walnuts, and 45 common walnut couples were planted per hectare. The plantation is divided into two areas, depending on the planting design adopted (A and B). Each area is divided in monoclonal plots of about 1.5 hectare for each clone. In design A, walnut trees (both hybrid and common walnuts) are set in a row with poplar at 5 m. In design B, walnut trees are staggered to poplars by 7.4 m. Nurse trees were black alder (*Alnus glutinosa* (L.) Gaertn.) and hazel (*Corylus avellana* L.); along with these other four valuable nurse trees were introduced, i.e. narrow-leaved ash (*Fraxinus angustifolia* L.), wild service tree (*Sorbus torminalis* (L.) Cranz.), English oak (*Quercus robur* L.), and pear (*Pyrus*

Table 1 - Main characteristics of poplar clones. Modified from Facciotto et al. (2003).

Clone	origin	main characteristics
Lena	Populus deltoides Bartr.	higher productivity in comparison with I214; resistance to leaf diseases (rusts and aphids); sensitive to wind; high shrinkage and nervousness in comparison with I214.
Neva	Hybrid Populus X canadensis Monch	sensitive to spring defoliation and rusts; resistance to bronzing; bark necrosis and brown spots; higher productivity in comparison with I214; sensitive to wind
I 214	Hybrid Populus X canadensis Monch	resistance to spring defoliation; virus and brown spots; green wood density lower to Lena and Neva; resistance to wind; easy to prune
Villafranca	Populus alba L. clone	resistance to main diseases (rusts. spring defoliation. bronzing. viruses and aphids); hard to prune; slower growth in comparison with I214

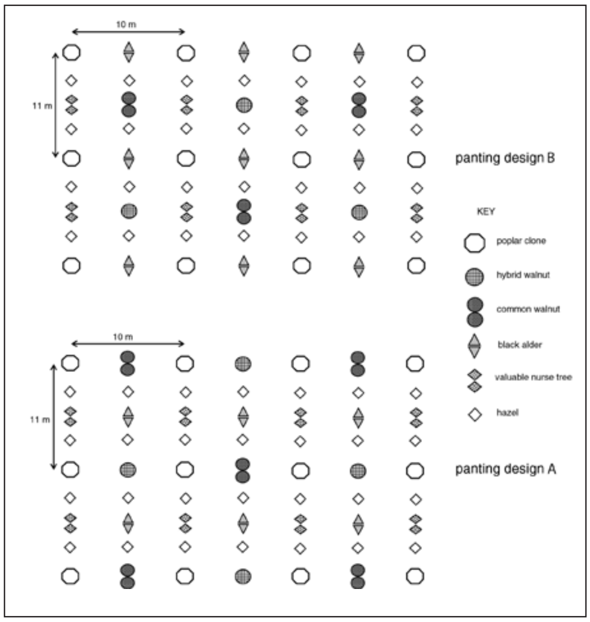

Figure 1 - The planting designs (A and B).

pyraster Burgsd.) (Fig.1). Valuable nurse trees, in addition to their own tending role, act as sort of insurance for the final outcome of the plantation, because they are able to replace any main crop tree in case of death, damage or if they do not achieve the expected development (Buresti and Mori 2004). Consequently, the valuable nurse trees must be subjected, at least for 4 to 6 years (pruning phase), to the same tending operations as the main crop trees (especially pruning).

In this plantation, the operations have been considerably reduced when compared with traditional monoclonal poplar plantations by:

1. Reduction of both fertilizers using N-fixing nurse trees, and pesticides using multi-clonal mixed plantations. These plantations allowed the reduction of spreading disease risk by poplar leaf rust (*Melampsora* spp.) or poplar leaf and shoot blight (*Venturia populina* (Vuill.) Fabric.), as already verified in other areas intensively cultivated with poplars (Coaloa and Vietto 2005).
2. Stimulation of poplar radial growth, with consequent reduction of the rotation, by planting more spaced trees that develop longer and well-lighted crowns over the whole cycle.

Over the first two years, only one treatment against wood insects' poplar-and-willow borer (*Cryptorrhynchus lapathi*) was performed; in the following two years a localized treatment to control longhorn beetle (*Saperda carcharis* L.) was carried out in the outside strips (about 20 m) to prevent the diffusion of this insect from neighbouring traditional poplar plantations. Weed control was carried out by polyethylene mulching and using both chemical and mechanical weeding during the first four years. On average two mechanical weeding and one chemical weeding per year were carried out.

No use of fertilizers or irrigations was made, whereas neighbouring traditional I214 plantations are managed intensively with one initial fertilization, 3-5 pesticide treatments per year and periodical emergency irrigations.

Selection of best trees between walnut's couples was accomplished at age 5 when trees differences in vigour and shape were already evident. Pruning of main trees and of valuable nurse trees was carried out up to the age of 6, i.e. when the farmer decided to promote walnut trees because of the good stem quality and clear boles at least up to 3 meters. Poplars were pruned up to 5.5 meters.

Field survey and data analysis

DBH surveys were performed yearly between the age of 4 and 9 (2006 to 2011). In the pruning phase (2006-2007) a sample of walnut and poplar clones only (at least 30 trees per species, clone and spacing) were considered. Since 2008, when the pruning ended, a complete survey of walnut and poplar DBH was made. Total tree and clear bole height of walnut and poplar clones were measured at ages 6 and 9 (2008 and 2011); in 2011 only 50% of poplar heights were measured. In 2011 an individual stem quality evaluation was carried out for walnut trees, ranking stems per quality classes, from A (veneer) to D (firewood) using the method set up for tree farming plantations proposed by Nosenzo et al. (2008) that assigns a quality class, valuing length, trunk axiality, knots presence and other defects. Only DBHs were measured on valuable nurse trees in 2008 and 2009.

First, the normality of distributions was evaluated by mean of Kolmogorof-Smirnov's test, then data were processed with the analysis of variance (ANOVA) comparing separately poplar clones, common walnut and hybrid walnut, but considering both planting designs (A and B). The comparison of means was performed by the Tukey's Test (HSD), with a significance of 0.05 (Statistica 2005). The walnut's distribution per stem quality classes was compared by χ^2 Pearson's test. The performances of valuable nurse trees and walnut trees were evaluated by comparing mean DBH at 2009 (age 7).

A comparison between traditional poplar plantation (Colaoa and Vietto 2005) and this new type of poplar and walnut plantation was carried out comparing the presence (1)/ absence (0) of cultural practices undertaken during the poplar rotation (10 years).

Results

Poplar

Stem diameter - Poplar clones showed different growth rates at the age of 7-8 (years 2009-10) Lena and Neva clones reached the commercial size (DBH=30 cm), whilst I214 and Villafranca clones reached the same size 1 or 2 years later (Fig. 2). In 2011, the ANOVA of DBH showed significant differences among the clones and blocks (designs) ranging from 38.0, 36.1, 31.5 and 30.1 cm respectively for Lena, Neva, I214 and Villafranca (Tab. 2).

DBH increments keep high, i.e. 3-4 cm yr$^{1.}$ In 2009, Lena pointed out significant higher increments as compared with all clones in both designs, differences that decreased in the following years. Less productive clones showed more steady increments while a heavy DBH increment reduction was highlighted in Lena and, to a lesser extent, in Neva. In the last two years the I214 clone showed higher DBH increments (Fig. 3).

Tree height - The ANOVA of height is significant for both years (2008 and 2011) pointing out, in 2011, a superior height growth of Lena and Neva clones that reached on average 24.4 m and 24.2 m respectively, in comparison with 20.8 m and 18.2 m of the I214 and Villafranca clones (Tab. 3). At the age of 9 all poplar clones had built up green and efficient, up to 12-18 m long, crowns in comparison with poplars cultivated as usual, where crowns are narrow and shorter because of their progressive elevation due to the heavy competition (poplar stem density = 277 tree ha^{-1}).

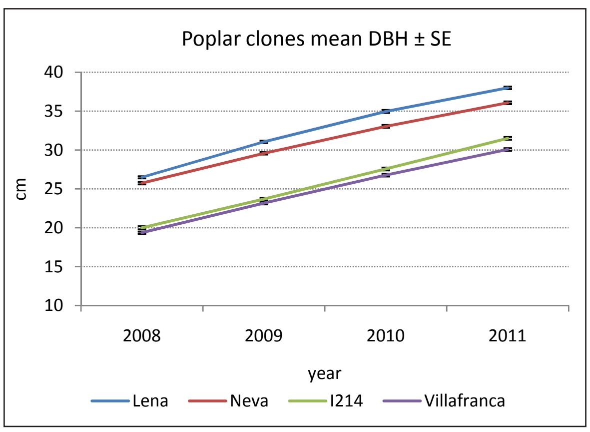

Figure 2 - Poplar clones DBH growth trend ± SE.

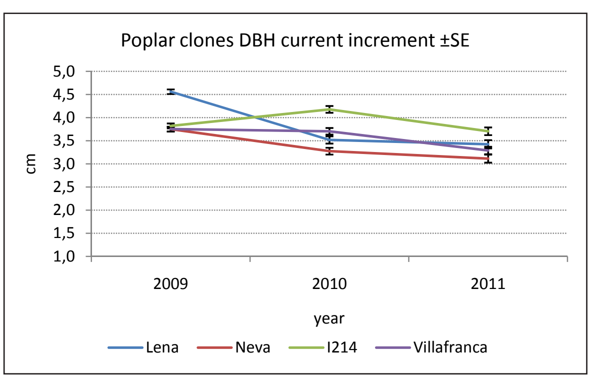

Figure 3 - Poplar clones DBH current increment ± SE.

Table 2 - ANOVA of poplar clones DBH 2011 (9 yrs).

Poplar clone	DBH (cm)	±SD (cm)	HSD	
Lena	38.0	2.2	a	
Neva	36.1	2.7	b	
I214	31.5	3.0	c	
Villafranca	30.1	2.1	d	
ANOVA	df	MS	F	P value
Clone	3	2559.1	516.4	*0.0000*
design (block)	1	896.2	180.8	*0.0000*
clone x design	3	65.9	13.3	*0.0000*
error	716	5.0		

Walnut

Stem diameter - Data analysis pointed out significant differences for walnut DBH grown with different spacings, it being lower in design A compared to B. Significant variations in DBH were also found for both walnuts originated by the different intercropped poplar clones (Fig. 4 and 5). Hybrid walnut reached on average lower DBH (13.2 cm and 13.7 cm) when intercropped with Lena and Neva in comparison with I214 and Villafranca intercropping (14.9 cm and 15.4 cm) in 2011 (age of 9). Common walnut reached 12.6 and 12.9 cm when intercropped with Lena and Neva and 13.1 and 13.6 cm when intercropped with I214 and Villafranca (Tab. 4).

A reduction of DBH increment was observed for both walnuts and designs within all the intercropped poplar clones in the last years. Since 2010, significant differences among intercropping and designs were found for both walnuts. A mean reduction of DBH increment from 1.6 to 0.6 cm in Lena and from 1.5 to 0.7 cm in Neva intercropping was observed for hybrid walnut over 2009-2011, whilst a lower DBH variation of annual increment was detected with the less productive clones: from 1.9 to 1.2 cm in I214 and from 2.0 to 1.1 cm in Villafranca intercropping (Fig. 6). In common walnut DBH increment variations were less significant and only walnut intercropped with I214 in design B was significantly different. A mean reduction of common walnut DBH increment from 1.7 to 0.9 cm in Lena and from 1.8 to 1.1 cm in Neva intercropping was observed along the full observation period; whilst a DBH increment variation from 2.0 to 1.3 cm and from 1.9 to 1.2 cm was recorded, respectively in I214 and Villafranca intercropping (Fig. 7). The trend of DBH increment highlights the different specific growth pattern of both walnuts. Hybrid walnut has an early more sustained growth followed by a progressive reduction due to poplar competition, up to a radial (DBH) growth lower than common walnut (Fig. 8).

Tree height - The ANOVA showed significant differences in height with common walnut for both intercropping types in 2008 and 2011, and for planting design in 2011 only. In hybrid walnut significant differences in height were noticed for the different

Table 3 - ANOVA of poplar clones tree height 2008 - 2011 (6-9 yrs).

Poplar clone	h2008 (m)	±SD (m)	HSD		h2011 (m)	±SD (m)	HSD	
Lena	17.43	1.43	a		24.38	2.06	a	
Neva	16.80	1.21	b		23.16	1.35	a	
I214	14.09	1.49	c		20.75	1.30	b	
Villafranca	12.13	0.99	d		18.23	2.00	c	
ANOVA	df	MS	F	P value	df	MS	F	P value
clone	3	1111.5	780.50	*0.0000*	3	798.6	285.58	*0.0000*
design (block)	1	114.5	80.40	*0.0000*	1	4.1	1.48	0.2242
clone x design	3	26.3	18.50	*0.0000*	3	25.2	9.02	*0.0000*
	726	1.4			357	2.8		

intercroppings in 2008 and 2011, and for planting design in 2011 only.

The best performances of common walnut at the end of 2011 were measured in the design B with Lena and Neva intercropping (13.7 and 14.4 m) while the worst results were found in design A with I214 (11.2 m) and Villafranca (11.6 m) (Tab 5). In 2011, the best performances of hybrid walnut were recorded in design B with Lena and Neva intercropping (14.9 and 14.5 m) and the worst results were achieved in design A with I214 (13.2 m) and Villafranca (12.8 m) (Tab. 6).

Stem quality - The quality of hybrid walnut showed to be significant superior ($\chi^2 = 31.2$ p<0.001) as compared with common walnut. The 72% of hybrid trees belong to classes A and B, suitable for veneer and first quality saw-timber production, while only 53% of common walnut trees reached the same category (Tab.7). Stem pruning was carried out up to the height of 3 m. Over this height, crowns were left to grow free. The percentage of trees suitable to produce valuable assortments could increase for both walnut species at higher plantation ages, because defects due to knots and small stem curves could be overestimated in trees aged 9 years.

Valuable nurse trees

Close to the end of the pruning phase (2009), the owner decided to concentrate operations only on walnut trees showing faster growth and/or fitting the expected stem quality, neglecting valuable nurse trees. Among these, the best DBH growth performance was recorded by narrow-leaved ash followed by pear, oak, and wild service trees. Mean DBH values measured in 2009 in walnuts and valuable nurse trees are reported in Fig. 9.

Cultivation practices

The comparison between cultivation practices undertaken in the two plantation types (pure and polycyclical) during the poplar rotation are showed in Tab. 8 and 9. In the mixed walnut-poplar plantation, the absence of any irrigation and fertilization, a heavy reduction of the use of pesticides (-90%) and of mechanical weed control (-60%) was recorded. On the other hand, the chemical weed control along walnut lines, the selection between walnut couples, and the increase of pruning (+25%), were necessary in this new type of plantation.

Discussion

At the age of 9 (2011), Lena and Neva clones reached notable diameters (34.7 to 38.4 cm) but showed already evidence of an incremental reduction, whilst the I214 and Villafranca maintained a more regular growth course with lower DBH (29.1 to 33.3 cm). These growth patterns highlight on one side the early establishment of intraspecific competition within the fastest growing clones, especially Lena, and on the other side, the delayed occurrence of the same condition within the less productive clones (I214 and Villafranca).

The year 2009 showed to be the right time for

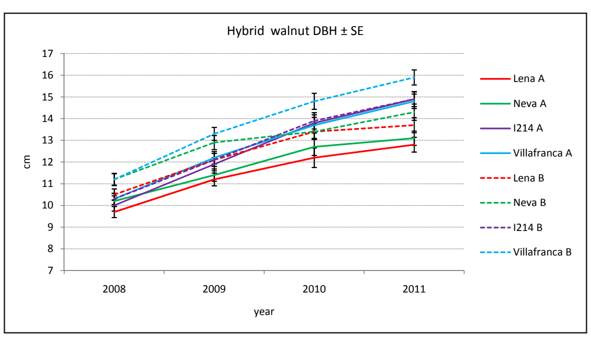

Figure 4 - Hybrid walnut DBH growth trend ± SE per intercropping and design.

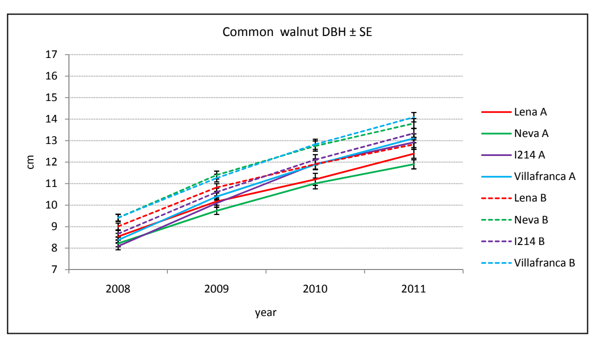

Figure 5 - Common walnut DBH growth trend ± SE per intercropping and design.

Table 4 - DBH 2011 (9 yrs) common and hybrid walnut ANOVA per planting design and intercropped poplar clones.

intercropping	design	Hybrid walnut DBH (cm)	±SD (cm)	HSD		Common walnut DBH	±SD (cm)	HSD (cm)
Lena	A	12.8	1.9	c		12.39	1.35	de
Neva	A	13.1	2.4	c		11.90	1.03	e
I214	A	14.9	2	ab		12.92	0.86	bcd
Villafranca	A	14.8	2.3	ab		13.11	1.68	bcd
Lena	B	13.7	2.2	bc		12.82	1.25	cd
Neva	B	14.3	2.1	bc		13.80	1.43	ab
I214	B	14.9	2.3	ab		13.34	1.59	abc
Villafranca	B	15.9	2.2	a		14.09	1.65	a
ANOVA	df	MS	F	P value	df	MS	F	P value
design	1	50.93	10.58	*0.0013*	1	70.06	36.31	*0.0000*
intercropping	3	79.69	16.55	*0.0000*	3	14.91	7.73	*0.0001*
intercropping x design	3	5.70	1.18	0.3160	3	9.42	4.88	*0.0025*
error	314	4.81			314	1.93		

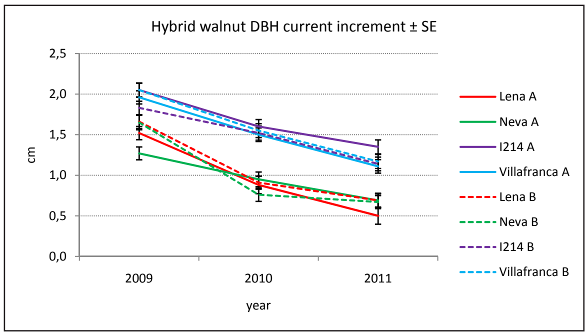

Figure 6 - Hybrid walnut DBH current increment per intercropping and design.

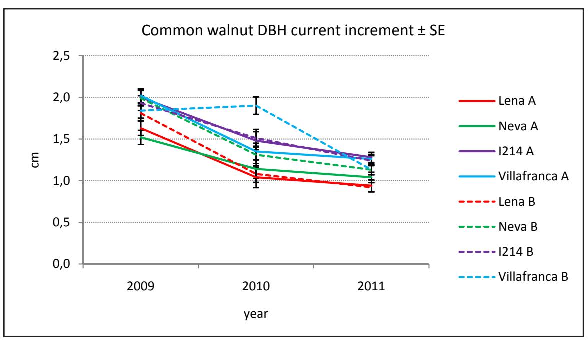

Figure 7 - Common walnut DBH current increment per intercropping and design.

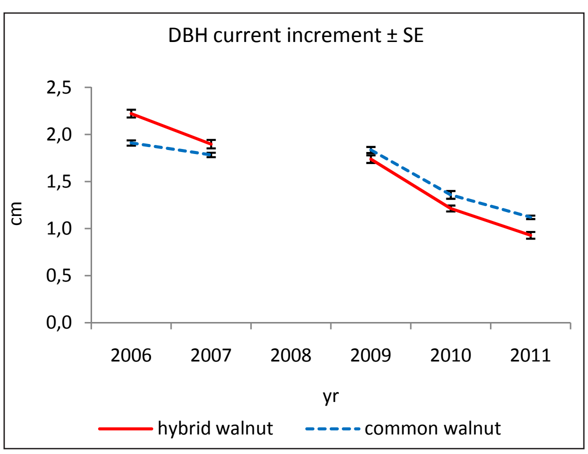

Figure 8 - Comparison between common and hybrid walnut DBH increment.

poplars harvesting, especially for the more productive clones - Lena and Neva - (Facciotto et al. 2003) already sized enough for marketing (DBH ≥30 cm), but adverse concomitant local market conditions didn't make profitable their felling to the farmer. Their maintenance for a longer time affected negatively walnut DBH increment, that is -63% compared with 2009 (hybrid walnut intercropped with Lena), -46% (common walnut) and -36% with the I214 intercropping in both walnuts spp. (Tab. 10). At the end of 2011, walnuts have still long, green functional crowns (12-18 m) and looked able to react to poplars' harvesting as compared with pure walnut plantations undergoing a late thinning, these generally showing a lower reaction (De Meo et al. 1999, Marchino and Ravagni 2007). Despite that, no data exist at now about the incremental DBH reaction of walnut following a period of heavy competition in this type of plantation. This points out the need of using larger poplar-walnut interplanting distances, especially if we are going to use both slower growing clones needing rotations of about 10 years to produce poplars sized more than 40 cm (Buresti and Mori 2013). The basic importance of defining suited planting designs and correct walnut-poplar distances is in this way underlined.

Both walnut trees (common and hybrid) showed a fast DBH growth. Hybrid walnut presented a superior stem quality in accordance with Paris et al. (2003), 72% of stems being suitable for good quality veneer and saw timber production. On the contrary, common walnut had only 53% of stems in the best quality classes (Tab. 7). Despite the worse performance in terms of growth and stem quality, the use of common walnut is more frequent since its timber is more appreciated by the Italian industry and because this species has been traditionally cultivated in Italy since the Roman period. The achievement of a good standard in the trunk quality has been determined by poplar's presence (i.e. fast growing species with low-covering crown) able to nurse, under his light canopy, walnuts characterized by

Table 5 - Tree height 2008 - 2011 (6-9 yrs) common walnut ANOVA per planting design and intercropped poplar clones.

		Common walnut							
intercropping	**design**	**h2008** (cm)	**±SD** (cm)	**HSD**		**h2011**	**±SD** (cm)	**HSD** (cm)	
Lena	A	8.26	1.06	a		13.13	1.60	a	
Neva	A	7.89	0.98	a		12.53	1.22	a	
I214	A	7.08	0.64	b		11.20	1.08	b	
Villafranca	A	7.80	1.15	a		11.63	1.50	b	
Lena	B	8.38	1.33	ab		13.71	1.63	a	
Neva	B	8.55	1.55	a		14.42	1.99	a	
I214	B	7.39	1.19	c		12.38	1.91	b	
Villafranca	B	7.74	0.89	bc		12.05	1.30	b	
ANOVA		gdl	MS	F	P value	gdl	MS	F	P value
design		1	4.86	3.86	0.0503	1	80.51	33.62	*0.000*
intercropping		3	16.97	13.48	*0.0000*	3	68.94	28.79	*0.000*
intercropping x design		3	1.70	1.35	0.2571	3	8.97	3.75	0.011
error	281	1.26				306	2.39		

Table 6 - Tree height 2008 - 2011 (6-9 yrs) hybrid walnut ANOVA per planting design and intercropped poplar clones.

		Hybrid walnut							
intercropping	**design**	**h2008** (cm)	**±SD** (cm)	**HSD**		**h2011**	**±SD** (cm)	**HSD** (cm)	
Lena	A	8.36	0.97	a		13.57	1.65	a	
Neva	A	8.14	1.40	a		13.69	2.03	a	
I214	A	8.11	0.75	a		13.22	1.44	a	
Villafranca	A	7.88	1.05	a		12.81	1.54	a	
Lena	B	8.57	1.40	ab		14.92	2.18	a	
Neva	B	9.08	1.38	a		14.51	2.03	ab	
I214	B	7.94	1.06	b		14.09	1.67	ab	
Villafranca	B	8.06	0.98	b		13.41	1.28	b	
ANOVA	df	MS	F	P value	df	MS	F	P value	
design		1	4.87	2.97	0.0862	1	65.07	21.1	*0,0000*
intercropping		3	6.01	3.66	*0.0131*	3	20.45	6.63	*0,0002*
intercropping .x design	3	3.15	1.92	0.1274	3	2.06	0.67	0.5722	
error	238	1.64			307	3.08			

Table 7 - Distribution of common and hybrid walnut per stem quality classes and relative χ^2 test.

Stem quality classes	**common walnut** n	%	**hybrid walnut** n	%
A	35	10.8	63	19.4
B	137	42.4	170	52.5
C	97	30.0	71	21.9
D	54	16.7	20	6.2
tot	323	100.0	324	100.0

χ^2 = 31.19 p=0.000

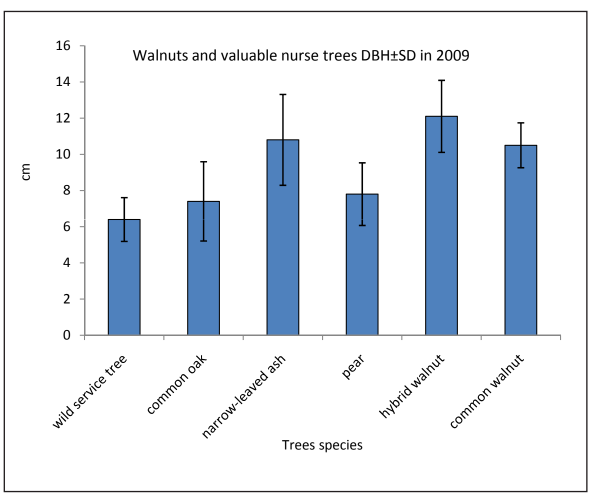

Figure 9 - Comparison among walnuts and valuable nurse trees DBH ±SD at the age of 7 (2009).

slender, cone-shaped crowns and small-sized, easily self-pruned branches (Buresti et al. 2008b). Valuable nurse trees were no longer managed (except the best phenotypes) because of the good walnut performance both in terms of growth and stem quality. That is why their cultivation (pruning) has been abandoned in this trial. In any case, according to Kelty (2006) and Buresti and Mori (2004), they can support an improvement of biodiversity and stability of mixed plantations and their intercropping is a sort of farmer's insurance for the final outcome of the plantation.

Results highlight that the concurrent cultivation of walnut and poplar species is possible and advisable because of the manifold positive outcomes: reduced environmental impact of the plantation type as compared with traditional poplar monoculture, since the trial pointed out a clear reduction of external inputs in terms of (i) fertilization (-100%), (ii) irrigation (-100%), (iii) use of pesticides (-90%) as compared with the traditional cultivation.

This was possible by using multi-clonal mixed plantations with N-fixing nurse trees that considerably reduce both the spreading of pests and diseases and also the consequent amount of chemical treatments. The use of fertilizers was cut down, too.

All these achievements are quite positive as

Table 8 - Presence (1) or absence (0) of cultural practices in traditional poplar plantations - modified from Colaoa and Vietto (2005).

Traditional poplar plantation *cultural operations*	years of poplar rotation 1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	total
mechanical weed control	1	1	1	1	1	1	1	1	1	1	**10**
irrigation	1	1	1	1	1	1	1	1	1	1	**10**
pesticide	1	1	1	1	1	1	1	1	1	1	**10**
chemical weed control	0	0	0	0	0	0	0	0	0	0	**0**
pruning	1	1	1	0	1	0	0	0	0	0	4
selection double walnut	0	0	0	0	0	0	0	0	0	0	**0**
fertilization	1	1	1	1	0	0	0	0	0	0	**4**
total interventions	**5**	**5**	**5**	**4**	**4**	**3**	**3**	**3**	**3**	**3**	**38**

Table 9 - Presence (1) or absence (0) of cultural practices in the studied plantation.

Polyciclical plantation *cultural operations*	years of poplar rotation 1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	total
mechanical weed control	1	1	1	1	0	0	0	0	0	0	**4**
irrigation	0	0	0	0	0	0	0	0	0	0	**0**
pesticides	0	1	0	0	0	0	0	0	0	0	**1**
chemical weed control	1	1	1	1	0	0	0	0	0	0	**4**
pruning	0	1	1	1	1	0	0	0	0	1	**5**
selection double walnut	0	0	0	0	1	0	0	0	0	0	**1**
fertilization	0	0	0	0	0	0	0	0	0	0	**0**
total interventions	**2**	**4**	**3**	**3**	**2**	**0**	**0**	**0**	**0**	**1**	**15**

Table 10 - Reduction of current DBH increments between 2009 and 2011

Intercropped clones	**hybrid walnut DBH increment reduction %**	**common walnut DBH increment reduction %**
Lena	63	46
Neva	53	37
I214	36	36
Villafranca	43	38

compared with the number of cultivation practices needed in a traditional poplar's plantations along the whole poplar rotation (Colaoa and Vietto 2005). Their occurrence was limited to less than one half in the studied plantation. The abatement of these cultivation costs has a notable economic advantage both for farmers and towards the environment.

A limitation to the use of the Lena and Neva clones is nowadays the shortage of market for these clones in Italy, in spite of their significant superior growth, the lower cultivation needs, in comparison with I214, and the suitable mechanical timber characteristics. Unfortunately, the higher shrinkage of timber in these clones decreases the value for veneer production, this determining a difficult marketing. At present, veneer industry fully prefers timber from I214 plantations (Facciotto et al. 2003). According to Vidal and Becquey (2008b), the mixture between poplar and walnut appears to be interesting from the economic point of view too. Further research trials are necessary to value the overall productivity of the two main tree species at the end of walnut rotation and the analytical evaluation of costs.

Conclusive remarks

The recent experimental trials on mixed *polycyclical plantations* (walnut, poplar and nurse trees) highlighted the notable potential of this type of plantation in flood plain areas favourable to the cultivation of both main species, providing interesting productive outcomes as well as ecological-environmental considerations. These mixed plantations, more resistant to external disturbances and less demanding in terms of energetic inputs (fertilization, pesticides, irrigation, etc.) proved to be innovative and more sustainable for poplar and walnut cultivation. It can become an advantage for the farmer, especially within the current unfavourable period for poplar timber marketing and for the quality of flood plain environment.

The experiences with this plantation design are at an early stage and more comparative tests, widespread trials and screening of results are necessary. The goals in progress are: development of suitable cultivation models with wide inter-distances walnut-poplar (≥7.4 m), enough to allow: (i) the early achievement of poplar's cultivation goals before heavy competition with walnut becomes established; (ii) the use of a fast growing species, i.e. poplar to nurse walnut trees provided with slender, conical-shaped crowns, and light branching.

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Research paper

Cambiamenti strutturali ed ecologici in cedui di leccio in Sardegna a 25 anni dal taglio di avviamento ad altofusto

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Riassunto - In Sardegna le formazioni forestali a prevalenza di leccio (*Quercus ilex* L.) derivano in gran parte da cedui invecchiati, molti dei quali avviati all'altofusto, e rappresentano un patrimonio importante per estensione (40% delle leccete italiane), valore ambientale e turistico-ricreativo. Questo studio è stato impostato nel 1994 per analizzare, in funzione della fertilità stazionale, gli effetti del taglio di avviamento ad alto fusto su produttività, biodiversità, dinamiche strutturali e caratteri della copertura in una foresta mesofila di leccio della Sardegna meridionale. In un ceduo matricinato di leccio di circa 55 anni (al 1994), ubicato nel complesso della Foresta dei Settefratelli (Cagliari), sono state realizzate due aree sperimentali permanenti, differenti per fertilità, struttura e densità del soprassuolo. I rilievi sono stati effettuati nelle stagioni 1994-95 e 2010-11 e hanno previsto il monitoraggio delle principali variabili dendrometriche (densità e produttività), lo studio della struttura (diversità specifica e strutturale) e la stima di alcuni parametri ecologici (LAI e trasmittanza). I risultati hanno evidenziato, a 9 anni di distanza dal diradamento e in entrambe le aree, una struttura semplificata, una scarsa diversità specifica, una ridotta copertura, valori di LAI bassi e di trasmittanza piuttosto elevati. Questi caratteri sono risultati più accentuati nell'area meno fertile, dotata di una copertura contraddistinta da vuoti consistenti. Nel 2010, a fronte di un aumento consistente del numero di piante ad ettaro, è seguito un rafforzamento della struttura a gruppi e un recupero netto della copertura ma non sono state registrate variazioni della diversità verticale e specifica. Nel complesso è stata evidenziata una reazione positiva al taglio di avviamento anche se l'eccessiva riduzione della densità nell'area meno fertile non ha ancora permesso la completa ricostituzione della copertura da un punto di vista qualitativo.

Parole chiave - leccio, struttura, dinamica, copertura, conversione all'alto fusto, monitoraggio

Abstract - *Stand structure and ecological changes in holm oak coppices 25 years later the opening of thinning operations for the conversion into high forest.* Holm oak (*Quercus ilex* L.) is one of the most diffuse and economically important forest species in Sardinia, where it holds about 40% of holm oak cover in Italy. The forest type has also acquired a high ecological, recreational and landscape value over the last decades. Most of holm oak stands originated from overgrown coppice forests partly undergoing conversion into high forest. This study was set up in 1994 to analyse, as a function of site-index, the effects of conversion thinning on productivity, biodiversity, structural dynamics and canopy characteristics in an holm oak forest located in southern Sardinia. Two experimental permanent plots, differing in site index, stand structure and tree density, were established. The surveys were carried out in 1994-95 and 2010-11. The analysis included growth pattern, dynamics of stand structure and estimation of forest canopy attributes as leaf area index and canopy transmittance. Results pointed out the simplified stand structure, the poor biodiversity, the low LAI and high transmittance values 9 years after thinning implementation. These characteristics were more pronounced in the less productive area, characterised by substantial canopy gaps. 25 years after thinning implementation, both stands showed significant increase in the number of trees, strengthening of the clustered structure and high canopy recovery. Conversely, no significant changes in biodiversity and vertical structure were observed. Overall results contributed to a positive evaluation of the conversion practice based on periodical thinnings, even if the excessive reduction of tree density, mainly in the lower site-index area, did not allow yet the fully achievement of canopy recovery.

Keywords - holm oak, stand structure, stand dynamics, canopy cover, conversion into high forest, monitoring

Introduzione

L'uomo ha da sempre utilizzato le foreste con conseguenze spesso anche importanti quali la forte perdita di biodiversità e la radicale alterazione della loro funzionalità bioecologica (Thomson et al. 2006, Gardner 2010). Negli ultimi decenni, in seguito a una nuova sensibilità ambientale sono state ri-attribuite alle foreste funzioni a scala globale per lungo tempo sottaciute, dalle quali l'uomo e il pianeta possono ottenere benefici non meno importanti di quelli più strettamente produttivi. Tra questi possiamo annoverare la protezione del suolo, la regimazione e la depurazione delle acque, la fissazione e lo stoccaggio del carbonio, la mitigazione degli effetti del riscaldamento globale e la regolazione del clima, la funzione di filtro degli elementi inquinanti, la riserva di biodiversità, la riqualificazione del paesaggio e infine il ruolo turistico-ricreativo.

Non sono sfuggite a tali dinamiche le foreste del bacino del Mediterraneo, dove l'attività antropica è stata particolarmente intensa fin dall'antichità, causandone spesso la riduzione e la frammentazione in termini di superficie o la degradazione a biocenosi semplificata. Un esempio sono le foreste di leccio (*Quercus ilex* L.) che nell'area mediterranea, secondo Quézel e Médail (2003),

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ricoprono una superficie approssimativa di 6.550.000 ha, la maggior parte della quale concentrata in Spagna e Marocco ma con una consistenza importante anche in Italia (circa il 6% del totale), dove la superficie dei boschi di leccio è pari a circa 680.000 ha (INFC 2005).

Tali formazioni sono state sottoposte per secoli a sfruttamento intensivo esercitato sia attraverso il governo a ceduo per la produzione di legna da ardere e di carbone sia con il pascolo; impatti particolarmente rilevanti sono stati poi osservati in concomitanza con l'aumento demografico registrato nel XIX secolo e con il primo sviluppo industriale. Tutto ciò ha favorito processi di degradazione verso formazioni a macchia, spesso innescati o favoriti anche dalle conseguenze degli incendi.

A partire dagli anni '50 del secolo scorso è stata registrata, in particolare sulle sponde nord del Mediterraneo, una inversione di tendenza. Le profonde trasformazioni socio-economiche di questo periodo, accompagnate da un forte calo del fabbisogno di legna da ardere e la conseguente riduzione della pressione antropica, delle utilizzazioni del bosco ceduo e del pascolo, hanno diminuito l'impatto su queste formazioni e, in alcune aree, comportato l'abbandono di qualsiasi tipo di pratica colturale. Alcuni studi realizzati nel bacino del Mediterraneo hanno dimostrato che l'interruzione della ceduazione, accompagnata o meno da interventi di avviamento ad alto fusto, ha innescato successioni secondarie caratterizzate da un incremento di funzionalità, complessità strutturale e ricchezza biologica dei soprassuoli (Ducrey e Toth 1992, la Marca et al. 1995, Amorini et al. 1996a, b, Cutini e Mascia 1996, Fabbio et al. 1996, Iovino e Menguzzato 2001, Ciancio et al. 2002, Dafis e Kakouros 2006, Fabbio 2010). In aggiunta, nei cedui in conversione è stato osservato un miglioramento delle disponibilità idriche sia nel suolo che nelle piante rilasciate (Cotillas et al. 2009, Di Matteo et al. 2009) con conseguente maggior resistenza alla siccità (Borghetti e Magnani 2009, Garfì et al. 2009).

In questo contesto si inserisce anche questa ricerca, impostata nel 1994 in una foresta mesofila di leccio della Sardegna meridionale per analizzare, a distanza di 9 anni dal diradamento, gli effetti del taglio di avviamento ad alto fusto.

In Sardegna i soprassuoli a prevalenza di leccio costituiscono il 22% della superficie forestale della regione, pari a 269.702 ha, rappresentando il 40% delle leccete italiane (INFC 2005). Il 47% delle leccete è rappresentato da cedui, la maggioranza dei quali sono matricinati o composti, in evoluzione naturale a causa della sospensione del taglio periodico. Quasi il 70% dei cedui di leccio sardi si può considerare adulto o invecchiato cioè prossimo o superiore al turno (INFC 2005). I soprassuoli a prevalenza di leccio più estesi e con maggiore valore bio-ecologico sono localizzati nelle foreste di proprietà demaniale e sono attualmente gestiti dall'Ente Foreste della Sardegna secondo criteri prioritariamente naturalistici e comunque orientati verso la multifunzionalità.

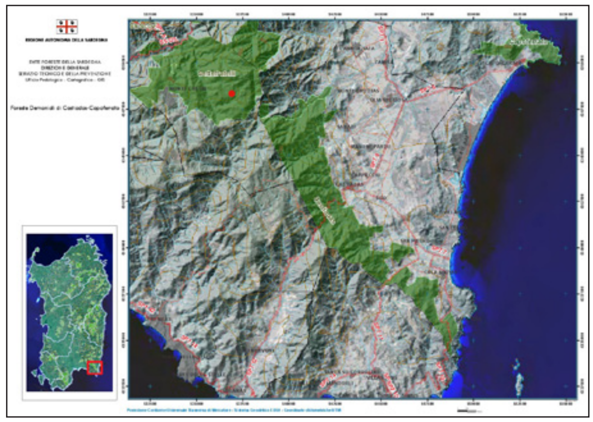

Figura 1 - Carta della Foresta Demaniale dei Settefratelli con l'ubicazione dell'area di studio (Ente Foreste della Sardegna).

Lo studio, condotto in due popolamenti di diversa fertilità stazionale in un arco temporale di 25 anni, si propone di descrivere l'evoluzione della struttura e della copertura, di valutare l'effetto del diradamento su efficienza e biodiversità dei soprassuoli, di fornire indicazioni colturali per la tutela, pianificazione e gestione attiva di tali formazioni.

Materiali e metodi

L'area di studio

L'area di studio si trova nel comprensorio della foresta demaniale dei Settefratelli (CA), uno dei luoghi più interessanti e affascinanti della Sardegna sud-orientale (regione del Sarrubus) attualmente soggetto a tutela paesaggistica, gestito dall'Ente Foreste della Sardegna ed inserito nel futuro Parco Naturale Regionale Settefratelli - Monte Genis (Fig. 1). La foresta ha una estensione di quasi 10.000 ha ed include l'omonimo massiccio montuoso costituito da affioramenti granitici modellati dall'erosione eolica e dal dilavamento che, con il tempo, hanno creato particolari formazioni morfologiche a torrioni da cui deriva il nome Settefratelli.

La lecceta, associata a elementi propri della macchia-foresta quali *Arbutus unedo*, *Phillyrea latifolia*, *Erica arborea*, *Rhamnus alaternus* e *Juniperus communis*, è la formazione forestale maggiormente diffusa. Fino alla fine del 1800 la foresta era assoggettata al regime d'uso in forma collettiva di legnatico, erbatico e ghiandatico, era mantenuta ad altofusto ed erano presenti anche leccete secolari e ultramature; solo agli inizi del secolo scorso ebbe inizio una intensa attività di taglio che si è protratta fino agli anni '50. Attualmente questi boschi sono cedui matricinati di leccio; alcuni avviati all'altofusto, altri in evoluzione naturale (Amorini et al. 1996a, b, Atzori 2004).

Secondo la Carta dei Suoli della Sardegna (1991) si tratta di paesaggi posti su rocce intrusive del Paleozoico e relativi depositi di versante, aree con forme da aspre a subpianeggianti, al di sotto di 800-1.000 m s.l.m., con prevalente copertura arbustiva ed arborea; i suoli da sabbioso-franchi a franco-sabbioso-argillosi, permeabili, da subacidi ad acidi, sono da poco profondi a profondi e

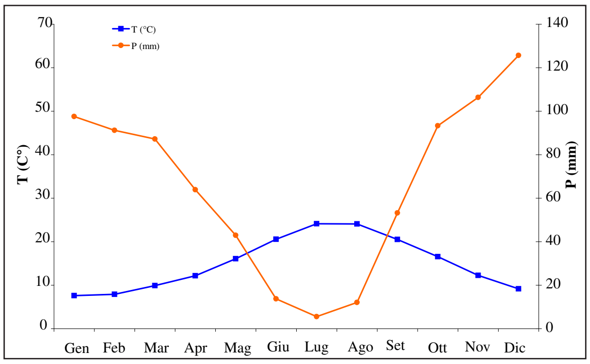

Figura 2 - Diagramma termo-pluviometrico della stazione Campuomu (380 m s.l.m., Burcei - CA) relativo al periodo 1922-2011.

presentano a tratti elevata pietrosità, eccesso di scheletro e forte pericolo di erosione. Il contenuto di sostanza organica è moderato (3%) e l'*humus* è di tipo mull da anellidi (Delogu e Passino 1983).

Per la descrizione del clima si dispone dei dati termopluviometrici della stazione di Campuomu (Idrografico di Cagliari, Regione Autonoma della Sardegna) posta presso la Caserma Forestale a 380 m s.l.m.. La temperatura media annua (periodo di osservazione 1924-2011) è di 15,1° C; il regime pluviometrico è tipicamente mediterraneo con 793 mm di pioggia annui (periodo di osservazione 1922-2011) e precipitazioni concentrate nel periodo autunno-inverno, mentre i mesi estivi sono fortemente siccitosi (Fig. 2).

Le aree di studio sono ubicate in località Acqueddas, ad una quota media di 765 m s.l.m., in una zona di altopiano, con una morfologia lievemente ondulata e poco acclive (3-5%). Oltre al leccio sono presenti corbezzolo in posizione generalmente dominata, e fillirea e alaterno con ruolo accessorio. Il soprassuolo attuale deriva da un ceduo matricinato avviato all'altofusto nel 1985, a 46 anni di età, con un diradamento selettivo di tipo misto. Il diradamento applicato (comunicazione orale) ha previsto sia l'intervento selettivo sulle singole ceppaie di leccio rilasciando 1-2 polloni migliori, sia la riduzione della densità delle specie associate.

Metodo

Nel 1994 furono realizzate due aree di saggio permanenti di 2.500 m^2 differenti per fertilità, struttura e densità (area A1 - N 39°16'34'' E 9°25'54'' e area A2 - N 39°16'27'' E 9°25'48'').

Il protocollo sperimentale (rilievi nel 1994-95 e nel 2010-11) ha previsto il monitoraggio delle principali variabili dendrometriche (diametro, altezza totale, altezza dominante, numero di piante ad ettaro, area basimetrica), lo studio della struttura tramite la realizzazione, in entrambe le aree di saggio, di due transetti (750 m^2), e la stima di alcuni parametri ecologici (LAI e trasmittanza).

Tutte le piante vive sono state numerate, è stata rilevata la circonferenza ad 1,30 m e la posizione sociale secondo 4 classi (D = dominante, I = intermedia, d = dominata, s = sottoposta). Nei transect è stata determinata la posizione topografica di ogni individuo, misurata l'altezza totale e quella di inserzione della chioma, l'area di insidenza della chioma secondo 8 raggi ortogonali, e rilevate le chiome delle piante esterne ma parzialmente ricadenti nel transect. L'elaborazione dei dati ha previsto la valutazione dell'altezza dominante e della copertura (grado di copertura e ricoprimento), la quantificazione della densità, dell'area basimetrica e del relativo incremento corrente, la stima della biomassa anidra attraverso l'uso di specifiche relazioni allometriche (Brandini e Tabacchi 1996), la determinazione di indici di diversità specifica e strutturale (Tab. 1).

All'inizio (1995) e alla fine (2011) del periodo di osservazione sono state effettuate misure di indice di area fogliare (LAI - Leaf Area Index) e di trasmittanza (radiazione solare trasmessa al suolo in percentuale rispetto a quella incidente il piano delle chiome), variabili caratteristiche della copertura forestale e capaci di evidenziare l'evoluzione della dinamica strutturale e la risposta agli interventi selvicolturali (Cutini 1994b e 1996, Cutini et al. 1998, Cutini et al. 2003). Le misure sono state effettuate mensilmente nel periodo di massima espansione fogliare, in corrispondenza di 9 punti distribuiti con criterio geometrico-sistematico in entrambe le aree di saggio. Per la stima dell'indice di area fogliare è stato utilizzato il Plant Canopy Analyser LAI 2000 (Li-Cor Lincoln NE USA); il rilievo è stato condotto in condizioni di radiazione diffusa (prossimità dell'alba o del tramonto) applicando un *cap* di 90° al sensore. La misura della radiazione fotosinteticamente attiva (PAR-

Tabella 1 - Caratteristiche degli indici di diversità scelti.

Descrizione indice	Formula con legenda	Bibliografia
Indice di diversità specifica di Shannon (SH), calcolato sia sul numero di fusti (SH-N) sia sui valori di area basimetrica (SH-G) relativi a ciascuna specie.	$SH = \sum(-\log_2 p_i)*p_i$ $p_i = n_i/N$ o g_i/G, n_i = numero di individui della specie i, g_i = area basimetrica della specie i, N = numero totale di individui, G = area basimetrica totale	Shannon 1948
Indice di diversità verticale (VE)	$VE = \sum((-\ln Ci)*Ci/\ln(ps))$ Ci = copertura relativa a ciascun piano sociale considerato, ps = numero di piani sociali	Neumann e Starlinger 2001
Indice di diversità orizzontale (CI)	$CI = S^2/X$ S^2 = varianza, X = media del numero di piante presenti all'interno delle subaree	Strand 1953, Cox 1971

Tabella 2 - Acqueddas - Foresta dei Settefratelli - Aree A1 e A2. Principali parametri dendrometrici rilevati nel 1994 e nel 2010, natalità (%N) e incremento corrente (Ic) relativi al periodo di monitoraggio.

		AREA A1				AREA A2			
		1994	2010	%N	Ic	1994	2010	%N	Ic
Numero ad ettaro	Leccio	1044	1068	2		808	832	3	
(n ha-¹)	Corbezzolo	268	608	56		416	1984	79	
	Altre	16	40	60		40	96	58	
	Totale	**1328**	**1716**	**23**		**1264**	**2912**	**57**	
Area basimetrica ad ettaro	Leccio	29,1	41,2		0,76	20,0	30,2		0,64
(m^2 ha-¹)	Corbezzolo	2,9	3,1		0,02	4,8	8,4		0,23
	Altre	0,1	0,2		0,01	0,3	0,2		0,00
	Totale	**32,1**	**44,5**		**0,78**	**25,1**	**38,8**		**0,86**
Diametro medio (cm)	Leccio	18,8	22,2		0,21	17,8	21,5		0,23
	Corbezzolo	11,7	8,0		-0,23	12,1	7,3		-0,30
	Altre	8,5	6,9		-0,10	9,6	5,6		-0,25
	Totale	**17,5**	**18,1**		**0,04**	**15,9**	**13,0**		**-0,18**
Altezza media (m)		**10,9**	**14,2**		**0,21**	**6,8**	**9,7**		**0,18**
Biomassa epigea ad ettaro									
(Mg ha-¹)	Leccio	140,3	301,8		10,10	73,5	185,8		7,02
	Corbezzolo	10,4	10,4		0,00	17,3	27,5		0,64
	Altre	0,3	0,5		0,01	1,0	0,7		-0,02
	Totale	**151,0**	**312,7**		**10,11**	**91,9**	**214,0**		**7,64**

Photosynthetically Active Radiation) per la determinazione della trasmittanza è stata effettuata utilizzando ceptometri (Sunfleck SF-80, AccuPAR model PAR-80 e LP-80, Decagon Devices Inc. Pullman, WA, USA); il rilievo è stato condotto in condizioni di radiazione diretta (mezzogiorno), mettendo in relazione le misure sottocopertura con quelle di riferimento effettuate in aree aperte (Cutini 1994b e 1996).

Infine sono stati determinati il LWR (*leaf weight ratio*) ossia il rapporto tra LAI e biomassa anidra epigea totale, ed il RGR (*relative growth rate*, modificato per il popolamento) dato dal rapporto tra incremento corrente periodico di biomassa anidra e indice di area fogliare (LAI).

Risultati

Le principali caratteristiche dendrometriche delle aree oggetto di studio sono riportate in Tab. 2. Nel 1994 (Fabbio et al. 1996) gli indicatori analizzati avevano evidenziato sia la differente fertilità delle due aree, sia il ruolo principale svolto dal leccio (91 e 80% dell'area basimetrica complessiva nell'area 1 e 2 rispettivamente). La quercia presentava il contributo maggiore nel piano dominante, mentre il corbezzolo e le altre specie mantenevano una presenza accessoria, limitata allo strato arboreo dominato.

Nel 2010 dopo 25 anni dal diradamento, si osserva un aumento consistente del numero di piante ad ettaro in entrambe le aree (A1 +23% e A2 +57%) ma particolarmente evidente nell'area 2 dove il corbezzolo si è notevolmente diffuso (natalità pari al 79%); l'abbondanza del leccio è invece rimasta immutata in ambedue i casi. Per quanto riguarda l'area basimetrica complessiva nell'ultimo inventario si osservano valori di 44,5 m^2 ha^{-1} nell'area A1 e di 38,8 m^2 ha^{-1} nell'area A2; il contributo del leccio è preponderante in entrambe le aree con valori di 41,2 m^2 ha^{-1} nella A1 (quasi il 93% dell'area basimetrica totale) e di 30,2 m^2 ha^{-1} nella A2 (quasi il 78% dell'area basimetrica totale); il corbezzolo invece mantiene un ruolo complementare rispetto alla quercia, ma maggiore nell'area A2 (8,4 m^2 ha^{-1} ossia circa il 21% dell'area basimetrica totale).

L'incremento corrente di area basimetrica registrato tra i due inventari (1994 e 2010) è risultato di 0,77 m^2 ha^{-1} an^{-1} nell'area A1, quasi completamente a carico del leccio (0,76 m^2 ha^{-1} an^{-1}), simile ma leggermente inferiore rispetto all'A2 (0,86 m^2 ha^{-1} an^{-1}) dove peraltro il contributo del corbezzolo è rilevante (0,23 m^2 ha^{-1} an^{-1}). Il diametro medio del leccio aumenta nel periodo considerato in entrambe le aree (A1=0,21 cm an^{-1} e A2=0,18 cm an^{-1}), mentre sia il corbezzolo sia le altre specie subiscono una riduzione del valore diametrico medio per l'ingresso di nuove piccole piante.

La biomassa epigea per unità di superficie, relativa al 2010, presenta valori maggiori nell'area A1 (A1=312,7 Mg ha^{-1} e A2=214,0 Mg ha^{-1}), ad indicare una maggiore produttività e fertilità (Tab. 3), che si mantiene e si incrementa nel tempo. Ciò è confermato dall'altezza dominante (Hd), che evidenzia valori maggiori nell'area A1 (10,9 m nel 1994 e 16,7 m nel 2010) rispetto all'area A2 (9,4 m nel 1994 e 14,4 m nel 2010).

Anche gli indici di diversità strutturale (Tab. 3) sottolineano bene le differenze tra le due aree. Sul piano orizzontale è stata riscontrata una maggiore omogeneità

Tabella 3 - Acqueddas - Foresta dei Settefratelli - Aree A1 e A2. Alcuni indici e parametri di diversità strutturale e specifica analizzati: fertilità (Hd), diversità sul piano orizzontale (CI) e verticale (VE), grado di copertura (C) e ricoprimento (R), diversità specifica (SH-N e SH-G).

	AREA A1		AREA A2	
	1994	2010	1994	2010
Altezza dominante Hd (m)	10,9	16,7	9,4	14,4
Diversità orizzontale (CI)	0,61	1,53	1,53	7,08
Diversità verticale (VE)	0,25	0,32	0,55	0,52
Copertura (C %)	80	89	62	98
Ricoprimento (R %)	125	126	109	172
Diversità specifica (SH-N)	0,92	1,09	1,12	0,96
Diversità specifica (SH-G)	0,44	0,39	0,87	0,99

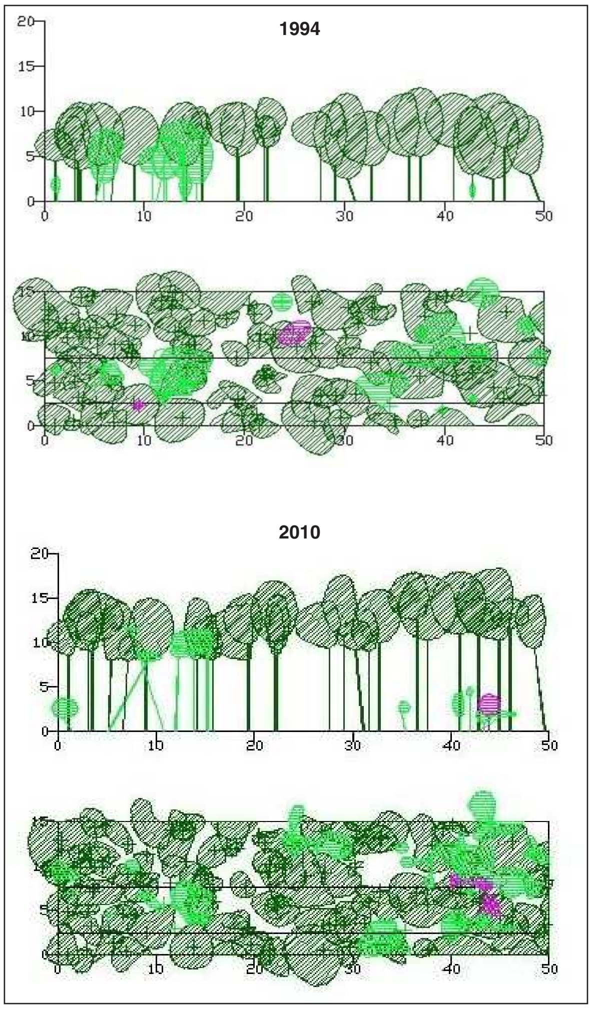

Figura 3 - Foresta dei Settefratelli - Acqueddas. Visualizzazione della struttura orizzontale e verticale del transect 1 nel 1994 e nel 2010 (■Quercus ilex; ■Arbutus unedo; ■altre specie).

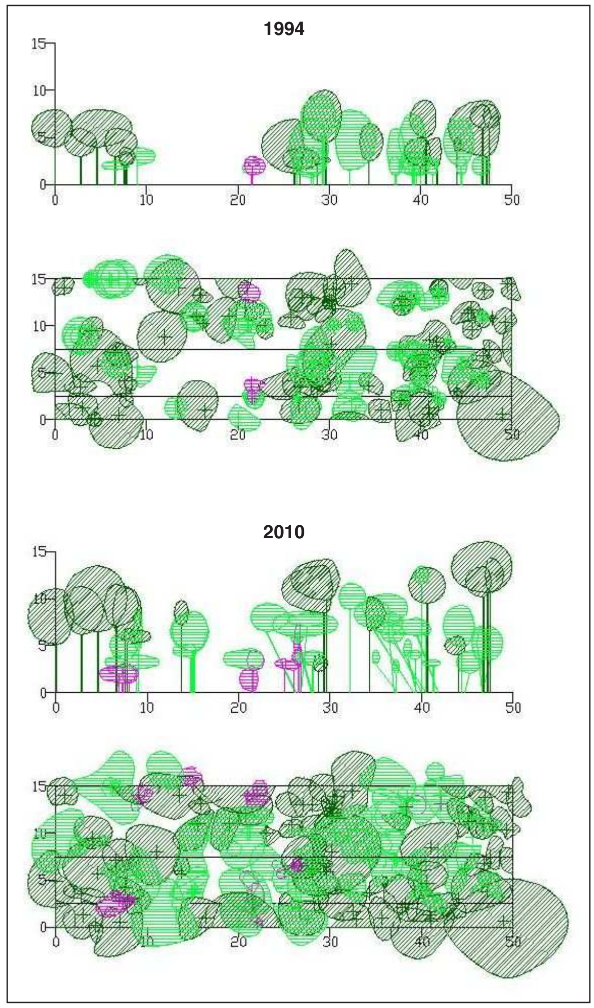

Figura 4 - Foresta dei Settefratelli - Acqueddas. Visualizzazione della struttura orizzontale e verticale del transect 2 nel 1994 e nel 2010 (■Quercus ilex; ■Arbutus unedo; ■altre specie).

strutturale nell'area A1 (CI = 0,61 e 1,53), e una struttura a gruppi, già evidente nel 1994 ma ancora più accentuata in seguito alle dinamiche evolutive occorse in 25 anni, nell'area A2 (CI = 1,53 e 7,08). La struttura sul piano verticale è risultata tendenzialmente monoplana in entrambe le aree e gli inventari, anche se una maggior articolazione è stata registrata nella A2. Il grado di copertura si mantiene relativamente costante nell'area A1 (C = 80% e 89%) ed indica una chiusura pressoché completa già nel 1994 (Fig. 3). Nel primo inventario l'area A2 (Fig. 4) era contraddistinta dalla presenza di ampi vuoti (C = 62%), che sono stati poi completamente colonizzati (C = 98% nel 2010). Il grado di ricoprimento (R) segue lo stesso trend mantenendo valori elevati e simili nel tempo nell'area A1 (R = 125% e 126%) e accrescendosi notevolmente nell'area A2 (R = 109% e 172%), in seguito alla diversa presenza e distribuzione spaziale del leccio e del corbezzolo. La diversità specifica calcolata sia in funzione del numero di piante che dell'area basimetrica non è molto elevata in entrambe le aree e non subisce significative variazioni tra i due inventari. Le principali differenze possono essere attribuite al diverso peso e ruolo che il leccio e il corbezzolo hanno assunto nel tempo nelle due aree. Nell'area A1 il leccio risulta preponderante sia in termini numerici che in area basimetrica e i rapporti tra le specie si mantengono costanti nel tempo. Nell'area A2 invece il peso relativo del leccio si riduce fortemente in termini numerici e leggermente anche in area basimetrica con il conseguente aumento del corbezzolo e in definitiva del valore di SH-G nel 2010.

Relativamente ai parametri ecologici, in Fig. 5 si riportano graficamente i dati di indice di area fogliare (LAI) stimati nelle due aree a inizio e fine periodo di studio. Nel 1995, i valori di indice di area fogliare erano modesti (pari a 2,56 ± 0,16 m^2 m^{-2} e 2,35 ± 0,18 m^2 m^{-2} rispettivamente nell'area Al e A2) e senza differenze significative tra le due aree. A distanza di 16 anni, il LAI risulta raddoppiato nell'area A1 (5,16 ± 0,34 m^2 m^{-2}) e incrementato del 60% nella A2 (5,86 ± 0,12 m^2 m^{-2}), anche se permane l'assenza di differenze significative tra le due aree. In maniera analoga si comporta la trasmittanza (Fig. 6) che si riduce da 10,17 ± 2,21 % (A1) e 10,17± 0,98 % (A2) registrata nel 1995 a 2,91 ± 0,70 % e 3,17 ± 0,56 % rispettivamente nell'area A1 e A2 nel 2011.

I valori di Leaf Weight Ratio (LWR) sono risultati costanti nel tempo e, unitamente a quelli del Relative Growth Rate (RGR), definiscono la maggior efficienza in termini di allocazione delle risorse dell'area A1 (Tab. 4), caratterizzata da valori inferiori di LWR (1,6 contro 2,7 dell'area A2 nel

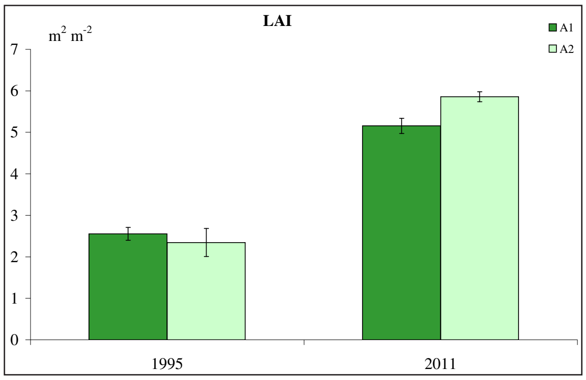

Figura 5 - Foresta dei Settefratelli - Acqueddas. Indice di area fogliare (LAI), relativo agli anni 1995 e 2011 nelle due aree (A1 e A2).

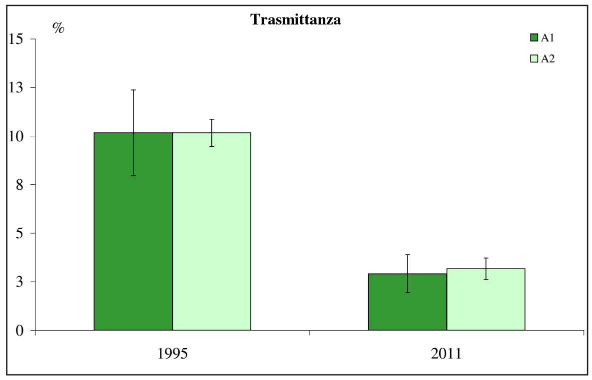

Figura 6 - Foresta dei Settefratelli - Acqueddas. Trasmittanza (%) media annua relativa agli anni 1995 e 2011 nelle due aree (A1 e A2).

2010) e maggiori di RGR (2,6 contro 1,9).

Discussione e conclusioni

Le principali variabili dendrometriche (densità e area basimetrica) analizzate collocano i popolamenti oggetto di studio nel *range* di variazione registrato da Gracia e Retana (1996) per popolamenti spagnoli strutturalmente simili. Valori maggiori sono stati invece rilevati in un ceduo invecchiato di 55 anni del Gargano (Marziliano 2009) e in cedui avviati ad alto fusto nella Foresta di Is Cannoneris (Amorini et al. 1996a, b, Bertini et al. 2012). Quest'ultima peraltro si caratterizza per tassi di accrescimento superiori (Amorini et al 1996a) a quelli riscontrati in questo studio per la maggior fertilità stazionale. Coerentemente con gli indicatori dendrometrici, pure i valori di biomassa sono tendenzialmente collocati al di sopra dei valori medi osservati in altre aree del Mediterraneo (Retana et al. 1992, Mayor e Rodà 1993, Huc e Ducrey 1996, Amorini et al. 1996a, b, Bonin e Romane 1996, Enjabal et al. 1996).

Anche i valori di LAI sono risultati superiori a quelli riscontrati in un ceduo di leccio di 30 anni dopo 10 anni dal diradamento (Huc e Ducrey 1996) e simili a quelli rilevati in due popolamenti puri di leccio siti nel nord-est della Spagna (Sala et al. 1994).

Le differenze tra le aree in termini di fertilità stazionale ed intensità del taglio di avviamento hanno condizionato quantitativamente e qualitativamente le dinamiche evolutive del soprassuolo.

Nel 1994, a distanza di 9 anni dal primo intervento di diradamento i dati hanno evidenziato in entrambe le aree, una struttura estremamente semplificata, una scarsa diversità specifica, una ridotta copertura, valori di LAI bassi e di trasmittanza piuttosto elevati in considerazione delle caratteristiche della specie. Questi caratteri sono risultati più accentuati nell'area A2, meno fertile e dotata di una copertura contraddistinta da vuoti consistenti. I valori degli indici di diversità strutturale hanno evidenziato popolamenti tendenzialmente monoplani ed una modalità di aggregazione sul piano orizzontale regolare nell'area A1 e a gruppi nella A2.

Nel 2010, 25 anni dopo il taglio di avviamento, è stato registrato un aumento consistente del numero di piante ad ettaro in ambedue le aree, particolarmente marcato nell'area A2 dove il corbezzolo ha colonizzato la maggior parte dei vuoti nella copertura che si erano creati con l'intervento di diradamento. Ciò ha provocato un rafforzamento della struttura a gruppi, mentre non ha influenzato né la diversità sul piano verticale né la diversità specifica, relativamente modesta ma comunque in linea con quella riscontrata in altri popolamenti cedui di leccio invecchiati (la Marca et al. 1995, Manetti et al. 2009). Al contrario, nell'area A1, più fertile e caratterizzata da una minore riduzione di densità, la copertura è prevalentemente costituita dal leccio con un basso indice di stratificazione verticale. La chiusura quasi totale del piano delle chiome in entrambe le aree è sottolineata dai parametri della copertura analizzati che hanno evidenziato una netta riduzione della trasmittanza e un aumento consistente sia dell'indice di area fogliare sia del grado di sovrapposizione delle chiome. Anche se il trattamento applicato ha ridotto la copertura arborea in entrambe le aree, e in modo particolare nell'area A2 oltretutto anche meno fertile, il recupero dopo 25 anni è stato analogo e ciò conferma alcuni risultati precedentemente ottenuti (Amorini et al. 1996a, b, Fabbio et al. 1996, Cutini 2002), ovvero che la maggiore entità di prelievo non incide in modo sostanziale sui caratteri della copertura arborea a lungo termine.

Infine anche i risultati riguardanti il Leaf Weight Ratio (LWR) e il Relative Growth Rate (RGR) indicano una migliore efficienza nell'uso delle risorse nell'area A1 per la prevalenza della biomassa legnosa rispetto alla quantità di foglie (Cutini 1994a).

Nel complesso i risultati hanno evidenziato la reazione positiva del popolamento al taglio di avviamento in termini di accrescimento e di recupero della copertura in entrambe le aree, anche se l'eccessiva riduzione della den-

Tabella 4 - Acqueddas - Foresta dei Settefratelli. Valori percentuali di Leaf Weight Ratio (LWR) e Relative Growth Rate (RGR) registrati nelle due aree.

	Area A1	Area A2
LWR 1994	1,7	2,6
LWR 2010	1,6	2,7
RGR	2,62	1,84

sità nell'area A2 non ha permesso la completa ricostituzione della copertura da un punto di vista qualitativo.

In conclusione si può affermare che la politica del taglio di avviamento può essere perseguita anche in situazioni di produttività non ottimali, modulando l'intensità e la modalità di prelievo in funzione delle condizioni stazionali, della fertilità e della composizione specifica della componente arborea e arbustiva.

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Research paper

Assessing impact of forest cover change dynamics on high nature value farmland in Mediterranean mountain landscape

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Abstract - A general trend of scrub encroachment and natural forest expansion (old-field succession) has been occurring in the past fifty years in Mediterranean mountain areas. While this phenomenon enhances a series of ecological processes and environmental services, it may represent a threat for biodiversity conservation when occurring on High Nature Value (HNV) extensive farmland. These open areas, created by traditional farming systems, have been recognized as a critically important European biodiversity resource. Understanding the drivers of Land Use and Land Cover Change (LUCC) and their implications on the dynamics of forest and HNV farmland habitats plays a crucial role in biodiversity conservation in protected areas. In this perspective, the case study here presented aims to model recent (1989-2008) LUCC in a National Park of the Central Apennines (Italy) and to produce a mid-term forecast (2008-2020). In the past twenty years, 57% of the land uptake by shrubland and 46% by forest has been occurring on former HNV farmland. Mid-term projections (2008-2020) confirm further HNV farmland decline. Localization of HNV farmland habitats vulnerable to change is a valuable decision-making tool to tradeoff in protected areas the conservation of traditional landscapes with the increase of forest and shrubland areas. In this perspective, concrete socio-economical and silvicultural measures are outlined to preserve these socially and economically-fragile open habitats.

Keywords - forest dynamics, Land Use and Land Cover Changes, spatial drivers, High Nature Value farmland

Introduction

Mountain environments of Southern Europe host significant biodiversity associated to a landscape mosaic, characterized by a high proportion of forest and low-input farmland habitats, like extensively grazed uplands, alpine meadows and pastures. While the key role of forests in biodiversity conservation is widely acknowledged, it is only recently that open habitats created by traditional farming systems have been recognized as a critically important European biodiversity resource (Baldock et al. 1993, Beaufoy et al. 1994), gaining the title of high nature value (HNV) farmland (EEA 2006, Paracchini et al. 2008). HNV farmland designates areas where agriculture supports, or is associated with, either a high species and habitat diversity or the presence of species of European conservation concern, or both. In fact, many grassland and heaths listed in the Annex I of the Habitats Directive depend on, or are associated with, extensive agricultural practices, like priority habitats 6210* (Semi-natural dry grassland and scrubland *facies* on calcareous substrates) and 6230* (Species-rich *Nardus* grassland on siliceous substrates in mountain areas). About half of Europe's endemic species depends on grassland and declining trends in the population of farmland birds and butterflies depend very much on the loss of HNV farmland (EEA 2010).

The landscape mosaic of forest and open habitats associated to extensive agriculture was relatively stable in Southern Europe until the 1950s. Since then, rapid changes in land use (intensification of agriculture, urbanisation, land abandonment and movement towards urban areas) has led to the widespread collapse of the socio-economic systems that supported these economically fragile farming systems.

The decrease of agricultural and pasture activities has determined the progressive colonization of grassland and agricultural lands by shrubland and forest. Moreover, the abandonment of management of trees outside forest in agricultural areas resulted in their spatial aggregation and the creation of new forest patches. In Mediterranean areas this general trend of scrub encroachment and natural forest expansion has been clearly documented in the past fifty years (Tatoni et al. 1994, Debussche et al. 1996, Bonet 2004, Pugnaire et al. 2006, Corona et al. 2008, Barbati et al. 2013). This phenomenon, also known as old-field succession, on one hand enhances a series of ecological processes and environmental

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services, but on the other hand may represent a threat for biodiversity conservation, when occurring on HNV farmland. The disappearance of cultural landscapes with a consequent increase of woodland cover is partially causing the decline of open habitats and associated species in the Mediterranean Basin (Finck et al. 2002, Mazzoleni et al. 2004, Bracchetti et al. 2012).

Understanding the drivers of Land Use and Land Cover Change (LUCC) and their implications on the dynamics of forest and HNV farmland habitats plays a crucial role in biodiversity conservation in protected areas. In this context, the development of robust models to project future LUCC might represent a valuable decision-making supporting tool to outline natural habitats vulnerable to change and to target land planning measures. According to this perspective, in this paper we present a case study in the Gran Sasso and Monti della Laga National Park (PNGSML), a high conservation value area, containing 32 Sites of Community Importance (SCI; Habitats Directive 92/43/EEC). The whole area is also recognized as Special Protection Area (SPA; Birds Directives 79/409/EEC).

The objectives of this study are: (i) to quantify the LUCC in the PNGSML focusing on recent dynamics of forest and shrubland expansion (period 1989-2008) and the related impacts on HNV farmland; (ii) to understand driving forces of the LUCC in the investigated area; (iii) to apply a LUCC model to predict future land cover scenario in order to identify areas and habitats most prone to LUCC in the upcoming decades.

Materials and methods

Study area and land cover history

PNGSML was established in 1995 and has become one of the largest protected areas in Italy. It spans over 143,300 ha in the Apennines mountains of central Italy (42° 10' N - 42° 50'N, 13° 10' E - 13° 16' E). Its elevation ranges from 225 to 2,908 m above sea level with an average elevation of 1,300 m above sea level (Fig. 1).

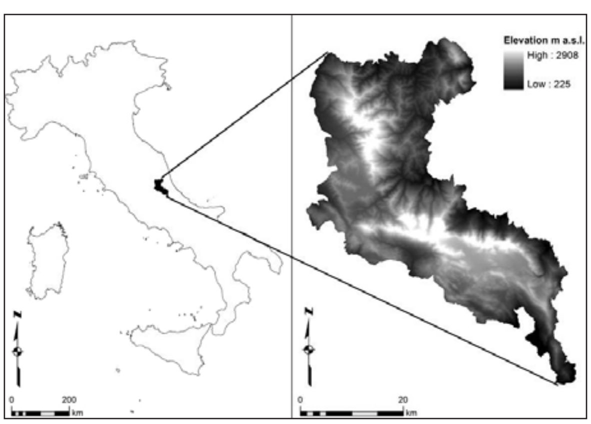

Figure 1 - Location of study area, the Gran Sasso and Monti della Laga National Park (PNGSML) in Central Apennines.

Table 1 - Park zoning of PNGSML

	Park zoning	Proportion of total PNGSML area (%)
A	strict nature reserve	11
B	general reserve with traditional sustainable use of natural resources by residents	41
C	protected landscape where new tourism, farming, pastoral and forestry activities may be permitted	39
D	economic and social promotion areas	9

Woodlands can be classified into six forest types: (i) beech forest (the dominant tree vegetation in the area), (ii) oak forest, (iii) hornbeams forest, (iv) chestnut forest, (v) mixed forest (which includes *Abies alba* remnants), (vi) riparian forest. HNV habitats are mainly represented by grassland notably priority habitats (Dir. 92/43/CEE) 6210* (Semi-natural dry grassland and shrubland *facies* on calcareous substrates) and 6230* (Species-rich *Nardus* grassland). According to the National Law on protected areas in Italy, Park zoning represents the main planning tool to pursue management objectives and to reconcile potential conflicts through a regulation of land use activities: zones vary from the strict level of protection (A Zone) to areas supporting sustainable land use activities (D Zone) (Tab. 1).

In the case of PNGSML, promoting local sustainable development becomes a key management issue also for the conservation of grassland, maintained by traditional pastoral activity. Like in other areas of the Apennines, the socioeconomic structure has been considerably altered after World War II. The population of mountain villages dropped greatly up to the first half of 1960s (Catorci 2007), while the inhabitants in the town of L'Aquila increased until 1970 and then stabilized. Today, the number of inhabitants living inside the PNGSML boundaries is 12% of the total population (137,635) of the 44 municipalities of the Park (ISTAT 2011).

Multi-temporal database and ancillary data

A summary of datasets processed for the study area is reported in Tab. 2. LUCC in the period 1989-2008 has been analyzed on the basis of high resolution land cover maps (minimum mapping unit: 0.5 ha) derived by visual interpretation of orthophotos images. Three broad land cover classes were adopted for mapping land cover in the considered period (1989-2008): (i) forest, (ii) shrubland, (iii) non-forest area. Forest and shrubland were classified according

Table 2 - Statistics of land use and land cover datasets used in the case study.

Year	Land cover datasets	Minimum mapping unit (ha)
1989	Land cover map from digital B/W orthophoto (TERRAITALY 1988/89)	0.5
1990	CLC	25
2006	CLC	25
2008	Land cover map from digital color) orthophoto (TERRAITALY 2008	0.5
2010	Land cover map from digital color orthophoto (Abruzzo Region)	0.5

to FAO/FRA2000 definition (UN/FAO 2001); non-forest class includes agricultural land, fallow land, grassland, bare ground and rocks, and settlements.

Besides the two maps at the year 1989 and at the year 2008 over the whole PNGSML territory, a third reference map, used as independent validation set, was also derived by the same method, to classify the land cover at 2010 for L'Aquila province territory included in PNGSML. To detect links between LUCC processes and the loss of HNV farmland, the Corine Land Cover (CLC) datasets (years 1990 and 2006) have been used to assess, on a coarser spatial scale, the distribution of HNV farmland in the PNGSML at the beginning and at the end of the reference period adopted for analyzing LUCC (1989-2008), following the methodology proposed by Paracchini et al. (2008).

The multi-temporal land cover databases were integrated with georeferenced ancillary information (Tab. 3). Spatial information on physiographic attributes (elevation, slope, aspect) was derived from the Digital Elevation Model (DEM, 20 m geometrical resolution). Road network was drawn from official cartographic sources provided by the PNGSML, urban areas were extracted from 2006 CLC map. As census observations indicate that population density in the study area was nearly stable during the investigated period (ISTAT 2011), inhabitants density at Municipality level for 1989 was used as reference data in this study. All spatial data were transformed to raster format with 20 m spatial resolution to match the DEM raster grid.

Forest cover change and future scenario

The integrated module of IDRISI Taiga Land Change Modeler (LCM) (Clark Labs, 2009) was used to model LUCC in the investigated period (1989-2008) and to predict a future scenario according to the steps showed in Fig. 2.

The LCM aggregates a Multi-layer Perceptron (MLP) and Markov Chains Analysis (MCA) for time prediction. The MLP neural network algorithm returns potential transition maps of each land cover class (Eastman 2009) modelling all transitions at once. The potential transition model serves as the basis for the future scenario of forest cover using a MCA. This process calculates the conditional probability of the state of a system at a given time (time t), based on the state of the system at the previous time (time t_0, with $t_0 < t$) (Reddy et al. 2009).

We assumed that (i) future LUCC dynamics (2008-2020) follows the same trend of the past twenty years (1989-2008), (ii) the changes in forest/shrubland cover most likely occur in areas close and/or adjacent to areas affected by recent changes. LCM has been run twice in this study: first to produce a short-term LUCC forecast (2010) and second to produce a mid-term forecast (2020).

The accuracy of the land cover forecast map at year 2010 was assessed by comparison with the reference map at the year 2010 for the L'Aquila province territory. Accordingly, a matrix of classification errors, Overall Accuracy (OA) index and Kappa Index of Agreement (KIA) were calculated; the Accuracy of User (AU) and the Producer (AP) were also estimated for each class (Congalton 1991).

Predictions of LUCC scenario for the year 2020 were processed in a hard prediction map to show the estimated spatial distribution of land cover classes according to results of the MCA.

Drivers of LUCC

The spatial pattern of areas affected by forest and shrubland expansion was analysed according to the set of independent spatial drivers (Tab. 1 and Tab. 3): (i) physiographic variables (aspect, elevation, slope); (ii) demographic variable (population density); (iii) distance variables, i.e. Euclidean distances between areas affected by LUCC and elements such as roadway infrastructure, town/village centres and forest edges; (iv) PNGSML zones.

A change/persistence density analysis was carried out to identify the spatial drivers most related to the spatial pattern of forest and shrubland expansion. The method is based on spatial overlay of change/persistence maps with the set of spatial drivers. Change/persistence maps were derived as

Table 3 - Statistics of spatial drivers datasets used in the case study.

Spatial drivers	Source	Unit	Mean	Coefficient of variation
slope	DEM	%	42.1	0.66
elevation	DEM	m	1,281	0.31
aspect	DEM	cosine	0.03	23.6
		sine	-0.004	177
population density	ISTAT	inhab. ha^{-1}	0.32	1.5
distance from town/village center	CLC	m	4,759	0.64
distance from road	PNGML	m	777	0.81
distance from forest edge	2008 land cover map	m	149	2.23

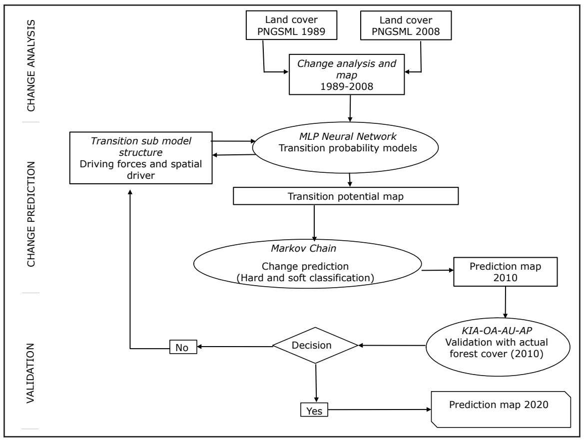

Figure 2 - Flow chart of the LUCC analysis.

Boolean raster pictures plotting the non-forest areas at the year 1989 converted to forest or shrubland at the year 2008 (change) and the remaining stable ones (persistence). The spatial overlay of the change/persistence maps with the geospatial ancillary information allowed to calculate the density of change or persistence by single spatial drivers, as follows:

$$d = \frac{r_i}{\sum_{i=1}^{n} r_i} \quad [1]$$

where d is density of change, r_i is the ratio between the area occupied by change and the whole surface in the i-th class of the considered independent variable and n is the total number of classes. Such an analysis allows comparing, by independent spatial drivers, the relative proportion of areas affected by changes and the remaining stable ones.

Results

LUCC and loss of HNV farmland

Land cover change in the past twenty years occurred in 4,871 ha of the PNGSML territory, corresponding to 3.4% of total area (Tab. 4). Forest spreading is the most relevant LUCC process, occurring on the 2.1% of the area; shrubland encroachment occurred on 1.2%. Forest spreading is mainly due to the evolution of areas covered by shrubland in 1989 into forest habitats (1.5% of the territory), thus causing a slight decline of shrubland habitats (-0.34%). Non-forest land cover classes affected by forest and shrubland expansion in the period 1989-2008 are identified by spatial overlay of the high resolution 2008 land cover map with 1990 CLC map (Tab. 5). A significant proportion of non/forest areas colonized by shrubland and forest (57% and 46%, respectively) were located in HNV farmland in 1990, to a large extent represented by grassland.

Table 4 - Transition matrix of LUCC from the year 1989 to the year 2008 (values expressed as percentage of the PNGSLM territory).

Land cover class		2008 shrubland	forest	non-forest
1989	*shrubland*	7.30	1.44	0.08
	forest	0.01	50.83	0.01
	non-forest	1.17	0.69	38.47
	total change	-0.34	2.11	-1.77

Table 5 - Land uptake by shrubland and forest in the period 1989-2008 by HNV and other land use classes.

		Shrubland		Forest	
	Land cover class	ha	% of total land uptake	ha	% of total land uptake
HNV farmland	olive groves	1.1	0.07	2.8	0.29
	pastures	17.2	1.03	23.8	2.39
	complex cultivation patterns	12.2	0.73	10.6	1.06
	lands principally occupied by agriculture	165.7	9.90	122.6	12.30
	natural grassland	749.4	44.80	290.4	29.14
	moors and heatland	2.3	0.14	3.5	0.35
	total of HNV land use classes	*947.9*	*56.66*	*453.7*	*45.54*
Other land use classes	discontinous urban fabrics	0.3	0.02	-	-
	arable lands	67.6	4.04	44.2	4.44
	broad-leaved forests	371.6	22.21	370.6	37.20
	coniferous forests	15.8	0.95	13.4	1.34
	mixed forests	7.6	0.46	30	3.01
	transitional woodland-shrubs	234.4	14.01	79.6	7.99
	bare rocks	6.2	0.37	0.04	0.00
	sparsely vegetated areas	21.5	1.29	4.7	0.48
	water bodies	0.05	0.00	-	-
	total of other land use classes	*725.1*	*43.34*	*542.5*	*54.46*

Characterization of forest cover change according to spatial drivers

Change/persistence density statistics by environmental spatial drivers are shown by Fig. 3 and Fig. 4. Forest and shrubland expansion occurred mainly on elevations below 1,000 m, with a low slope gradient (< 40%). Distance-related variables show that change was higher near the edge of forest (≤ 500 m) and near the roads (≤ 500 m). Aspect and proximity to urban settlements have a less clear effect. However, much change (40%) occurs in the neighbourhood of villages (distinctively, within the first 3 km). Concerning functional zoning of PNGSML, the areas corresponding to strict and integral protection (zone A and zone B) are more stable compared to the C and D zones.

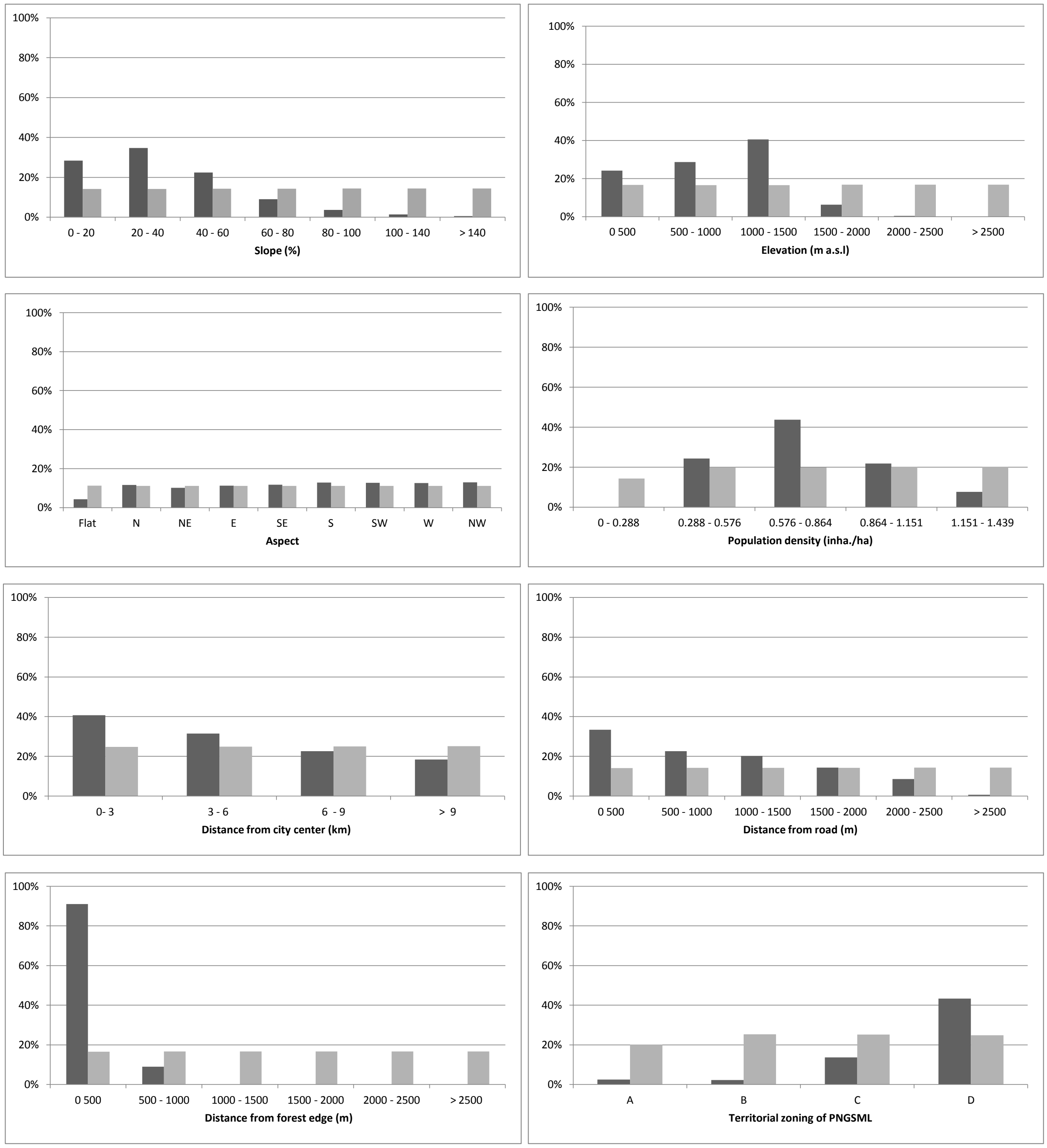

Figure 3 - Density (y-axis, values expressed as percentage) of change from non-forest areas to shrubland (dark grey) and no-change areas and other transitions (light grey) with respect to the considered spatial drivers. Data for the continuous variables (elevation, slope, aspect, density, distance from town/village center, distance from road and from forest edge) are shown by class intervals (x-axis).

Location and forest cover scenario

The transition probability matrix of LUCC in the period 2008-2010 is shown in Tab. 6. The diagonal cells represent the probability for a given land cover class to remain stable, whereas the off-diagonal values indicate the probability of a change from one land cover class to another. Results of the accuracy assessment of the model prediction at year 2010 are highly satisfactory (KIA and OA index > 0.99), as reported in Tab. 7.

The PNGSML areas prone to change cover class have been identified (Fig. 5) by projecting the transition potential observed in the period 1989-2008 into the future (year 2020), based on the transition probability matrix shown in Tab. 8. The projected landscape is characterized by an increase in forest areas and a persistence of shrubland (Tab. 9). Most non-forest land projected to be colonized by shrubland and forest in the period 2008-2020 is localized on areas currently covered by HNV farmland, 42% and 36% respectively (Tab. 10).

Discussion

LUCC analysis in the PNGSML territory reveals a general trend from 1989 to 2008 characterized by a continuous increase in forest cover, confirming the trend documented over Mediterranean Europe

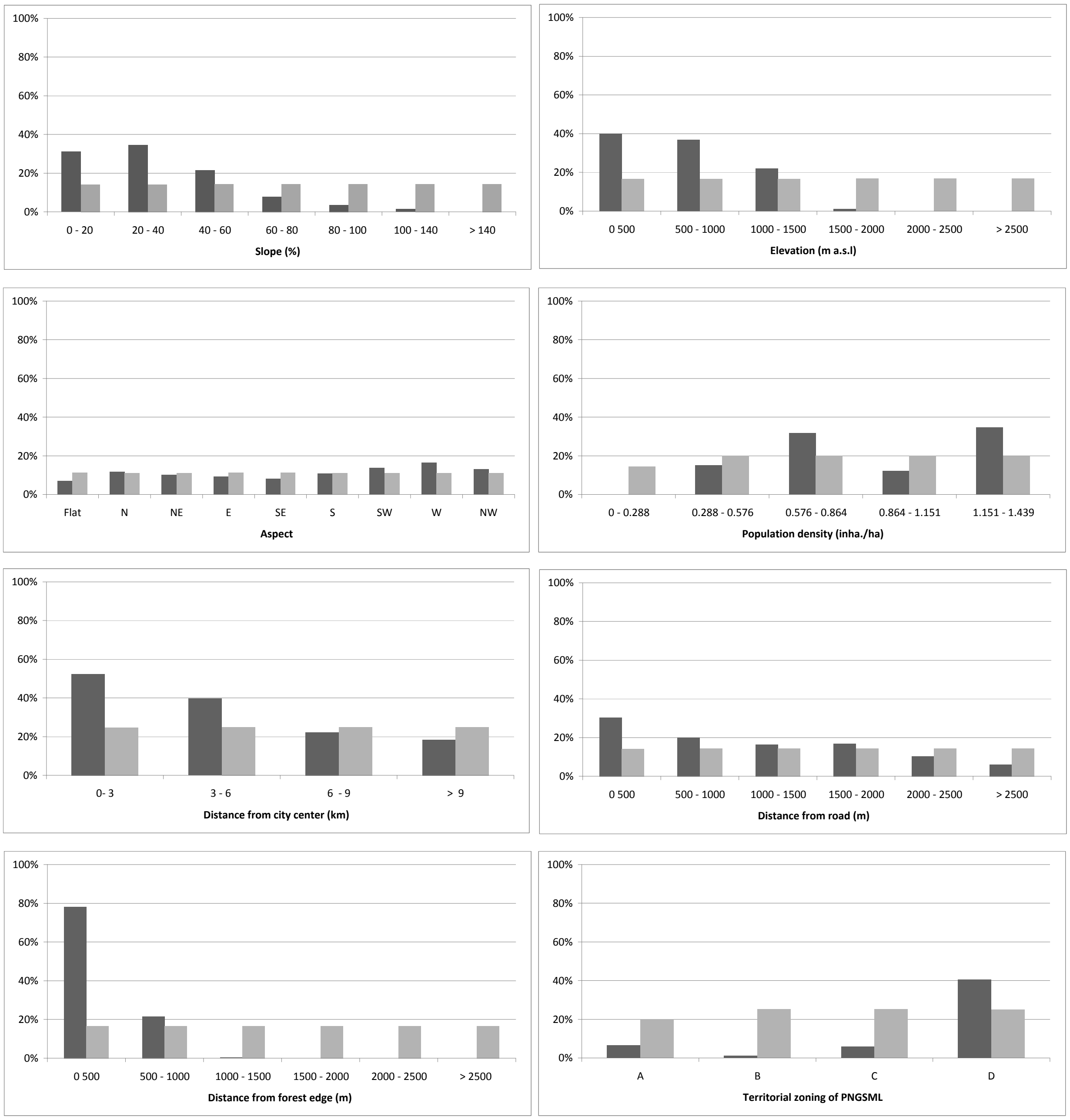

Figure 4 - Density (y-axis, values expressed as percentage) of change from non-forest areas to forest (dark grey) and no-change areas and other transitions (light grey) with respect to the considered spatial drivers. Data for the continuous variables (elevation, slope, aspect, density, distance from town/village center, distance from road and from forest edge) are shown by class intervals (x-axis).

since the early 1950s (Moreira et al. 2011). These observations indicate that a period of 19 years is sufficient for tree canopy closure from scattered trees in farmland and for the evolution of shrubland into forest. On one hand, this value is compatible with those reported by Bracchetti et al. (2012); on the other hand, our results also suggest that the considered period is sufficient for forest vegetation to colonize the most suitable sites.

Natural forest expansion produces complex and far reaching effects on rural environment: it brings production of direct and indirect benefits, mainly related to the reduction of water runoff and soil erosion (Garcia Ruiz et al. 1996, Tasser et al. 2003), the control of sediment yield (Boix-Fayos et al. 2008), the improvement of soil properties (Seeber and Seeber 2005), and the increase of presence of large vertebrates (Falcucci et al. 2007). Therefore, an enlargement of forest land is usually expected to provide the increase of ecosystem services. Conversely, this phenomenon can cause a sensible decrease of HNV farmland, including high value grassland as in this case study, which are extremely important to preserve rare plants and feeding habitats of many birds, and to maintain landscape

Table 6 - Markov transition probabilities for the period 2008-2010 derived by the 1989-2008 change analysis.

Land cover class	shrubland	forest	non-forest
shrubland	0.976	0.023	0.001
forest	0.000	0.999	0.001
non-forest	0.004	0.001	0.995

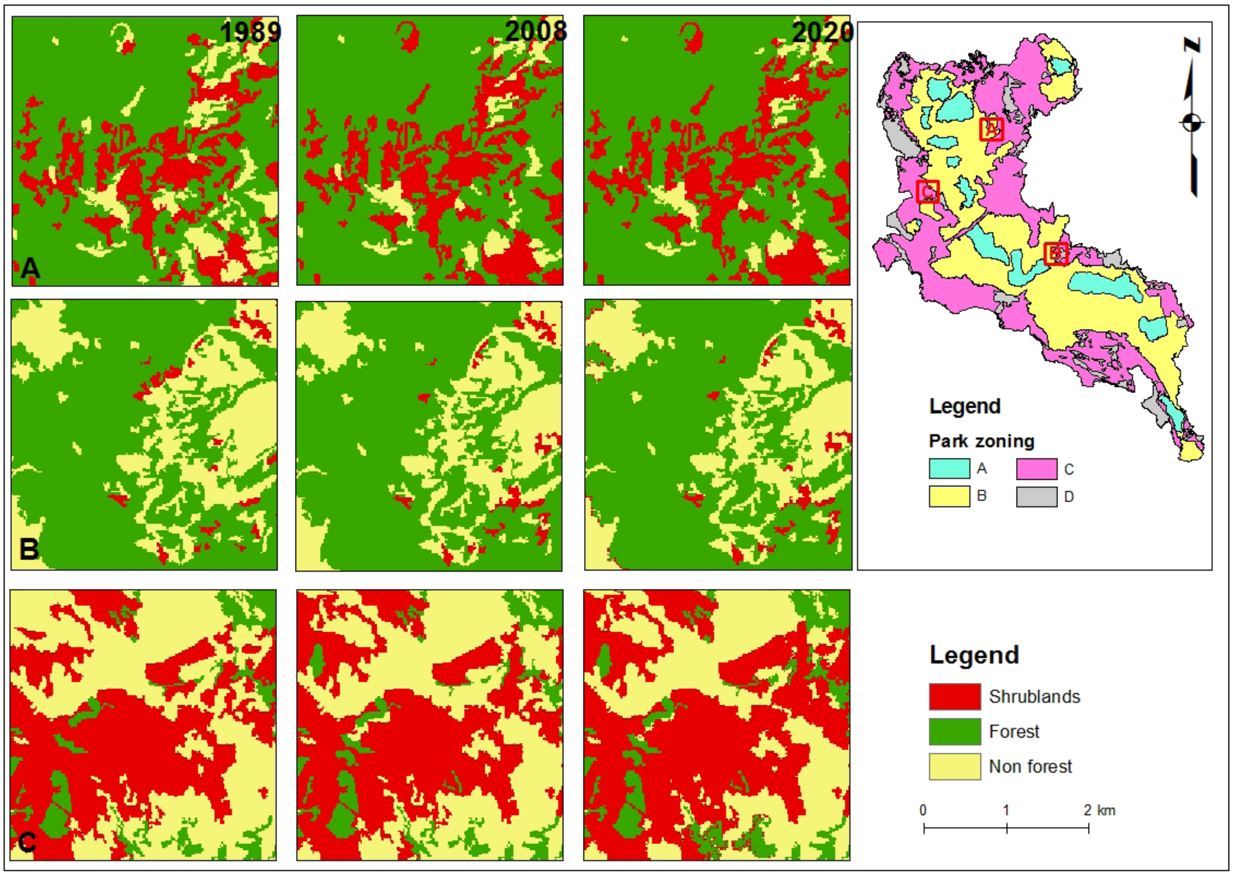

Figure 5 - Land cover maps at the year 1989 (observed), 2008 (observed) and 2020 (predicted) in three sample areas of the PNGSML.

diversity too (Bracchetti et al. 2012). In Mediterranean mountain landscapes, especially within areas designated for nature conservation, a tradeoff between the increase of forest and shrubland and the conservation of traditional landscapes is needed. In this perspective, the present study provides a methodological framework to spatially assess the localization of open natural habitats vulnerable to change. It represents a valuable decision-making support tool to better establish tradeoffs between forest expansion and HNV farmland protection.

Analyzing drivers of change and land cover general trend, we found that the increase in wooded areas is located mainly in mountain areas where a greater decrease in farming and pastoral activities has taken place, producing the same effect highlighted in other studies (Moreira et al. 2011). This phenomenon significantly decreases over 2,000 m a.s.l., confirming that in Central Apennines this altitude can be considered as a threshold for forest cover evolutionary dynamics. Distance from the mature woods is highly related to cover change. These edges are, in fact, the most susceptible to change (Matlack 1994, Oikonomakis and Ganatsas 2012). Also areas near roads are significantly affected by re-naturalization phenomena linked to the increase of the woods and scrubs: this may be explained, at least partially, by the fact that roads and other infrastructures (power lines, canals, railways) can

Table 7 - Summary of Kappa Index of Agreement (KIA) and User's (AU), Producer's (AP), and Overall (OA) accuracies for the map predictions at the year 2010.

Land cover class	AU	AP	KIA	OA
shrubland	0.977	0.999		
forest	0.998	0.999	0.999	0.995
non-forest	1.000	0.995		

Table 8 - Markov transition probabilities for the period 2008-2020 derived by 1989-2008 change analysis.

Land cover class	shrubland	forest	non-forest
shrubland	0.89	0.109	0.001
forest	0.00	1.00	0.00
non-forest	0.02	0.01	0.97

be considered as potential corridors for some generalist species (Spellerberg 1998), above all when their maintenance works are reduced or suspended.

The observed spatial drivers are not expected to change, so that the trend of HNV farmland loss, due to forest and shrubland expansion, might not be reversed, as confirmed by the mid-term scenario for 2020. Park zoning, that is the most important management and planning tool for habitat conservation, cannot provide protection against the loss of HNV farmland, as documented by the high level of HNV farmland land uptake within those zones with a low degree of protection (C and D zones). Concrete efforts are therefore required to counteract this phenomenon: specific approaches must be adopted to

Table 9 - Forest cover values at the years 1989 (observed), 2008 (observed) and 2020 (predicted).

Land cover class	1989		2008		2020	
	ha	%	ha	%	ha	%
shrubland	12,643	8.82	12,157	8.48	13,067	9.12
forest	72,867	50.85	75,897	52.96	76,579	53.44
non-forest	57,794	40.33	55,250	38.56	53,659	37.44

maintain the socially and economically-fragile HNV farming systems (EEA 2010). In this perspective, PNGSML has supported this approach, activating an European LIFE+ project to help maintaining and enhancing the presence of high value grassland by concrete conservation measures aimed at the sustainability of pastoral activities in mountain areas. This goal could be achieved by building new infrastructures such as watering places or shelters, but also by training farmers about good practices for pasture management (Felli 2013).

Moreover, silvicultural practices able to contain the expansion of shrubland and forest can be proposed. Cutting of invasive shrubs within high value farmland and grassland could be a successful measure to contrast grassland decline, as demonstrated in several LIFE+ projects in Europe (Toland et al.

Table 10 - Land uptake by shrubland and forest in the period 2008-2020, by HNV and other land use classes.

	Land cover class	Shrubland ha	Shrubland % of total land uptake	Forest ha	Forest % of total land uptake
HNV farmland	olive groves	0.3	0.03	5.5	0.37
	pastures	3.1	0.27	26.7	1.79
	complex cultivation patterns	1.7	0.15	63.4	4.24
	lands principally occupied by agriculture	16.3	1.43	185.2	12.38
	natural grassland	448.9	39.33	263.4	17.61
	moors and heatland	8.3	0.72	-	-
	total of HNV land use classes	*478.6*	*41.93*	*544.2*	*36,39*
Other land use classes	discontinous urban fabrics	0.05	0.00	0.7	0.05
	industrial areas	-	-	0.1	0.01
	arable lands	9.7	0.85	65.5	4.38
	broad-leaved forests	202.5	17.75	628.8	42.03
	coniferous forests	5.7	0.50	20.7	1.38
	mixed forests	3.4	0.30	9.6	0.64
	transitional woodland-shrubs	195.9	17.16	197.6	13.21
	bare rocks	61.1	5.36	4.7	0.31
	sparsely vegetated areas	178.8	15.67	22.8	1.52
	water bodies	5.5	0.48	1.1	0.07
	total of othe land use classes	*662.7*	*58.07*	*951.6*	*63.61*

2008). Thinning of woodlands near open areas within the forest can also create link-areas where spreading of pasture and grassland species is promoted. This practice can help enhancing the connectivity between grassland by linking many fragmented open areas (Seravelli et al. 2005). A careful management of forests near grassland, the most prone to change as demonstrated by this case study, can also help restoring grassland edges in order to control the colonization of new areas within HNV farmland.

Conclusions

In this paper we have demonstrated the close connection between forest and shrubland expansion dynamics in the last decades and HNV farmland loss. Because of the importance of HNV farmland in biodiversity conservation, especially within protected areas, the establishment of a tradeoff between forest increase and protection of HNV farmland and grassland is needed.

In this perspective, specific protection and management measures, such as building new infrastructures to support the sustainability of pastoral activities in mountain areas (Felli 2013), occasional and continuous cutting of invasive shrubs and thinning of forests near HNV grassland (Seravelli et al. 2005, Toland et al. 2008) could represent effective tools for the protection of these landscape mosaic elements strongly influenced by human traditional activities.

Under a more general framework, distinctive concern should be paid at territorial planning level to reduce the loss of biodiversity and habitats of traditional landscapes, that in Italy and in the Mediterranean mountains result from traditional agricultural and silvicultural activities of thousands of years of human presence.

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Research paper

Effetto di differenti tipologie di consociazione sull'accrescimento e sulla qualità del noce comune (*Juglans regia* L.) in un impianto di arboricoltura da legno nell'Italia centrale

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Riassunto - Si riportano i risultati di una piantagione sperimentale di noce (*Juglans regia* L.) realizzata nel febbraio del 1999 su una superficie di circa 3 ettari nei pressi di Pesaro. Sono state realizzate 8 tesi: una con il noce in purezza, due con noce ed eleagno (50 e 75%) e cinque con il noce consociato con 5 diverse specie arboree (olmo, acero, ontano, salice e platano) per un totale di 8 parcelle elementari di circa 0,35 ha ciascuna. La piantagione è stata oggetto di monitoraggio a partire dall'anno 2000: sono stati valutati l'accrescimento in diametro, l'altezza e la qualità del fusto del noce. La stima della produzione di biomassa è stata realizzata per le 3 specie più competitive al momento della loro ceduazione (salice e olmo a 6 anni, platano a 7 anni) e successivamente a 12 anni per tutte le 5 specie arboree consociate. I dati dendrometrici raccolti hanno consentito il confronto sulle differenze di accrescimento del noce in funzione della pianta accessoria con cui è stato consociato. La consociazione che meglio ha influenzato l'accrescimento diametrico del noce è quella con eleagno al 75%. Con questo arbusto azotofissatore il diametro medio rilevato nel 2012 è risultato pari a 25,8 cm contro i 14,1 cm per il noce puro e i 12,2 cm rilevati per la consociazione con l'olmo che appare la specie meno indicata. Non esiste una relazione positiva fra accrescimento diametrico e qualità del fusto del noce. I fusti migliori sono stati classificati nella consociazione con il platano; la consociazione con l'olmo si conferma invece come la meno indicata. Alcune piante accessorie sono risultate interessanti anche per la produzione di biomassa. In particolare a queste distanze il platano è stato in grado di allevare positivamente il noce e di produrre circa 12,2 t ss ha^{-1} di biomassa alla prima stima e 29,6 t ss ha^{-1} alla seconda.

Parole chiave - accrescimento del noce, consociazioni, biomassa, qualità del fusto

Abstract - *Effects of different intercropping on walnut growth and stem quality in a plantation close to Pesaro (Marche Region).* The experimental plantation, about 3 hectares, was set up in 1999 in a floodplain near Pesaro (Marche Region) on a fertile crop land. Eight theses were compared: 1 thesis: pure walnut, 2: walnut intercropped with autumn olive (50% and 75%), and 5 theses: walnut intercropped with different nurse trees (elm, field maple, white willow, italian alder and plane). Each plot/ thesis was 0.35 ha wide. Since 2000, the plantation has been monitored: dbh, tree height and stem quality of walnut trees have been measured. The estimate of biomass production has been undertaken for the 3 more competitive species (at the age of 6 for willow and elm and at the age of 7 for plane). Twelve years after planting, biomass production of all the intercropped nurse trees was estimated a second time. This dataset allowed a comparison among walnut trees grown according to different mixtures and in monoculture. In 2012 walnut grown in mixture with 75% of autumn olive tree (N-fixing shrub) showed the best dbh performance reaching on average dbh of 25.8 cm, the same parameter being conversely 14.1cm in monoculture and 12.2 cm in combination with the most competitive spp. (i.e. elm). No positive relationship between walnut growth and stem quality was found. The best stem quality was attained in mixture with plane, while elm confirmed to be an unsuitable nurse tree for walnut. The same nurse trees showed to be interesting for biomass production, too. Especially plane resulted to be an interesting species able to nurse profitably walnut and to have an interesting biomass production around 12.2 t ha^{-1} in the first rotation and 29.6 t ha^{-1} in the following one.

Keywords - walnut growth, intercropping, biomass, stem quality

Introduzione

A partire dagli anni '90 le tipologie di piantagione per la produzione di legname di pregio si sono evolute verso nuove forme, passando dalla coltivazione in purezza di singole specie alle consociazioni di più specie. Un impulso forte alla diffusione delle piantagioni si è avuto grazie al Regolamento CEE 2080/92 con il quale sono stati realizzati prevalentemente impianti puri e misti con noce o ciliegio (Colletti 2001) e, in fase sperimentale, impianti di più specie in consociazione.

Le prime esperienze di arboricoltura da legno prevedevano piantagioni pure realizzate con sesti di impianto quadrati (da 3x3 m a 5x5 m) allo scopo di permettere il passaggio di mezzi meccanici. I principali vantaggi degli impianti puri sono da individuare nella semplicità in fase di progettazione, realizzazione e gestione grazie alla presenza di una sola specie; per contro gli svantaggi sono da ricercare

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nella difficoltà della scelta della specie idonea, nei maggiori rischi di danni per diffusione di patogeni o per andamento climatico avverso rispetto ad un impianto misto e all'incertezza economica legata alla singola produzione legnosa (Buresti et al. 2001, Mohni et al. 2009). Nel tempo si sono evidenziate problematiche soprattutto per quanto riguarda l'elevato costo delle potature e la necessità di diradare l'impianto per mantenere costante l'accrescimento delle piante da portare a fine ciclo (Marchino e Ravagni 2007). Per ridurre questi inconvenienti, soprattutto per quanto riguarda la realizzazione degli interventi di diradamento, sono state sperimentate piantagioni con piante principali di pregio poste a distanze finali 8-12 m. Tale soluzione non ha però portato a dei vantaggi economici in quanto le cure colturali alle singole piante e alla piantagione devono essere realizzate con maggiore attenzione per non declassare la produzione legnosa finale.

Proprio a causa di queste difficoltà e per i non sempre brillanti risultati ottenuti dalle monoculture, la tendenza è stata quella di sperimentare piantagioni pure con accessorie, miste e miste con accessorie (Buresti e Frattegiani 1995, Buresti et al. 2006b, Clark et al. 2008, Loewe et al. 2013a, Loewe et al. 2013b). Si introduce un nuovo concetto e cioè la presenza su una stessa superficie di piante appartenenti a più specie o alla stessa specie che assumono un ruolo diverso durante il ciclo produttivo. La pianta principale è quella destinata alla produzione legnosa, la pianta accessoria invece serve a facilitare la gestione dell'impianto e a favorire l'accrescimento della principale allo scopo di raggiungere l'obiettivo produttivo (Buresti e Mori 2005a, Buresti e Mori 2005b); dalle accessorie si ricavano prodotti legnosi minori come legna da ardere o biomasse o anche prodotti non legnosi (funghi, miele, ecc.). Può accadere che in una piantagione il ruolo di principale ed accessoria sia svolto da una stessa specie, può variare in questo caso la lunghezza del ciclo produttivo come ad esempio per il pioppo che può essere coltivato contemporaneamente per produzioni legnose di pregio e per biomassa (Buresti e Mori 2012).

Come riportato da Vandermeer (in Piotto 2008) e come emerso in altre esperienze (Forrester et al. 2006), la realizzazione di impianti misti può stimolare la crescita delle piantagioni attraverso due effetti: *competitive production* e *facilitation.* Nel caso di *competitive production* si utilizza una specie meno competitiva in modo che la competizione interspecifica risulti minore di quella intraspecifica. Un esempio può essere l'uso di piante eliofile a rapido accrescimento in grado di condizionare lo sviluppo delle piante principali a più lenta crescita e più tolleranti all'ombreggiamento. Nel caso di *facilitation* si utilizzano una o più specie con il compito di stimolare positivamente la crescita di un'altra specie in mescolanza. In pratica una pianta può condizionare positivamente l'ambiente nel quale viene introdotta migliorando ad esempio le condizioni nutritive del terreno (Hansen e Dawson 1982). Un tipico esempio può essere l'utilizzo di specie azotofissatrici.

Contemporaneamente ad altri Paesi (Schlesinger e Williams 1984, Paschke et al. 1989, Bohanek e Groninger 2004, Becquet e Vidal 2006, Clark et al. 2008, Lowe et al. 2013a, Loewe et al. 2013b), in Italia si è diffuso l'impiego di alcune specie azotofissatrici arboree ed arbustive appartenenti ai generi *Alnus, Robinia* e *Eleagnus* (Buresti et al. 1997, Becciolini e Pelleri 2006, Tani et al. 2006, Corazzesi et al. 2010). I risultati ottenuti hanno generalmente fornito buoni risultati grazie allo stimolo diretto sull'accrescimento delle piante principali ad esse consociate; nei casi di piantagioni con terreni fertili o in condizioni fisico-chimiche particolari, l'effetto dell'azotofissatrice è risultato meno evidente (Contu e Mercurio 2003, Buresti com. pers.).

Gli effetti positivi della consociazione si possono individuare principalmente nel migliore accrescimento della pianta principale che presenta fusti dritti, più lunghi con nodi contenuti e accrescimenti annuali costanti che valorizzano la qualità delle produzioni legnose (Berti 1995, Becquey 2006). Le specie accessorie possono variare le condizioni ecologiche e stazionali non solo dal punto di vista nutrizionale ma anche dal punto di vista fisico del suolo e dello spazio a disposizione (Buresti e De Meo 2000).

Infatti, la distribuzione degli spazi fra le specie (arboree ed arbustive) all'interno degli impianti, può ridurre notevolmente alcune pratiche colturali, prime fra tutte le potature, le lavorazioni meccaniche e l'impiego di prodotti chimici per il contenimento delle infestanti grazie alla maggiore copertura del terreno che controlla naturalmente il loro sviluppo. Inoltre la disposizione su più piani porta a vantaggi nello sfruttamento della radiazione luminosa e degli spazi grazie alla diversa architettura degli apparati epigei ed ipogei delle specie presenti. L'impiego di specie a ciclo colturale diverso (Buresti et al. 2006a) permette ai proprietari di ottenere redditi anticipati dal taglio delle piante accessorie prima di quello finale realizzando così la massimizzazione del reddito. La progettazione di questi impianti è più complessa rispetto a quelli puri in quanto è richiesta un'esperienza consolidata nella scelta delle specie da assegnare al ruolo di principale e di accessoria e alla definizione delle distanze di impianto più indicate (Buresti et al. 2001).

Oltre ai vantaggi colturali si possono avere anche vantaggi di tipo ambientale, quali ad esempio quelli riguardanti l'aspetto paesaggistico con attenuazione dell'impatto visivo rispetto alle piantagioni pure. Inoltre si realizza un maggiore livello di biodiversità ambientale grazie alla presenza di più specie che incrementano la ricchezza floristica del sottobosco e di conseguenza una maggiore ricchezza di specie animali che rendono nel complesso il sistema più stabile riducendo la sensibilità a perturbazioni esterne. Gli impianti consociati possono essere un valido strumento alternativo e a minore impatto colturale in molte aree dove tradizionalmente le piantagioni vengono coltivate con tecniche gestionali a elevato impatto ambientale.

Il presente lavoro ha lo scopo di valutare gli accrescimenti del noce allevato in purezza e in consociazione con 6 differenti piante accessorie (arboree ed arbustive) e di valutare la produttività di queste per la produzione di biomassa.

Materiali e metodi

La piantagione è stata realizzata nei pressi di Pesaro (PU) a 50 m s.l.m., in una zona pianeggiante caratterizzata dalla coltura prevalente di cereali. Il terreno è a medio impasto e di buona fertilità anche grazie alla vicinanza del corso del fiume Foglia con falda acquifera stabile a circa 2,50 m di profondità. La piantagione è stata realizzata nel febbraio del 1999, su terreni in precedenza coltivati a mais e interessa una superficie di circa 3 ha, in questa superficie il noce (*Juglans regia* L.) è stato allevato con piante accessorie di diverse specie e in purezza.

Il noce è posto sempre secondo uno schema a settonce con lato di 8 m;. sono state realizzate 8 tesi: una con il noce in purezza, due con noce ed *Elaeagnus umbellata* Thumb (al 50 e 75%) e cinque con il noce consociato con 5 diverse specie arboree (*Ulmus minor* Miller, *Acer campestre* L., *Salix alba* L., *Alnus cordata* Loisel, *Platanus* spp) per un totale di 8 parcelle elementari di circa 0,35 ha ciascuna. Sulla fila il noce è sempre alternato, a 4 m, all'eleagno mentre le accessorie sono alternate alle file di noce a 4 m di distanza. In Figura 1 sono rappresentati i principali schemi d'impianto.

Il clima dell'area di studio secondo i dati della stazione termo-pluviometrica dell'Osservatorio Valerio (periodo di osservazione 1998-2012), situata a circa 7 km dall'impianto, è di tipo mediterraneo con periodo siccitoso estivo di circa 2 mesi, precipitazioni medie annue di 827 mm con massimi delle precipitazioni in primavera ed autunno e temperatura media annua di 14,7° C (Fig. 2).

Le operazioni colturali realizzate si sono limitate nei primissimi anni a operazioni di trinciatura per il controllo delle infestanti e alle potature delle piante principali durante la fase di qualificazione, al fine di ottenere un fusto privo di rami sviluppato in altezza per almeno 2,50 m.

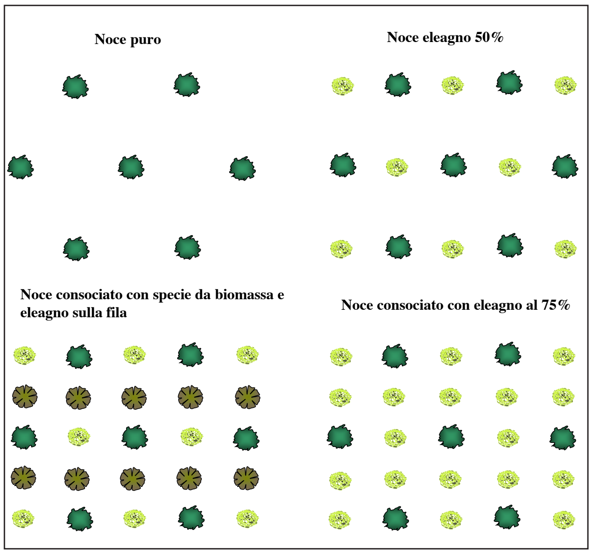

Figura 1 - Tipologie di sesti di impianto presenti nella piantagione.

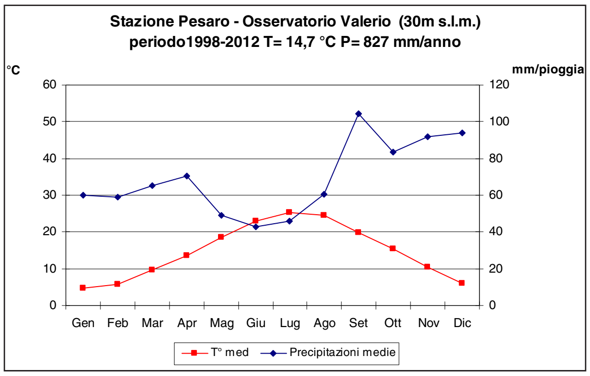

Figura 2 - Diagramma termo-pluviometrico di Bagnouls & Gaussen.

La piantagione è oggetto di monitoraggio da parte di CRA-SEL a partire dall'anno 2000. Negli anni 2002, 2004, 2006, 2009 e 2012 sul noce è stato eseguito il rilievo del diametro a 1,30 m (D) mentre l'altezza (H) è stata rilevata solo negli anni 2004 e 2012. I dati dendrometrici raccolti hanno consentito di effettuare un confronto sulle differenze di accrescimento del noce in funzione della pianta accessoria con cui è stato consociato. Inoltre a settembre 2011 si è valutata la qualità dei fusti di noce secondo la classificazione in 4 categorie proposta da Nosenzo (Nosenzo et al. 2008).

I dati quantitativi rilevati su tutta la piantagione e in particolare sulle piante principali, sono stati analizzati mediante l'analisi della varianza a una via (ANOVA) eseguendo il confronto delle medie tramite il test di Tukey's HSD per campioni diseguali (p-level=0.05) utilizzando il software (Statistica 2005). La distribuzione in classi di qualità dei fusti e stata comparata per mezzo del test χ^2 di Pearson.

A 6 anni dall'impianto è stata effettuata la raccolta e la stima della produzione di biomassa delle accessorie più produttive, olmo e salice, e a 7 anni del platano, le specie che iniziavano a svolgere un'azione di concorrenza negativa nei confronti del noce. Nel 2011 (a 12 anni) è stato realizzato il campionamento di tutte le 5 specie idonee per la produzione di biomassa presenti nella piantagione tralasciando l'eleagno. La produzione della biomassa è stata sempre valutata prelevando un campione di 3 piante di dimensioni medie sulle quali è stato determinato il peso di fusto e rami, mentre su un sottocampione è stato determinato il peso secco previa essiccazione in stufa a 95°C. La produzione ad ettaro è stata calcolata considerando la densità delle accessorie (357 piante ha^{-1}) e stimando in via prudenziale una mortalità del 7%.

Risultati

Effetto della consociazione sull'accrescimento del noce.

Diametro – L'effetto delle consociazioni risulta evidente già a partire dal primo rilievo dove si osservano accrescimenti del noce minori nella tesi in purezza e in quella consociata con olmo e salice. Negli anni successivi si osserva sempre una supremazia delle parcelle consociate con piante azotofissatrici (eleagno e ontano) e con il platano (Fig. 3).

Grafico1

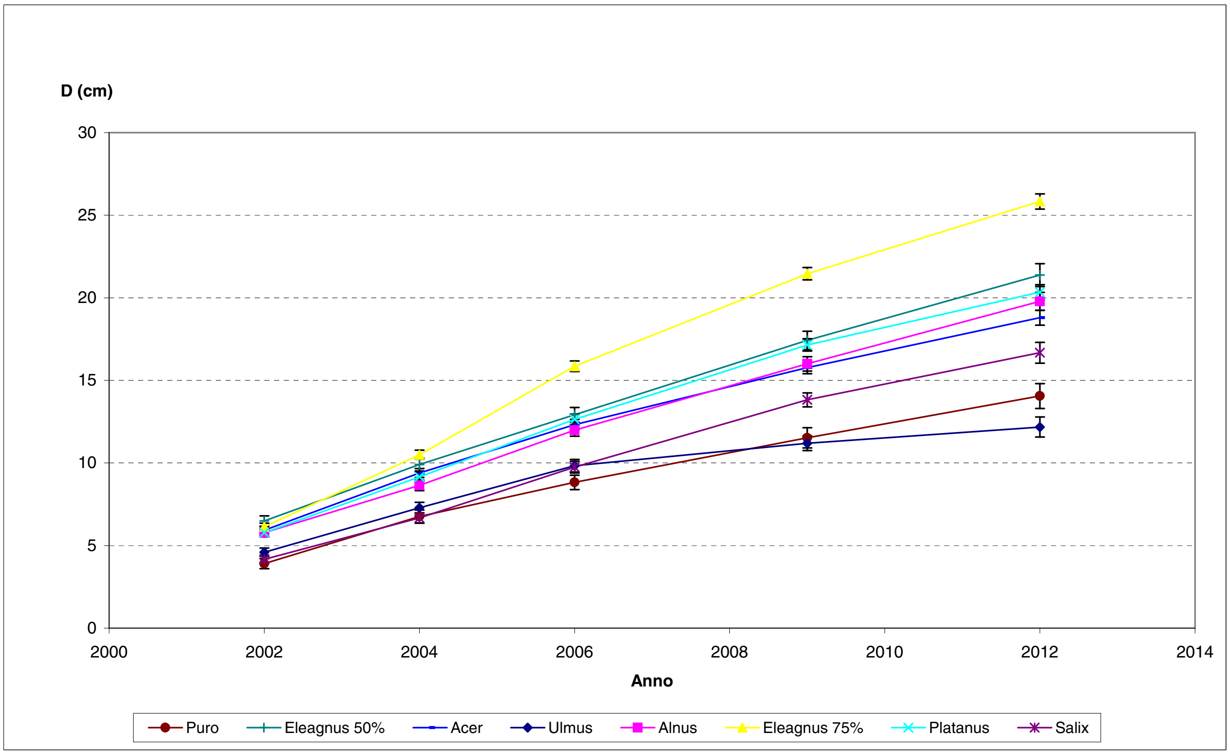

Figura 3 - Variazione dell'accrescimento diametrico del noce in relazione alla consociazione nel periodo osservato.

Tabella 1 - Risultati dell'ANOVA e del test HSD per il diametro del noce all'anno 2012.

Tesi	D_2012		
	Medie (cm)	SD	HSD
Puro	14,05	0,75	ab
Olmo	12,18	0,61	a
Salice	16,68	0,63	bc
Acero	18,80	0,46	cd
Ontano	19,78	0,54	d
Platano	20,60	0,46	d
Eleagno 50%	21,38	0,69	d
Eleagno 75%	25,83	0,46	e
ANOVA	**GdL**	**F**	**P-value**
Intercetta	1	8132,285	0,000
Consociazione	7	60,145	0,000
Errore	248		

In particolare la consociazione con eleagno al 75% già dal 2006 risulta significativamente diversa da tutte le altre.

Il noce in questa consociazione, all'ultimo rilievo (Tab.1), raggiunge 25,8 cm di diametro medio mentre nelle consociazioni con le altre azotofissatrici e il platano si ottengono valori variabili da 20 a 21 cm. La pianta accessoria che presenta un effetto negativo sull'accrescimento diametrico è l'olmo, che nel 2012 determina diametri medi del noce di 12 cm che risultano però non significativamente diversi da quelli del noce allevato in purezza, pari a 14 cm.

Incremento corrente di diametro – In Tabella 2 sono riportati i valori di incremento corrente di diametro nel periodo di osservazione. La consociazione con eleagno al 75% già nel periodo 2002-2004 mostra un incremento corrente significativamente diverso rispetto alle altre consociazioni con valori di incremento diametrico superiori a

Tabella 2 - Risultati dell'ANOVA e del test HSD per l'incremento diametrico del noce nei periodi di osservazione per ciascuna tesi.

Tesi	IcD_02_04			Icd 04_06			Icd 06_09			Icd 09_12		
	Medie (cm)	SD	HSD	Medie (cm)	SD	HSD	Medie (cm)	SD	HSD	Medie (cm)	SD	HSD
Puro	1,35	0,10	abc	1,11	0,11	a	0,64	0,10	a	0,84	0,1	b
Olmo	1,35	0,09	ab	1,27	0,09	a	0,45	0,07	a	0,29	0,08	a
Salice	1,25	0,08	a	1,45	0,09	ab	1,42	0,07	bc	0,94	0,08	bc
Acero	1,73	0,07	c	1,50	0,07	ab	1,13	0,06	b	1,01	0,06	bc
Ontano	1,43	0,08	abc	1,67	0,09	b	1,34	0,07	bc	1,26	0,07	bcd
Platano	1,69	0,07	bc	1,74	0,08	b	1,48	0,06	c	1,17	0,06	bc
Eleagno 50%	1,69	0,10	abc	1,55	0,11	ab	1,50	0,09	bcd	1,32	0,09	cd
Eleagno 75%	2,18	0,07	d	2,68	0,08	c	1,87	0,06	d	1,46	0,06	d
ANOVA	**GdL**	**F**	**P-value**	**GdL**	**F**	**P-value**	**GdL**	**F**	**P-value**	**GdL**	**F**	**P-value**
Intercetta	*1*	*2793,085*	*0,000*	*1*	*2663,841*	*0,000*	*1*	*2114,434*	*0,000*	*1*	*1419,158*	*0,000*
Consociazione	*7*	*15,314*	*0,000*	*7*	*34,448*	*0,000*	*7*	*40,262*	*0,000*	*7*	*22,621*	*0,000*
Errore	271			271			264			248		

Tabella 3 - Risultati dell'ANOVA e del test HSD per la altezze del noce negli anni 2004 e 2012.

Tesi	H_04 Medie (cm)	SD	HSD	H_12 Medie (cm)	SD	HSD
Puro	5,13	0,29	a	8,68	0,49	a
Eleagno 50%	6,25	0,25	abc	12,34	0,42	b
Olmo	6,98	0,22	bcde	8,45	0,37	A
Acero	6,43	0,16	cd	13,02	0,28	bc
Ontano	6,44	0,19	cd	14,33	0,33	cd
Platano	7,29	0,17	bd	14,68	0,28	d
Salice	7,38	0,23	de	12,27	0,3	b
Eleagno 75%	7,40	0,17	e	14,58	0,28	d
ANOVA	**GdL**	**F**	**P-value**	**GdL**	**F**	**P-value**
Intercetta	*1*	*7739,564*	*0,000000*	*1*	*9150,156*	*0,00*
Consociazione	*7*	*10,806*	*0,000000*	*7*	*45,042*	*0,00*
Errore	246			246		

Tabella 4 - Distribuzione delle classi di qualità del fusto del noce per ciascuna tesi.

Tesi	Classe di qualità A+B n	%	Classe di qualità C+D n	%	Totale n	%
Acero	9	18,4	40	81,6	49	100
Olmo	5	35,7	9	64,3	14	100
Ontano	17	30,4	39	69,6	56	100
Platano	24	51,1	23	48,9	47	100
Puro	0	0	26	100	26	100
Salice	13	39,4	20	60,6	33	100
Eleagno 50%	7	28	18	72	25	100
Eleagno 75%	16	28,6	40	71,4	56	100
Totale	91	29,7	215	70,3	306	100

Pearson's χ^2 test=26,06 p<0,01 gradi di libertà 7
p-level 0,05=14,07; p-level0,01= 18,48

Tabella 5 - Produzione di biomassa ricavata dai due interventi realizzati (6, 7 e 12 anni dall'impianto).

Pianta accessoria	1° Intervento (2005 e 2006*) Peso fresco Kg pianta	t ha-1	Peso secco Kg pianta	t ha-1	2° Intervento (2011) Peso fresco Kg pianta	t ha-1	Peso secco Kg pianta	t ha-1
Salice	271	90	140	48,8	279	92,6	144	47,9
Olmo	190	63,1	102	35,6	43	14,3	25	8,3
Platano*	75	24,9	35	12,2	192	63,7	89	29,6
Acero	--	--	--	--	170	56,4	79	26,1
Ontano	--	--	--	--	402	133,5	209	69,4

2 cm, mentre per le altre tesi si riscontrano valori variabili da 1,25 cm (salice) a 1,73 (acero). Nel periodo 2004-2006 si riscontra ancora una significativa superiorità dell'eleagno. Nel periodo 2006-2009, in seguito all'utilizzazione delle accessorie più competitive (olmo, salice e platano), si verifica una ripresa incrementale nelle consociazioni con platano e salice; l'olmo invece, nonostante il taglio, risulta ancora competitivo in virtù del forte sviluppo di polloni radicali. Nello stesso periodo l'incremento del noce nella consociazione con eleagno al 75% si mantiene ancora significativo con valori prossimi a 2 cm, mentre successivamente (2009-2012) le tesi con eleagno mostrano valori inferiori rispetto ai periodi precedenti (1,5 cm) pur rimanendo significativamente superiori a quelli delle altre tesi. Le altre consociazioni presentano valori intorno a 1 cm; per il noce in purezza si nota una leggera ripresa mentre per l'olmo gli incrementi confermano l'andamento negativo dei periodi precedenti.

Altezza – L'ANOVA dell'altezza a 5 anni dall'impianto, pur risultando significativa, non permette di evidenziare in modo chiaro l'effetto delle specie azotofissatrici e delle accessorie che con il loro rapido accrescimento dovrebbero condizionare precocemente la crescita in altezza del noce (Tab. 3). Nel 2012, a 13 anni dalla piantagione, le consociazioni che hanno determinato un effetto positivo sull'altezza sono il platano, l'eleagno al 75% e l'ontano con valori intorno a 14,5 m. Il noce in purezza e consociato con l'olmo presenta altezze significativamente inferiori con valori intorno a 8,5 m.

Qualità del fusto – Il test del χ^2 di Pearson evidenzia la presenza di una relazione fra consociazione e qualità del fusto. Il platano risulta essere la specie che meglio condiziona nel noce la qualità del fusto con il 51% delle piante appartenenti alle classi migliori (A e B) idonee per la tranciatura e la segagione. I fusti del noce allevato in purezza in questa piantagione non sono di buona qualità e ricadono tutti nella classi più scadenti (C e D) idonee per falegnameria andante e per biomassa (Tab. 4).

Produzione di biomassa – Si riportano, per le 5 specie arboree consociate, i valori in peso fresco e biomassa stimata per le piante di dimensioni medie e le relative produzioni di biomassa ad ettaro e di incremento medio annuo (Tab. 5). La stima della produzione di biomassa è stata valutata per le specie a più rapida crescita (salice, olmo e platano), a 6 e 7 anni. I valori di produzione stimati sono interessanti e variano da 48,8 t ss ha^{-1} per il salice a 35,6 t ss ha^{-1} per l'olmo e a 12,2 t ss ha^{-1} per il platano. A 12 anni dalla piantagione sono state utilizzate tutte le accessorie interessanti per la produzione di biomassa. L'ontano è risultata l'accessoria più produttiva tra le tesi campionate una sola volta nel 2011, fornendo produzioni di 69,4 t ss ha^{-1} mentre l'acero ha prodotto 26,0 t ss ha^{-1}. La produzione ottenuta dal secondo ciclo delle specie precedentemente utilizzate è stata notevole per salice e platano e scarsa per l'olmo rispettivamente con 47,9, 29,6 e 8,3 t ss ha^{-1}

Discussione

L'utilizzo di piante accessorie ha effetti positivi sull'accrescimento del noce come emerso da altre esperienze (Becquey 2006, Buresti e De Meo 2000, Buresti et al. 1997, Clark et al. 2008, Tani et al. 2006). Il ruolo assegnato alle accessorie è quello di condizionare positivamente l'accrescimento della specie principale e la sua forma allo scopo di ottenere legname di qualità ma anche per ridurre alcune operazioni colturali, prime fra tutte le potature, oppure le concimazioni nel caso vengano utilizzate specie azotofissatrici.

L'eleagno si conferma una valida azotofissatrice idonea ad essere consociata con il noce e, seppure in misura minore, anche l'ontano. Fra le specie arboree buoni risultati si sono avuti soprattutto per il platano che ha condizionato positivamente sia gli accrescimenti che la forma del noce. Per quanto riguarda le azotofissatrici, già a pochi anni dall'impianto l'eleagno al 75% evidenzia valori maggiori rispetto alle altre consociazioni. A 13 anni dall'impianto (anno 2012) il noce in consociazione con eleagno al 75% presenta un diametro medio maggiore dell'84% rispetto al noce puro. Con le altre accessorie come eleagno 50%, platano e ontano, il noce mostra diametri medi superiori rispetto al puro rispettivamente del 52%, 47%, 41%. Le specie meno indicate ad essere consociate al noce sono il salice e l'olmo che determinano, in particolare quest'ultima, un effetto significativamente negativo con riduzione dell'accrescimento diametrico del 13% (nel 2012) rispetto al puro.

Un comportamento analogo a quanto descritto per il diametro medio si riscontra anche per i relativi incrementi. Nel 2006 l'utilizzazione delle specie accessorie più aggressive (platano, salice e olmo) ha consentito al noce, consociato con le prime 2 accessorie, di mantenere ritmi di crescita costanti rispetto al periodo precedente, mentre il noce consociato con l'olmo dopo il taglio ha manifestato una riduzione progressiva degli incrementi diametrici. Ciò è da mettere in relazione al comportamento infestante dell'olmo che in seguito al taglio tende ad emettere numerosi polloni radicali che si sviluppano su tutta la superficie entrando in forte competizione con la specie principale.

Anche lo sviluppo in altezza del noce sembra essere condizionato dalla specie consociata. Nei primi anni l'effetto della consociazione con azotofissatrici è nel complesso meno evidente rispetto a quanto rilevato per il diametro. Solo nel caso dell'eleagno al 75%, in cui la presenza di azotofissatrici è maggiore, si rilevano effetti positivi anche sull'altezza. Le altre specie arboree che nei primi anni hanno effetti positivi sono le specie a rapido accrescimento quali il platano e il salice. Il noce puro invece presenta altezze medie inferiori rispetto alle altre consociazioni in virtù anche della minore densità d'impianto. Nel 2012 l'effetto positivo sulla crescita in altezza è confermato per le tesi con platano, eleagno al 75% e ontano, rispettivamente con incrementi, in paragone con il puro, del 69%, 68% e 65%. Valori intermedi si evidenziano per acero (50%), salice (41%) ed eleagno al 50% (42%), mentre valori significativamente inferiori sono da attribuire al noce in purezza e alla consociazione con l'olmo (-3%) che si conferma come una specie particolarmente aggressiva. In altre piantagioni di arboricoltura realizzate su terreni meno fertili l'effetto della consociazione si è dimostrato evidente anche con percentuale di presenza di azotofissatrici inferiori, stimolando sia il diametro che l'altezza (Becciolini e Pelleri 2006, Tani et al. 2006, Tani et al. 2007). L'effetto positivo della consociazione con eleagno sugli accrescimenti del noce può per contro in alcuni casi manifestare aspetti negativi che richiedono un'attenta gestione a causa della facilità di diffusione della specie, che può diventare invasiva (Stark 2000). Nella piantagione tale comportamento si è manifestato negli ultimi anni con lieve intensità nella tesi noce puro, risultando comunque trascurabile nei confronti dell'accrescimento dello stesso noce.

Le specie arboree condizionano meglio la qualità del fusto del noce rispetto a quelle arbustive; in particolare quelle a rapida crescita con chiome poco coprenti e forma slanciata come platano, ontano e salice riescono a condizionarne la forma favorendo la costituzione di piante di noce slanciate, con fusti meno rastremati, chioma leggera e rami sottili. Specie arbustive come l'eleagno e il nocciolo hanno un effetto positivo nei primi anni. Successivamente, quando le piante principali superano in altezza l'accessoria, tale effetto viene meno e pertanto è necessaria una maggiore professionalità nella gestione degli interventi di potatura per ottenere fusti di buona forma.

Pur non essendo un impianto specializzato per la produzione di biomassa, le produzioni ottenute possono essere considerate per alcune specie interessanti. L'esperienza ha fornito informazioni sulla gestione e sulla conseguente capacità produttiva; in particolare è emerso come le specie a più rapido accrescimento, alle distanze assegnate nella piantagione, devono essere utilizzate con turni indicativamente tra i 4 e 6 anni per evitare l'insorgenza di fenomeni di competizione con le piante principali. In questa esperienza si sono ottenuti con turni di 6 e 7 anni buone produzioni con salice e olmo (rispettivamente 48,8 e 35,6 t ss ha^{-1}) e discrete produzioni con il platano (12,2 t ss ha^{-1}). Al secondo taglio, a 5 e 6 anni dal primo, si sono riscontrate buone produzioni del salice e del platano, mentre si assiste a un crollo in produttività dell'olmo attribuibile al modesto riscoppio della ceppaia principale e alla presenza di numerosi e piccoli polloni radicali diffusi sull'intera superficie che aumentano la competizione con la pianta principale, senza fornire un rilevante contributo in termini di produzione di biomassa. Le altre accessorie, che hanno subito un solo taglio, possono essere utilizzate con turni più lunghi (10-12 anni) data la loro minore aggressività. Le produzioni ottenute da queste sono state buone per l'ontano (69,4 t ss ha^{-1}) in linea a quanto dimostrato in altri lavori (Paris et al. 2010) e sensibilmente inferiori per l'acero campestre (26,1 t ss ha^{-1}).

Conclusioni

L'esperienza ha evidenziato gli effetti positivi della consociazione nella coltivazione di specie a legname di pregio come il noce. Va però sottolineata la necessità di una corretta gestione degli impianti e di una tempestiva utilizzazione delle piante accessorie all'insorgere di fenomeni di competizione negativa con le piante principali. Nella scelta delle specie accessorie è importante prendere in considerazione, oltre alle esigenze ecologiche delle specie e ai loro rapporti con le piante principali, anche le esigenze del mercato locale (produzione di cippato e/o legna da ardere), per non trovarsi in difficoltà nel collocare i prodotti. In caso contrario, la loro difficile collocazione potrebbe risultare un onere piuttosto che un reddito aggiuntivo per l'imprenditore agricolo.

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Research paper

Multifunctionality assessment in forest planning at landscape level. The study case of Matese Mountain Community (Italy)

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Abstract - The main objective is to improve a method that aims at evaluating forest multifunctionality from a technical and practical point of view. A methodological approach - based on the index of forest multifunctionality level - is proposed to assess the "fulfilment capability" of a function providing an estimate of performance level of each function in a given forest. This method is aimed at supporting technicians requested to define most suitable management guidelines and silvicultural practices in the framework of a Forest Landscape Management Plan (FLMP). The study area is the Matese district in southern Apennines (Italy), where a landscape planning experimentation was implemented. The approach includes the qualitative and quantitative characterization of selected populations, stratified by forest category by a sampling set of forest inventory plots. A 0.5 ha area around the sample plot was described by filling a form including the following information: site condition, tree species composition, stand origin and structure, silvicultural system, health condition, microhabitats presence. In each sample plot, both the multifunctionality assessment and the estimate of the effect of alternative management options on ecosystem goods and services, were carried out. The introduction of the term "fulfilment capability" and the modification of the concept of priority level - by which the ranking of functions within a plot is evaluated - is an improvement of current analysis method. This enhanced approach allows to detect the current status of forest plot and its potential framed within the whole forest. Assessing functional features of forests with this approach reduces the inherent subjectivity and allows to get useful information on forest multifunctionality to support forest planners in defining management guidelines consistent with current status and potential evolutive pattern.

Keywords - forest multifunctionality, Forest Landscape Management Planning, function fulfilment index, silvicultural system, Matese district (Italy)

Introduction

The Sustainable Forest Management (SFM) paradigm - defined at the Montreal Process (1987) - aims to balance social, economic, ecological, and cultural needs of present and future generations (Wyder 2001, Tabbush 2004) and to maintain resources based on the multiple use of forests (Garcıa-Fernandez et al. 2008).

The theoretical and practical development of multiple use forest management (MFM) started in North America and was re-conceptualized in Europe, giving greater emphasis to the concept of forest functions instead that to the concept of forest use. Nix (2012) referred to MFM as "the management of land or forest for more than one purpose, such as wood production, water quality, wildlife, recreation, aesthetics, or clean air". According to this definition, MFM is an approach that combines two or more uses of forests (i.e. wood production, maintenance of proper conditions for wildlife, landscape effects, recreation, protection against floods and erosion, and protection of water supplies).

In Europe the concept of forest multifunctionality was born in 1953 in Germany with the elaboration of the "Theory of Forestry Function" by Viktor Dieterich of the University of Munich. In this theory, the concept of multiple-use was developed and widened through a less anthropocentric vision where the functions have an intrinsic importance (vitality and health of ecosystem).

Over the last years, MFM has been envisioned as a promising and more balanced alternative to sustained yield strategies. Some authors emphasize that the inclusion of multiple values and multiple stakeholders might give SFM a much needed social and financial boost (Campos et al. 2001, Hiremath 2004, Kant 2004, Wang and Wilson 2007). The incorporation of multiple forest values in forest management decisions is one of the important dimensions of SFM (Kant 2007). Nowadays a modern forestry vision requires forests to satisfy demands of many

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stakeholder for multiple products and services (Kant 2004, Cantiani 2012).

SFM is a concept in continuous evolution both in time and space (Angelstam et al. 2005, Straka 2009). The multifunctional forest management planning aims to integrate in decision making the non-productive issues of the forest, just as well as the socio-cultural and environmental issues (Vincent and Binkley 1993, Kangas and Store 2002). In such planning approach the logical process that leads to the final management choice becomes considerably complicated (Pukkala 2002). For this reason, the most unambiguous, reproducible and economically sound definition and experimentation of a methodology regarding the planning process is necessary (Paletto et al. 2012).

During the last years, in Italy, forest management planning is not only realized through traditional plans at stand or regional level, but new Forest Landscape Management Plans (FLMP) are gaining importance as well. FLMPs provide alternative scenarios of forest landscape management rather than defining where and when a specific forest practice must be applied (Agnoloni et al. 2009).

Many forest planners have recognized the development of planning systems on a landscape scale as the proper tool to analyse the forest complexity and to define the management guidelines (Kant 2003, Kennedy and Koch 2004, Farcy and Devillez 2005, Cubbage et al. 2007, Schmithüsen 2007).

FLMP addresses long-term forest management issues, with special attention to environmental issues that cannot be properly considered by referring to a single forest management unit (i.e. single forest ownership).

In addition, FLMP provides management recommendations and silvicultural guidelines, according to forest category and silvicultural system (coppice or high forest). These are then divided and adapted for every function (Paletto et al. 2012).

Referring to the method developed by Paletto et al. (2012), devoted to define the forest multifunctionality from a practical point of view to support the forest practitioners, the main objective of this study is to improve this method in several aspects.

Specifically, we implemented the following three issues:

i) introduction of the priority level of every function. Zero priority function no longer exists; instead a priority ranking will be established among all functions;
ii) introduction of an index of the forest multifunctionality level. This index is defined through the capability of function fulfilment which provides an estimates of how much every function is performed in a given forest plot compared to the average performance of the same forest category. This feature introduces the novel concept of the relative performance in a 0 to 10 range.
iii) identification of which forest functions we have to take into consideration is carried out through a participatory process involving local stakeholders and experts.

Furthermore we aimed to test the method proposed by Paletto et al. (2012) in a different forest

Figure 1 - The study area and its municipalities.

Table 1 - Forest categories distribution in the study area.

Forest categories	Area (ha)	%
Beech forests	4785	29.7
Turkey oak forests	6644	41.2
Downy oak forests	290	1.8
Hop-hornbeam forests	1556	9.7
Chestnut forests	320	2.0
Riparian forests	842	5.2
Holm oak forests	18	0.1
Other broadleaved forests	1020	6.3
Shrublands	406	2.5
Coniferous plantations	212	1.3
TOTAL	**16094**	**100**

environment. Indeed, the application of the method in a different social and ecological context is a further element useful to improve the method and it can provide important suggestions from a practical point of view.

Materials and methods

Study area

The study area is included by the "Comunità Montana" of Matese, located in the Molise Region in Central Italy (Fig. 1). It has a total area of 36,500 ha and includes 11 municipalities.

The altitude ranges from 422 m a.s.l. of Spinete lowland to the 2,050 m a.s.l. of Monte Miletto.

The study area has 15,687 ha of forest lands and 407 ha of other wooded lands (Chirici et al. 2011). Forest area covers 43% of Matese district; the percentage of forest area varies from a maximum of 75% in Guardiaregia municipality to a minimum of 19% in Cercepiccola municipality.

The most forested area is represented by the South-western part of study area; in the North-eastern part forests are more fragmented and juxtaposed with urban and agricultural lands.

In terms of surface (Fig. 1), Turkey oak (*Quercus cerris* L.) forests are the most extended forest category (41.2% of forest area), they are often pure and fertile stands with well-shaped trees. Turkey oak forests are divided into the following forest types: i) mesophilous Turkey oak forests, closed and mainly pure stands growing in very fertile sites; ii) meso-xerophilous Turkey oak forests, with the significant presence of meso-xerophilous species or more rarely mesophilous species such as common hornbeam (*Carpinus betulus* L.), sycamore maples (*Acer pseudoplatanus* L.) and downy oak (*Quercus pubescens* Willd.).

The second forest category is represented by European beech (*Fagus sylvatica* L.) forests which occupy an area of 4,785 ha (29.7% of forest area) and are localized at the highest elevations and northern expositions. European beech forests are divided into the following three forest types (Chirici et al. 2011): i) high-mountainous beech forests, localized just below the timberline, in high slopes or in peak summits often characterized by rocky soils, strong winds, soil aridity and low fertility; ii) mountainous beech forests, which are the beech main forest type characterized by pure and fertile stands, where the understory vegetation is very sparse or absent; iii) sub-mountainous beech forests, localized in the transition zone between beech and Turkey oak forests or more rarely hop-hornbeam forests.

Other significant forest categories are represented by hop-hornbeam forests (9.7% of forest area) and by other broadleaved forests (6.3% of forest area). Finally riparian forests occupy the 5.2% of forest area and are localized along main creeks and rivers at the lowest altitudes.

Considering the economic importance of European beech and Turkey oak forests which occupy the 70.9% of forest area, for the multifunctionality analysis we focused only on these two forest categories which represent our reference population.

Method

We characterized the selected forest categories surveying 117 inventory plots and collecting qualitative and quantitative data.

We carried out an unaligned systematic sample design consistent to the Italian National Forest and Carbon sinks Inventory (INFC, 2004).

We generated a geo-referenced squared grid with 1 km step and random origin. A point with random coordinates was positioned in every square. Finally all points (more than 10,000) were overlapped to Molise forest types map (Chirici et al. 2011) in order to select the reference sample plots (117) in European beech or Turkey oaks forests (Fig. 2).

We described a 0.5 ha area around the sample plot by filling a form including the following information: site condition, tree species composition, stand origin and structure, silvicultural system, health condition, microhabitats presence.

In every sample plots we carried out the multifunctionality assessment and the effect estimation

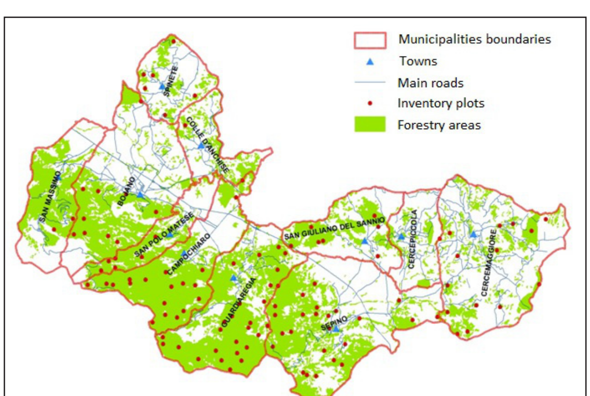

Figure 2 - Distribution of sample plots over the map of forest land use in the study area.

Table 2 - Stakeholders interviewed during the first phase of the participatory process.

Stakeholder	Num.
Majors	10
Forest enterprises	8
Associations	7
Agri-touristic farms	3
Freelance foresters	4
Local Action Groups	3
Forest nurseries	1
Sawmills	1
Mushrooms/truffles canning industry	1

of alternative management options on ecosystem goods and services by the method described below.

From 117 plots, 63 plots (53.8%) were classified as Turkey oak forests and 54 plots (46.2%) as European beech forests. In terms of silvicultural system, instead, 65 plots (55.6%) fell into coppice system and 52 (44.4%) into high forest system. In high forests, the most represented structure were the one-layered (32.5%), this suggesting shelterwood as the most common system. Nonetheless, also more complex high forest structures were found: two-layered (10.3%) and multi-layered (8.5%).

Multifunctionality: silvicultural system and forest category

At the purpose of this study, we considered the ability of forest ecosystem to supply goods and services. As a consequence, multifunctionality was assessed by a forest experts' team in each plot by assigning a value for two parameters: i) function priority level and ii) capability of function fulfilment.

The function priority level is a score aiming to relatively rank all functions considered essential for each plot in the specific context where the forest is located. The score consisted in an integer positive value ranging from 1 to n, where n is the number of all functions considered essential for that specific plot. The most important function takes the value 1 and the less important function takes the value n. An even score is possible if two functions are considered equally important.

The capability of function fulfilment is an estimation of how much that forest can perform every considered function compared to the average performance of the same forest type. The score ranges from 0 (no performance) to 10 (best performance for that forest type).

Forest functions considered in the study area were selected taking into account four aspects at once: i) ecological, social and economic context of the study area, ii) internationally recognized forest functions resulting from a literary review, iii) a participatory process involving local stakeholders, and iv) existing and up to date forest planning at unit level in the study area.

Concerning the participatory process, 39 stakeholders were contacted and interviewed to highlight the most relevant forest functions in the study area (Table 2).

The seven forest functions identified are described below.

- Landscape conservation. Considering the landscape as the result of interaction between human and natural environment (Brady 2003), landscape management is based on multiple values including ecological, economic, cultural and perception aspects (Sepp et al. 1999). Evaluation criteria were: the relative importance of the landscape in the local cultural context and the visibility from road and trail networks.
- Firewood/biomass production. All products (primary and secondary) provided by the forest for domestic heating.
- Timber production: all wood assortments not used for heating.
- Non-wood forest production. The total of non-wood forest products such as truffles, mushrooms, berries, etc.
- Soil and water protection. Direct and indirect protection against natural hazards such as floods, landslides, rock falls, soil erosion, etc. (Führer 2000).
- Touristic/recreational function. Forests provide many recreational opportunities such as trekking, bird-watching, biking, orienteering, plant and animal observing etc. (Krieger 2001).
- Environment conservation. It considers the positive effect that forests have on biodiversity and microhabitat conservation. We evaluated the possibility/ opportunity of increasing the number of microhabitats and diversifying forest structure (horizontal and vertical) to promote wildlife biodiversity (FAO 2006).

In a first step, we stratified plots by silvicultural system (coppice or high forest) and by forest category. During a second step, we compared the strata by multifunctionality level indicators using two indicators described below.

Mean priority level and mean fulfilment capability were calculated for each function as:

Where:

$$\bar{v}_{f\ ft} = \frac{\sum_{i=1}^{n} v_{f\ i}}{n}$$

n = total number of plots per stratum;
v_{fi} = priority level or fulfilment capability for the f function in the i-th plot.

This indicator assesses the priority level or the fulfilment capability for every forest category (or silvicultural system) and for each function. Thus it

Table 3 - Silvicultural options.

coppices	1)	traditional coppicing: total harvesting of trees except the release of a variable number of standards with a main dissemination function (Perrin, 1954);
	2)	conversion into high forest: set of techniques aiming at the preparation for the conversion into high forest. The application of these treatments lead to a transitory stand alike to a high forest structure (Bernetti, 2005).
	3)	natural evolution of the stand.
high forests	1)	even-aged high forest regeneration practices: shelterwood, large-medium strips or large-medium groups felling (Kimmins, 2004);
	2)	coppice/high forest integration;
	3)	high forest in continuous regeneration: to get an uneven-aged structure per single tree by selection felling or per small groups by small strips or group shelterwood (Helms, 1998);
	4)	natural evolution of the stand

gives useful indications for operational purposes at a stratum level.

Total mean priority level and fulfilment capability as:

Where:

$$\overline{V}_{F\,FT} = \frac{\sum_{j=1}^{m} \overline{v}_{f\,ft\,j}}{m}$$

m = total number of selected functions;
$\overline{v}_{f\,ft\,j}$ = mean priority level or mean fulfilment capability of the stratum for the *j*-th function.

This indicator assesses the total multifunctionality value of the stratum giving a synthetic value. It is useful to compare different forest categories and silvicultural systems.

The joint analysis of these indicators provide a synthetic evaluation of the current multifunctionality of the stratum (forest category or silvicultural system) which is the base to analyse future silvicultural options (Paletto et al. 2012)

Performance capability of silvicultural options

In this study we evaluated the capability of each silvicultural option to perform the requested function, that means how much each treatment application can affect the function fulfilment both in the short- and mid-term (Agnoloni et al. 2009).

We considered for each plot the silvicultural options described in Table 3.

In each plot, a team composed by two forest experts evaluated each silvicultural option by giving a synthetic score for the capability of the treatment to perform each function.

In Table 4 we reported the correspondence between the evaluation and the score in 7 classes.

N.P. represents a null fulfilment capability, it is used when a specific silvicultural option is not able to allow the stand to perform a specific function (e.g. natural evolution is evaluated N.P. for firewood production function).

N.A. is used when a specific silvicultural option is technically or legally not applicable in that particular forest context (e.g. coppicing option is evaluated N.A. in the case of a coppice abandoned for more than the legally allowed period to be coppiced, specifically two times the rotation period).

The evaluations were carried out considering the effects of each treatment both in short-term (validity of a management plan, equal to 10 years), and in mid-term (20-30 years).

A degree of function fulfilment of each silvicultural option was calculated for every forest category by the Capability of Function Fulfilment Index. It was calculated as the mean of the product between the index of importance of function and the capability of the silvicultural option to fulfil the function of all sampling points related to the forest category:

Where:

$$C_{s\,ft\,f} = \frac{\sum_{i=1}^{n} I_{f\,i} \cdot c_{s\,i}}{n}$$

n = total number of plots per stratum;
$I_{f\,i}$ = priority level of *f* function for the i-th plot;
$c_{s\,i}$ = capability of s silvicultural option to fulfil the *f* function in the i-th plot.

Expert evaluation acquires a relevant importance for forest planning, because experts assess directly in field the possible effects of a silvicultural option which can affect positively or negatively each forest function (Paletto et al. 2012).

Our dataset do not respect all assumptions for parametric analysis and almost all the variables are ordinal and non-normally distributed. Thus, we carried out a non parametric analysis. Specifically the Mann-Whitney (U) test (Mann and Whitney 1947) was utilized to investigate the differences between forest categories (European beech and Turkey oak forests) and between silvicultural systems (coppices and high forests); we set a p-level = 0.01 to separate significant from non-significant differences.

Table 4 - Score to evaluate the fulfilment of each silvicultural option.

Evaluation	Score
Good	5
Average good	4
Average	3
Average poor	2
N.P. = Not performing	1
N.A. = Not applicable	0

Table 5 - Mean values of functions' priority level and fulfilment capability by silvicultural systems.

Function/Silvicultural system	Priority level		Fulfilment capability	
	Coppices	*High forests*	*Coppices*	*High forests*
Landscape conservation	4.98	4.52	7.19	7.13
Firewood/biomass production	6.03	4.31	6.86	6.28
Timber production	2.70	4.31	4.29	6.06
Non-wood forest production	4.00	3,61	6.00	5.85
Soil and water regulation	4.24	4.50	6.90	6.98
Touristic/recreational function	3.52	4.07	5.94	6.44
Nature conservation.	3.81	4.07	6.37	6.57
Mean value	**4.18**	**4.20**	**6.22**	**6.47**
Standard deviation (σ)	**1.07**	**0.32**	**0.97**	**0.46**

Results

Priority level

Regarding the silvicultural system and considering the full set of functions, we obtained the following results of multifunctionality (V): for coppices the mean priority level was 4.18 (σ = 1.10), and the mean fulfilment capability was 6.18 (σ = 0.82); for high forests the priority level resulted 4.22 (σ = 0.82) and the mean fulfilment capability resulted 6.54 (σ = 0.63) (Table 5).

Considering the value of priority level for single functions (v), we can note that firewood production is the main function for coppices and the third for high forests. The difference between coppices and high forests is statistically significant (U = 2,466.5, Expected value = 1,701, p-value = 0.0001)

Both landscape conservation and soil and water protection have high priority for both silvicultural systems.

Concerning the fulfilment capability of single functions, high forests fulfil more non-productive functions such as (in order of importance) landscape conservation, soil and water protection, environment conservation and touristic/recreational function.

Another result is the high mean priority level of coppices for (in order of importance) the landscape conservation and the soil and water protection.

Moreover, timber production resulted as one of the less important function for both silvicultural systems. This is probably due to the main use of wood coming from Matese forests i.e. firewood, also when it could be useful for alternative uses.

Nonetheless, timber production resulted more important in high forests than in coppices and this difference is statistically significant (U = 1,037.5, Expected value = 1,701, p-value = 0.0001). Also the fulfilment capability of this function resulted significantly higher for high forests than for coppices (U = 839, Expected value = 1,701 , p-value = 0.0001)

Regarding the forest category and considering the full set of functions, we obtained the following results of multifunctionality (V): for Turkey oak the mean priority level was 4.18 (σ = 1.07), and the mean fulfilment capability was 6.22 (σ = 0.97); for European beech forests priority level was 4.20 (σ = 0.32) and the mean fulfilment capability was 6.47 (σ = 0.46) (Table 5).

Considering the value of priority level for single functions (v) we can note that in Turkey oak forests firewood production is the most important function and significantly more important than in European beech forests (U = 2,447.5, Expected value = 1,690, p-value = 0.0001). Furthermore, Turkey oak forests have a priority level of the landscape conservation function higher than European beech forests (U = 2,311, Expected value = 1,690, p-value = 0.001).

On the other hand, European beech forests showed two prior functions: the most important was the soil and water protection (U = 1,098, Expected value = 1,690, p-value = 0.001), the second was the environmental conservation.

These results reflect very clearly the different geo-morphological position of the two forest categories. Indeed, Turkey oak forests are mainly located at a lower altitude and in sites with lower slopes than European beech forests.

Concerning the productive aspects, European beech forests have a significantly higher priority level for the timber production function (U = 1,203, Expected value = 1,690, p-value =0.006). Instead, for Turkey oak forests the timber production show the lowest priority level among functions considered.

On the other hand, European beech forests show to fulfil better non-productive functions: soil and water protection, landscape conservation and environmental conservation.

Particularly, European beech forests show a significantly higher fulfilment capability than Turkey oak forests for soil and water protection (U = 910.5, Expected value = 1,690, p-value = 0.0001), and for environmental conservation (U = 1,113, Expected value = 1,664, p-value = 0.002).

Fulfilment capability of timber production is for both silvicultural systems at the last rank. None-

Table 6 - Mean values of functions' priority level and fulfilment capability by forest categories.

Function/Silvicultural system	Priority level		Fulfilment capability	
	Turkey oak forests	*Beech forests*	*Turkey oak forests*	*Beech forests*
Landscape conservation	5.37	4.02	7.20	7.12
Firewood/biomass production	5.98	4.31	6.74	6.40
Timber production	2.89	4.13	4.60	5.73
Non-wood forest production	4.05	3.54	5.97	5.88
Soil and water regulation	3.82	5.04	6.54	7.44
Touristic/recreational function	3.54	4.08	6.03	6.35
Nature conservation.	3.58	4.42	6.16	6.87
Mean value	**4.18**	**4.22**	**6.18**	**6.54**
Standard deviation (σ)	**1.10**	**0.46**	**0.82**	**0.63**

Table 7 - Results of objectives-options matrix for Turkey oak forests.

Option	Coppicing (only coppice)		Conversion into high forest (only coppice)		Even-aged high forest (only high forest)		Coppice/high forest integration (only high forest)		Uneven- aged high forest (only high forest)		Natural evolution (both coppices/ high forest)	
Function	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
Landscape conservation	23.5	23.9	24.6	25.7	22.3	22.4	9.7	10.0	18.9	19.0	26.7/26.7	25.3/25.6
Firewood/biomass production	29.8	30.5	19.9	23.5	20.3	21.2	6.2	6.8	10.4	10.9	0/0	0/0
Timber production	4.5	5.2	4.8	8.3	13.0	16.1	2.9	3.6	8.7	11.1	0/0	0/0
Non-wood forest production	13.3	14.7	14.2	15.8	14.3	15.0	5.7	5.0	11.4	11.8	13.3/13.5	13.6/13.8
Soil and water regulation	15.5	15.8	16.9	17.6	15.7	16.2	7.1	7.2	14.5	14.7	17.5/17.6	17.4/18.0
Touristic/recreational function	10.6	10.9	12.8	15.0	12.8	13.8	4.0	4.8	10.5	11.4	11.3/11.6	12.8/12.9
Environmental conservation	12.5	12.6	14.0	15.3	13.4	13.2	6.2	6.4	12.9	13.1	15.9/16.0	17.4/17.6
Mean value	**15.7**	**16.2**	**15.3**	**17.3**	**16.0**	**16.9**	**5.8**	**6.3**	**12.5**	**13.2**	**12.1/12.2**	**12.4/12.6**
Standard deviation (σ)	**8.4**	**8.4**	**6.2**	**5.8**	**3.8**	**3.6**	**2.2**	**2.1**	**3.4**	**2.9**	**9.6/9.6**	**9.4/9.5**

theless, the non-parametric test of Mann-Whitney shows statistical significantly differences for this function in the European beech forests (U = 1,153.5, Expected value = 1,690, p-value = 0.003)

From a productive viewpoint, we can confirm that firewood/biomass production is the only product requested by the market for both forest categories. This is particularly relevant for Turkey oak forests.

Silvicultural options and multifunctionality

Concerning Turkey oak fulfilment capability calculated for every silvicultural option (Table 7), results show very high values for firewood/biomass production function by coppicing. This capability increase from short-term (29.8) to long-term (30.5). Coppice system allows to maintain good capability to fulfil soil and water protection (15.5-15.8) and landscape conservation (23.5-23.9).

These results highlight that coppicing and even-aged high forest options are more able to fulfil every function than the integration of both options.

Concerning timber production, results show that longer is the term of application of every option, higher is the capability to fulfil a specific function. This aspect is especially evident for even-aged high forest option which has a capability to fulfil timber production of 13.0 in the short-term and 16.1 in the long-term.

Besides, the experts' team evaluated natural evolution as the optimal option to foster together environmental conservation, soil and water protection, and landscape conservation.

Concerning European beech forests (Table 8), firewood/biomass production by coppicing has a fulfilment capability halved compared to Turkey oak forests. This aspect is due to the position of European beech coppices mainly located at high elevation on sloping and medium-low site-index terrains often going to be naturally converted to high forests.

Coppicing, conversion into high forests and even-aged high forest options are fulfilling firewood production with similar performance.

As already reported for Turkey oak, timber production by even-aged high forests options is fulfilled better in the long-term (20.7) than in the short-term (17.7).

Furthermore, this option allows to maintain good fulfilment capability for non-monetary forest functions such as: soil and water protection, touristic/recreational function, environment conservation and landscape conservation.

Also for European beech forests, natural evolution fulfils forest services such as: landscape conservation, soil protection and water regulation, environmental conservation. The same option fulfils better than others non-wood forest production, too.

Discussion and conclusions

Forest planning in Molise has been and still is very active. Economic planning of regional forests started to be active since the 20th century and also contributed - thanks to its methodological consistency - to create a still lasting standardization of forest planning methods (Cantiani et al. 2010).

This consideration is valid also for the Matese area, where economic targets conditioned forest planners and managers choices, influencing both structure and developmental stages of forest stands.

Concerning Turkey oak high forests, their old customary management has been linked to the railway sleepers production. This context produced the spreading of even-aged stands, initially generated from shelterwood. Nonetheless, because of the

Table 8 - Results of objectives-options matrix for beech forests.

Option	Coppicing (only coppice)		Conversion into high forest (only coppice)		Even-aged high forest (only high forest)		Coppice/high forest integration (only high forest)		Uneven- aged high forest (only high forest)		Natural evolution (both coppices/ high forest)	
Function	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term	Short-term	Long-term
Landscape conservation	11.6	12.4	14.8	15.8	15.0	15.4	8.9	9.3	13.1	13.5	18.7/19.7	16.8/17.2
Firewood/biomass production	16.3	16.1	16.2	16.6	15.9	16.2	10.8	12.8	12.7	13.8	0/0	0/0
Timber production	4.3	4.3	6.3	9.8	17.7	20.7	5.1	6.2	14.2	16.8	0/0	0/0
Non-wood forest production	10.5	10.5	12.8	13.8	12.8	12.8	10.2	10.1	11.5	11.4	13.9/14.5	13.4/14.1
Soil and water regulation	14.7	15.9	22.7	22.9	19.2	20.3	13.3	13.7	19.1	19.2	24.0/22.9	22.6/21.7
Touristic/recreational function	7.6	7.6	9.3	11.8	17.2	18.4	7.1	7.9	15.2	15.4	11.1/11.9	18.7/17.9
Environmental conservation	9.2	9.4	16.5	20.1	16.9	17.6	10.9	11.7	16.5	17.0	20.8/22.4	19.9/20.1
Mean value	**10.6**	**10.9**	**14.1**	**15.8**	**16.4**	**17.3**	**9.4**	**10.2**	**14.6**	**15.3**	**12.7/13.1**	**13.0/13.0**
Standard deviation (σ)	**4.1**	**4.3**	**5.3**	**4.6**	**2.1**	**2.8**	**2.7**	**2.7**	**2.6**	**2.6**	**9.6/9.8**	**9.4/9.2**

unsuitable application of thinning and regeneration felling, these stands have been acquiring an irregular structure favouring the invasion of secondary species, these contributing to threaten Turkey oak regeneration (Cantiani et al. 2010).

Only at 36% of Turkey oak high forests plots the presence of Turkey oak regeneration was reported. Turkey oak's natural regeneration can be considered absent at the remaining 64%.

Based on the traditional presence of Turkey oak, the experts considered landscape conservation one of the most important functions performed by this forest type. The more appropriate options to fulfil this function were assumed to be natural evolution and shelterwood system (uniform or by groups); this last option, indeed, allows both natural regeneration, and environmental conservation as well as soil protection and water regulation.

From the perspective of production, Turkey oak high forests are linked exclusively to the increase of local firewood demand. Nonetheless, the fulfilment of timber production was considered to increase from short to long-term management under an even-aged regime. This aspect highlights that an appropriate silvicultural treatment (e.g. selective thinning) and in-depth studies on technological features of Turkey oak wood fibre, can improve its market value.

Quite similar considerations can be performed about European beech high forests. Also this type underwent the shelterwood system for many decades as confirmed by all economic plans in the area. Even though many stands reached their technical maturity, the regeneration process has not been activated yet by consistent silvicultural practices.

Multifunctionality analysis of these forest categories highlighted that non-productive functions in Matese are more important for European beech forests than for Turkey oak ones. Especially, natural evolution has been selected by experts as the most appropriate options to fulfil functions such as: soil and water protection, touristic/recreational function, environmental conservation and landscape conservation.

Nonetheless, wood production function of beech forests must be considered, especially their high capability to fulfil timber and firewood production functions.

Shelterwood has been considered the silvicultural options maximising productivity and maintaining optimal values of fulfilment capability also for non-monetary forest functions.

Concerning coppice system, few are similarities between the two forest categories. In the study area, Turkey oak coppices are more actively managed than European beech coppices. This is confirmed by the low percentage overcoming the maximum legal age to be coppiced (20%) as compared with European beech (40%). This trend is due to the localization of coppices of the two forest categories and to the economic importance of firewood for the area.

These considerations are confirmed also by the multifunctionality indices: firewood production is the most important function for Turkey oak coppices but not for beech coppices. Furthermore, coppicing ensures high values of fulfilment capability also for landscape conservation. This result classifies coppiced Turkey oak patches as very important elements of the Matese landscape.

Firewood production shows on the contrary very low values for European beech coppices: about half of the deciduous oak type. Beech is mainly located at high elevation, in sites with medium-low site-index and their management has been not very active over the last decades leading them towards a natural conversion into high forests. That is why, both the active conversion into high forest and the natural evolution showed to be the most performing option for European beech coppices to fulfil several functions both in the short and in the long-term.

As after Paletto et al. (2012) the synthetic indicators of multifunctionality:

1. provided adequate outputs: the value of overall multifunctionality increased with the altimetric gradient, from Turkey oak forests at low altitudes to European beech forests at higher elevations;
2. the analysis proved the low economic value of the Matese forests and limited to firewood production;
3. the high forest system provided the fulfilment of the highest number of functions;
4. conversion from coppice to high forest may increase the overall value of the Matese forests because of the parallel increase of protective, touristic and productive functions.

The introduction of the fulfilment capability and the modification of the priority level concept - by which we evaluated how much a function is important compared to the others at each time and for the same plot - represented an improvement to the method proposed by Paletto et al. (2012). This enhanced approach allowed to detect the current state of each plot and its potentiality in the framework of the whole forest. The evaluation of forests functional features using the proposed approach reduces the inherent subjectivity.

The proposed method allows to elaborate useful information on forest multifunctionality and to support forest planners in defining management guidelines consistent with current state and the evolutionary potentiality of forest stands.

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ASR

Research paper

Early impact of alternative thinning approaches on structure diversity and complexity at stand level in two beech forests in Italy §

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Abstract - Stand structure, tree density as well as tree spatial pattern define natural dynamics and competition process. They are therefore parameters used to define any silvicultural management type. This work aims to report first data resulting from a silvicultural experiment in beech forests. The objective of the trial is testing the structure manipulation in terms of diversity and the reduction of inter-tree competition of different thinning approaches. Alternative thinning methods have been applied in two independent experimental sites located in the pre-Alps and southern Apennines, in Italy. Specific goals were to: (i) verify the impact early after thinning implementation on forest structure through a set of diversity and competition metrics resulting from a literature review; (ii) the sensitivity of tested indexes to detect effectively thinning manipulation. Main results show the low sensitivity of stand structure indexes and the ability of competition metrics to detect thinning outcome.

Keywords - stand structure, beech forest, thinning, structure diversity, competition, indexes

Introduction

Forest structure plays today a major role in the analysis and management of forest ecosystems (Roberts and Gilliam 1995, Oliver and Larson 1996, Latham 1998, Zenner and Hibbs 2000, Neumann and Starlinger 2001). Both structural diversity and tree competition (Brand and Magnussen 1988) are considered main factors to describe stand dynamics and define ecologically sound and economically sustainable management practices.

Stand structure is defined by tree species composition, tree age, size distribution and spatial patterns, canopy layering, within the forest stand (Husch et al. 2003). Stand structure influences individual tree growth and a number of biotic and abiotic processes (Garcia 2006, Eerikainen et al. 2007, Fox et al. 2007a,b). Silvicultural practices as thinnings and regeneration cuttings, heavily manipulate stand structure (Bailey and Tappeiner 1998) and this impacts wildlife populations (Harrington and Tappeiner 2007, Yamaura et al. 2008), stand dynamics (Saunders and Wagner 2008), tree regeneration dynamics (Getzin et al. 2008) and understory vegetation (Kembel and Dale 2006).

Horizontal/vertical tree density and spatial arrangement, tree species composition and intermingling as well as the range of tree dendrotypes, are usually related to biological diversity, ecological stability, competition processes and forest ecosystem functioning (Sallabanks et al. 2002, Kint et al. 2004).

The analysis of stand structure, tree density and tree species diversity are basic tools to explain both spatial heterogeneity and mechanisms of inter-tree competition (Oliver and Larson 1996, Pommerening 2006). Indeed, structural parameters at the macro, meso, and micro level are reliable indicators of diversity and ability of persistence (Margalef 1982) of forest ecosystems, and thus of the sustainability of the applied management's option (Haber 1982).

Based on these premises, a number of indexes has been developed over the last decades to quantify forest structure (Pommerening 2002). It has also been suggested that different sets of indicators may usefully be used to assess and simulate the effect of silvicultural treatments according to specific research references. Indexes-based literature, however, mainly deals with high forests (Ladermann and Stage 2001, Neumann and Starlinger 2001, Staudhammer and LeMay 2001, Corona et al. 2005, Motz et al. 2010). Few authors analysed the suitability of structural diversity indexes in coppice forests (Fabbio et al. 2006, Becagli et al. 2009). As for studies devoted to competition processes, these were carried out both in naturally originated forests and plantations (Hegyi 1974, Brand and Magnussen 1988, Biging and Dobbertin 1992, Piutti and Cescatti 1997, Cescatti and Piutti 1997, Schroder and von Ga-

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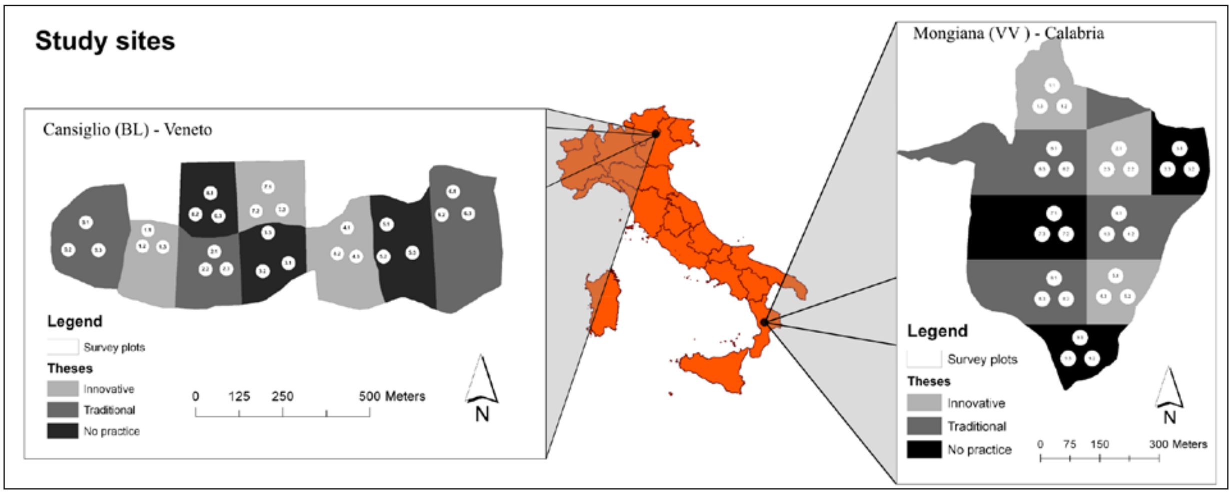

Figure 1- Location of the study areas.

dow 1999, Fichtner et al. 2012, Fichtner et al. 2013).

The knowledge of stand dynamics supports the focus on management goals by (i) predicting the future stand structure and relative pattern; (ii) reducing silvicultural costs, on average and (iii) increasing stand productivity and developing diagnostic criteria for describing, prescribing and marketing decisions for silvicultural operations (Oliver and Larson 1996).

Objective of the analysis is to evaluate the early change in stand structure following thinning practice by a set of indexes and the modification arising from the differently-based silvicultural interventions applied to managed beech forests. A more specific goal is to answer the following question: are all the calculated indexes capable to detect the effect of the intermediate removal and of criteria of intervention on stand structure and tree competition level immediately after their implementation at the tested sites?

Materials and methods

Study sites

The study was carried out in the pre-alpine region (Cansiglio-Veneto) and in southern Apennines (Mongiana-Calabria), two main beech vegetation areas (Fig. 1).

The study area located in the plateau of Cansiglio consists of an even-aged (120 to 145 yrs) compartment. The forest has age-long custom in forest management. Regular applied silviculture along the stand life-cycle consisted of low-mixed thinnings repeated every 20-25 years on the same management unit. Stand regeneration was successfully established following the group shelterwood system. Standing crop is quite uniform resulting from the long-lasting repetition of practices aimed at growing an one-storied structure. Natural variation in site-index makes the only evidence of a different arrangement in the crown layer.

The main management goal in these forests was to get uniform and well-shaped logs for the production of quality timber. Rotation time has been anyway shifting over the last decades and, as in other forest districts, from the customary age of 100-120 years to indefinite ages at now, this better matching the emerging recreational, scenic and mitigation functions besides wood-production goal. Site and climate characteristics are optimal for beech vegetation, these conditions well-supporting the extension of standing crop permanence time (Tab. 1).

The study area established in Mongiana consists of a forest aged about 70 years originated by a set of regeneration cuttings, the group shelterwood system, the clear-cut and clear-cut with reserves. The resulting standing crop is made by a main even-aged stand, where some trees of former cycle are present both grouped and along streams crossing the compartment. The patchy presence of silver fir mother trees and cohorts of regeneration provides spots of compositional and structural diversity. The forest position in the upper part of the mountain system facing the Tyrrhenian sea, the interception of fogs, wet winds and rain, makes physical environment

Table 1 - Site characteristics.

	Cansiglio Forest	Mongiana Forest
Area (ha)	30 - 35	30
Geographical coordinates (UTM-WGS84)	46° 03'N, 12°23' E	38° 30'N, 16°14'E
Altitudinal range (m a.s.l.)	1100 – 1200	1100
Landscape morphology	Gently sloping mountainsides and plains	Patchy succession of small hills (slope 40%), valleys and plateaux
Bedrock	Limestone, Marlstone (Cretaceous Med.- Sup.)	Granite ("Serra and Sila" formation)
Mean Temp °C	5.6	10.1
Max Temp °C (average warmest month)	14.8, August	18.4, July
Min Temp °C (average coldest month)	-4, January	2.2, February
Total Rainfall (mm)	2004	1808

consistent with beech vegetation in this southern Apennines area. Here too, the customary management system based on low to mixed thinnings usually does not open lasting canopy gaps. The random or patchy presence of trees much older than the dominant crop age, makes the physiognomy less regular and to some extent diverse than the typical even-aged beech forest.

Experimental design

An area of 30 hectares was devoted to the management trials at each site. Three theses were identified and randomly assigned in three replicates to each compartment (1 to 9). One thesis is made by the customary thinning practice (T), i.e. the low-mixed thinning as applied by local managers. The second silvicultural option is made by the innovative (for the forests concerned) criterion (I) consisting in a crown thinning at Cansiglio and on the selection of 45-50 trees per ha, with removal of direct competitors at Mongiana. Number of selected trees per unit area was determined on the foreseeable number of mother trees needed to carry out the future regeneration stage. The no-thinning thesis (control C) completes the experimental layout. A cluster of three circular sampling plots (radius 20 m) was established within each compartment according to a systematic design to survey mensurational parameters.

Structural and competition indexes

The impact of silvicultural practice on forest structure following each applied criterion has been assessed by a set of structural diversity and competition metrics resulting from a literature review. Both "spatial" and "non-spatial" indexes were accounted, the term "spatial" being referred to the information needed to get each index. Indexes requiring the calculation of individual tree position were considered as spatial indexes; all the others were considered as non-spatial indexes. To avoid the edge effect, trees at plot border were not considered as references. Selected indexes of stand structure and inter-individual competition are listed in Table 2. The Aggregation index by Clark and Evans (CE) characterizes the horizontal trees' distribution pattern at the stand level by the method of the nearest neighbouring trees. The theoretical range of CE lies between 0 (the maximum aggregation) and 2.1491 indicating a regular, hexagonal distribution pattern. Values about 1 comply with a random distribution. Diameter (TD) and tree height (TH) differentiation indexes provide information on tree size distribution of neighbouring trees. Values range between 0 and 1, with increasing values highlighting higher dbh or tree height variability.

Further non-spatial indexes of tree size diversity are the dbh ($STVI_{dbh}$) and Htot. ($STVIH_{tot}$) variance, They range between 0 and 1. The index is 1 when the parameter (dbh, Htot) distribution is uniform and is 0 when all values are equal or the distribution reaches its maximum bimodality. The advantage inherent to these indexes is their objectiveness compared to class-based indexes. Subjectivity is limited to maximum theoretical values, these being set at 150 cm (dbh) and 40 m (Htot) following Staudhammer and LeMay (2001).

As for tree competition, Hegyi (HG) index, a tree level, spatial indicator where neighbouring trees (competitors) are being selected according to a circle count criterion (Hegyi 1974) using Htot/3 of the reference tree as default distance, was considered. A modified version (HG_{MOD}) was tested too, to take into account larger neighbouring trees lying outside the default distance. Neighbouring trees are being selected here in accordance with an horizontal angle count (Pretzsch 2009).

A second competition index (Schroder and von Gadow 1999) is BAL_{MOD}, a distance-independent competition index derived from the basal area in larger trees (BAL) index combining individual tree's basal area percentile with a relative-spacing stand-density measure (RS_i). BAL_{MOD} assumes value equal to zero for the largest tree in a stand with a basal area percentile equal to 1, assuming that the largest tree provides the maximum growth rate. The minimum growth rate corresponds with the maximum index value. Within this range, the BAL_{MOD} index of trees with the same basal area percentile increases exponentially as RS_i decreases. Assuming constant stand density, the index provides the biologically reasonable effect that a high rank tree has a lower index value than a low-hierarchy tree.

Canopy structure was also assessed, since incoming light is a major driver of inter-tree competition (Kimmins 1987). Two canopy indexes, i.e. crowns coverage (CC) and the sum of crown projections (SCP) were selected to describe canopy structure. CC is a distance-dependent index representing the portion of horizontal space covered by at least one tree crown, theoretically ranging from 0 to 100. SCP, a spatially-independent index, is the sum of all crown areas per ground area unit and is a positive real number $\gtrless 100$.

Values before (BT) and after-thinning (AT) were compared also in terms of relative change (RC) of a specific index (i) as follows:

$$RC_i = \frac{(AT - BT)}{BT} \qquad [1]$$

BAL_{MOD}, HG and HG_{MOD} indexes are being calculated iteratively for each tree. To assess the ranks of tree population promoted by thinning practice, the first quartile was adopted as the reference value. Hegyi distribution per competition classes was also considered in the analysis.

Non-parametric inference was used to compare the selected indexes among the different silvicultural treatments due to the restricted sample size and the deviation from normality of many variables. Mann-Whitney U statistics was carried out testing for differences between the applied treatments at different probability levels.

Table 2 - List of the stand structure diversity and inter-tree competition indexes.

Index	Equation	Range and reference values
Aggregation index [CE] (Clark and Evans 1954)	$CE = \frac{r_A}{r_E}$ Where: $r_A = \sum_{i=1}^{n} HDist_i$; $r_E = \frac{1}{2}\sqrt{\frac{A}{N}}$; $HDist_i$ = Euclidean distance between *i-th* tree and its nearest neighbour; A = plot area; N = total number of trees in the plot	Min value = 0; Max value = 2.1491; CE = 1 → completely spatially random distribution; CE < 1 → spatially clustered distribution; CE > 1 → spatially regular distribution
DBH-Differentiation [TD] (Pommerening 2002)	$TD = \sum_{i=1}^{N} \frac{1}{n} \sum_{j=1}^{n} \left(1 - \frac{\min(DBH_i, DBH_j)}{\max(DBH_i, DBH_j)}\right)$ Where: n = number of the first 4 nearest neighbours; DBH = diameter at height = 1.3 m; N=total number of trees in the plot	Min value = 0; Max value = 1; TD = 0 → all neighbors have equal DBH; TD = 1 → all neighbours have different DBH
Height-Differentiation [TH] (Pommerening 2002)	$TH = \sum_{i=1}^{N} \frac{1}{n} \sum_{j=1}^{n} \left(1 - \frac{\min(H_i, H_j)}{\max(H_i, H_j)}\right)$ Where: n = number of the first 4 nearest neighbours; H = total stem height; N=total number of trees in the plot	Min value = 0; Max value = 1; TD = 0 → all neighbours have equal height; TD = 1 → all neighbours have different height
Diameter diversity based on variance [$STVI_{dbh}$] and Height diversity based on variance [$STVI_{Htot}$] (Staudhammer and LeMay 2001)	$\begin{cases} 1-\left(\frac{S_U^2 - S_k^2}{S_U^2}\right)^{p1} & if\ S_k^2 \le S_U^2 \\ 1-\left(\frac{S_U^2 - S_k^2}{m \cdot S_{max}^2 - S_U^2}\right)^{p2} & if\ S_k^2 \ge S_U^2 \end{cases}$ Where: S_k is the empirical variance (dbh or tree height); S_U is the variance of the univariate uniform distribution (dbh or tree height); S_{max} is the maximum possible variance (when the distribution is maximally bimodal)	Min value = 0; Max value = 1; STVI= 0 → when all values (DBH or Htot) are equal or when DBH (or Htot) distribution is very close to be maximally bimodal; STVI = 1 → highest diversity
BAL modified [BAL_{MOD}] (Schroder and von Gadow 1999)	$BALMOD_i = \frac{1-p_i}{RS}$ Where: p_i is the basal area percentile of the reference tree; RS is a relative spacing index (stand level)	Min value = 0; The higher the value the higher the competition the reference tree is subjected to
Hegyi [Hg] (Hegyi 1974)	$Hg_i = \sum_{i=1}^{n} \frac{DBH_j}{DBH_i \cdot HDist_{ij}}$ Where: DBH_i = diameter at breast height of the competitor trees; DBH_j = diameter at breast height of the reference tree; $HDist_{ij}$ = Euclidean distance between *i-th* tree and its nearest *j-th* neighbor; n = number of competitors (all trees that fall within a distance of $1/3 \cdot H_i$)	Min value = 0; The higher the value the higher the competition the reference tree is subjected to
Hegyi modified [Hg mod] (Pretzsch 2009)	$Hg_i = \sum_{i=1}^{n} \frac{DBH_j}{DBH_i \cdot HDist_{ij}}$ Where: DBH_i = diameter at breast height of the competitor trees; DBH_j = diameter at breast height of the reference tree; $HDist_{ij}$ = Euclidean distance between *i-th* tree and its nearest *j-th* neighbour; n = number of competitors (trees identified from an horizontal angle count sample)	Min value = 0; The higher the value the higher the competition the reference tree is subjected to

Results

Main mensurational parameters are reported in Table 3. Values at each site well-depict the differences between, mainly due to stand age and former applied silviculture. Mean values of structural diversity indexes before and after the occurrence of silvicultural practices are reported in Table 4. Thinning operations slightly changed the former values at both sites. CE index moved from random towards regular trees' distribution for both the applied criteria at Cansiglio, whilst it remained quite steady (i.e. random) at Mongiana. As for diameter differentiation (TD), dbh variability was low at Cansiglio and increased slightly at Mongiana (both criteria). As for tree height differentiation (TH), height variability was reduced by customary practice at Cansiglio only. Dbh variance ($STVI_{dbh}$) was kept close to zero by the occurrence of practices at Cansiglio; the same index did not show any significant change following thinnings at Mongiana. Tree height variance ($STVIH_{tot}$) was also very low and kept unchanged (innovative practice) or dropped (customary practice) at Cansiglio, whilst the opposite took place at Mongiana.

Values of relative change (Fig. 2) referred to the set of structural indexes do not exceed 15%, this showing the slight structural differences recorded across the theses.

As for tree competition, the first quartile (Tab. 5) and relative change (Fig.2) were examined. All indexes showed higher values at Mongiana than at Cansiglio before and after the implementation of thinning practices, independently of the applied criterion. All of them proved to be sensitive to the manipulation of stand structure, each one showing a reduction in accordance with the own algorithm. The innovative thesis promoted a higher cut of tree competition than the customary practice at both sites.

The Hegyi distribution pattern per competition classes was also recorded (Fig. 3). The graphical arrangement is similar as for Cansiglio (both theses) and Mongiana (innovative trial), i.e. the increase in low competition classes, the heavy reduction in medium-low competition classes and the zero setting in medium-high competition classes. On the contrary, a much more smoothed pattern across all competition classes was produced by customary practice at Mongiana.

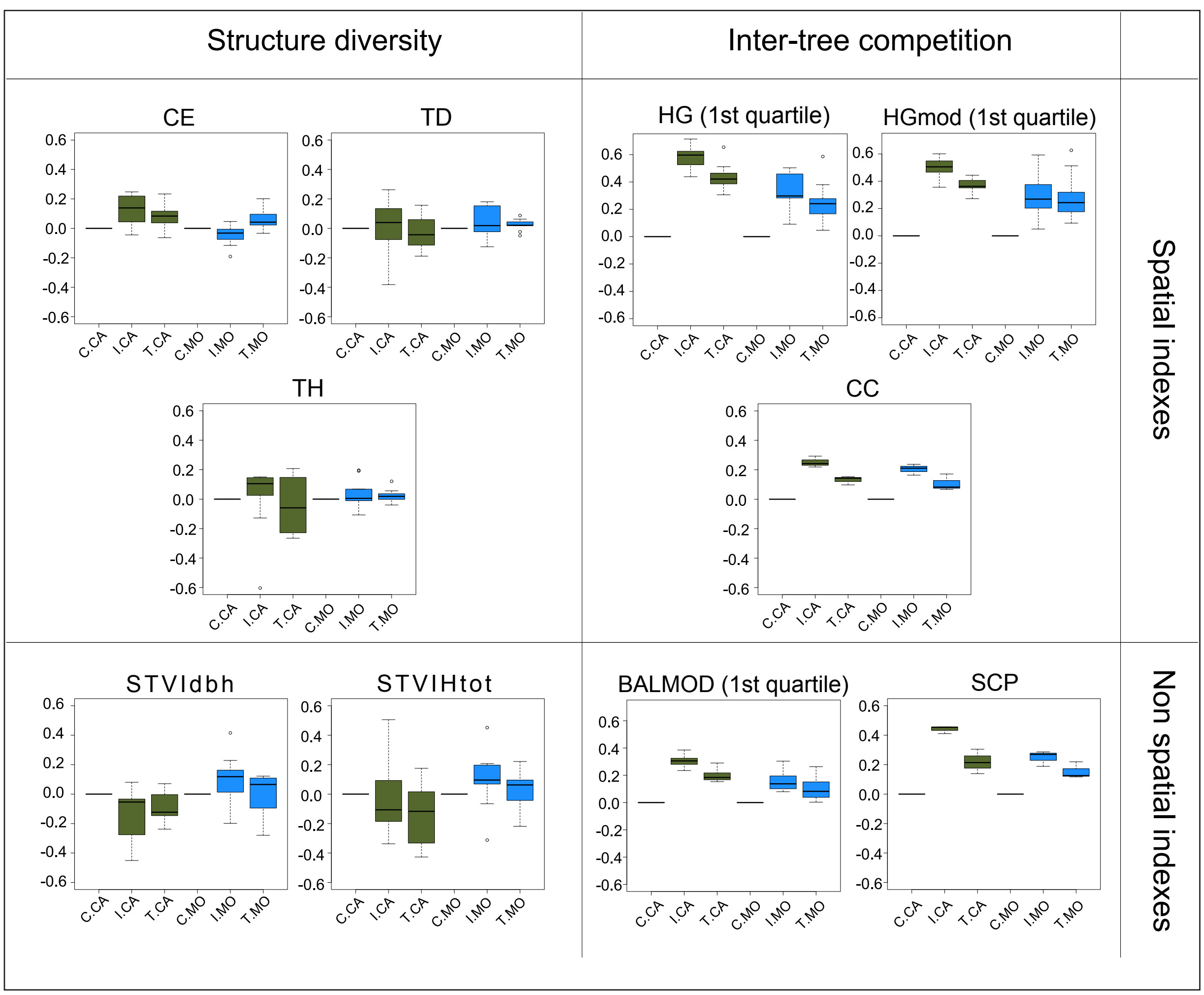

Figure 2 - Relative change of stand structure diversity and inter-tree competition indexes following thinning implementation per forest and thesis.

Table 3 - Main mensurational parameters (±sd) at sites.

Parameters	Before thinning Cansiglio	Before thinning Mongiana	After thinning Cansiglio Innovative	After thinning Cansiglio customary	After thinning Mongiana Innovative	After thinning Mongiana customary
Tree Density	323±65.9	510±130.4	187±9	235±29	409±100	408±168
Basal area m²/ha	40.9±5.2	41.2±7.3	26.3±1.3	30.3±4	33.7±7.7	31.6±3.1
Mean Height (m)	26.6±0.5	23.3±1.5	27±0.7	26.5 ±0.4	23.3±1.5	23.5±2
Mean (DBH) (cm)	40.6±3	32.9±6.1	43.7±2.4	40.5±2.6	33±6.2	33.4±8.2
Dominant DBH (cm)	49±3.6	46.2±6.8	48.1±0.8	46.9±1.2	47±7.9	47.0±7
Dominant Height (m)	27±0.6	26.2±1.2	27±0.1	26.6±0.1	24.2±1.6	26.0±1
Standing Volume (m³)	543±72	497±110.8	358±16	402±60	401±123	376.7±55.3

Table 4 - Mean values of stand structure diversity indexes before and after thinning implementation.

index	Before thinning Cansiglio	Before thinning Mongiana	After thinning Cansiglio Innovative	After thinning Cansiglio customary	After thinning Mongiana Innovative	After thinning Mongiana customary
CE	1.2	1.1	1.4	1.4	1.1	1.2
TD	0.2	0.2	0.2	0.2	0.3	0.3
TH	0.08	0.1	0.09	0.05	0.1	0.1
STVIdbh	0.1	0.2	0.09	0.09	0.3	0.1
STVIHtot	0.1	0.2	0.1	0.03	0.1	0.2

Table 5 - Tree competition indexes: 1stq before and after thinning implementation. Cansiglio = CA; Mongiana = MO.

thesis	BAL_{MOD} before	BAL_{MOD} after	Hegyi before	Hegyi after	$Hegyi_{MOD}$ before	$Hegyi_{MOD}$ after
CA_innovative	0.64	0.45	0.75	0.32	0.97	0.48
CA_customary	0.66	0.53	0.79	0.43	0.91	0.57
MO_innovative	0.96	0.81	1.21	0.79	1.27	0.88
MO_customary	0.88	0.81	1.13	0.80	1.21	0.81

Results of statistical tests are reported in Table 6. A significant difference ($p < 0.01$) is detected as for tree distribution pattern (CE) - innovative thinning thesis - at Cansiglio. A highly significant difference ($p < 0.001$) is present at the same forest for both thinning theses and all tested competition indexes. A significant differences ($p < 0.01$) is also reported by BAL_{MOD} at Mongiana - innovative thesis. Less significant ($p < 0.1$) are the differences recorded by HG and HG_{MOD}. No differences are detected as for the customary thesis at Mongiana.

Finally, mean values of crown-based indexes (Table 7) showed a notable reduction at both sites following thinning practices. Values before, different at each forest, were adjusted unlike. At Cansiglio, SCP dropped drastically with the innovative thesis (-44%) and less with the customary thesis (-19%), whilst, as expected, CC showed a lower reduction (-25% and -13 % respectively). At Mongiana, values before were much lower and, in accordance with the reduced cover before, CC dropped a bit more than SCP in the innovative thesis and followed the same pattern as in Cansiglio as for the customary thesis.

Discussion

The main outcome from the use of stand struc-

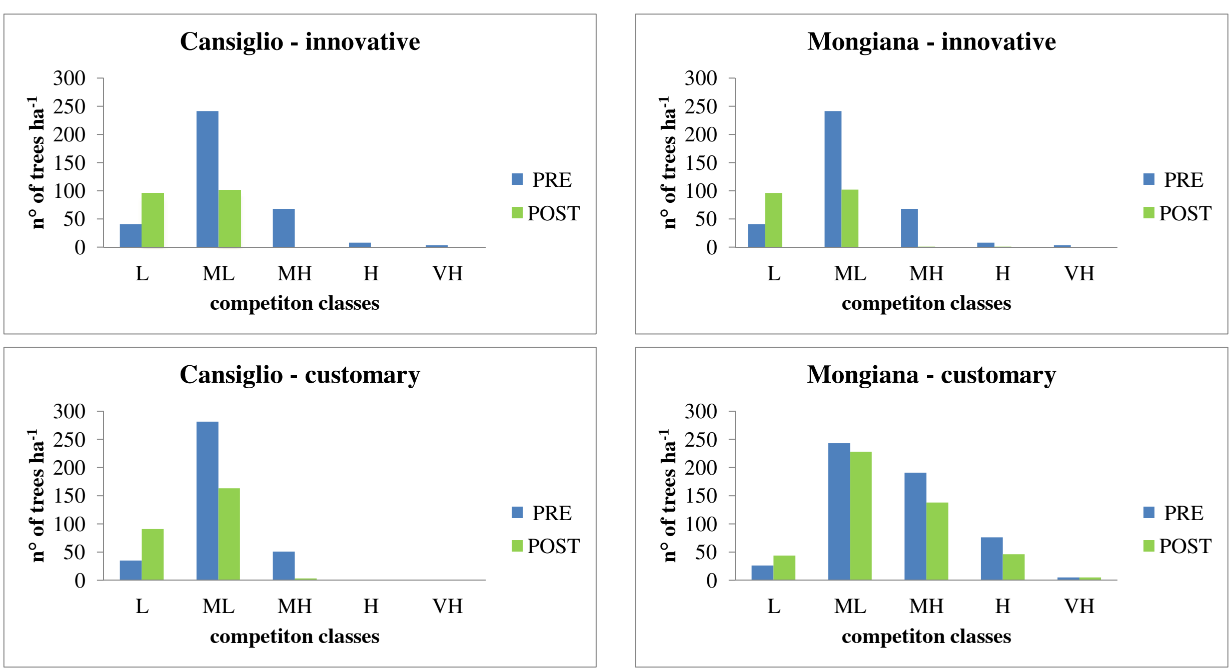

Figure 3 - Tree frequency distribution per competition classes (L: low, ML: medium low, MH: medium high, H: high, VH: very high).

Table 6 - Non-parametric statistics of tested indexes (Cansiglio = CA; Mongiana = MO). Asterisks indicate significant difference at * p < 0.1, ** p < 0.01, *** p < 0.001.

Comparison	Site	test	CE	TD	TH	$STVI_{dbh}$	$STVI_{Htot}$	BAL_{MOD}	Hegyi	$Hegyi_{MOD}$
innovative pre vs innovative post	CA	Mann Whitney U	10**	39	39	23	34	2***	7***	0***
customary pre vs customary post	CA	Mann Whitney U	16	35	39	32	34	1***	1***	0***
innovative pre vs innovative post	MO	Mann Whitney U	28	36	34	36	39	11**	16*	17*
customary pre vs customary post	MO	Mann Whitney U	31	34	39	40	39	25	22.5	19.5

tural indexes to highlight possible, early differences in tree texture and tree sizes was from the Aggregation Pattern index CE. It showed to be sensitive to stand manipulation and able to discriminate the higher heterogeneity of standing crop at the younger site (Mongiana) with respect to the older site (Cansiglio), it being manipulated for a much longer life-span. This sensitivity is well-summarized by the still random trees' horizontal distribution following thinning operations in Mongiana compared with the more regular pattern in Cansiglio. Among the applied theses in Mongiana, customary practice slightly moves the distribution towards regular distribution, given this intervention is performed all over the forest ground.

As for tree diameter differentiation, both spatial (TD) and non-spatial index ($STVI_{dbh}$), highlight similar dbh values in the sample considered. This peculiar feature is linked to the shade-tolerance of beech able to grow quite dense stands made of trees sized likewise. Both indexes do not detect any change as for the condition post-thinning at Cansiglio, whilst an even reduced sensitivity is proved at Mongiana. The typical even-aged structure and the one-storied arrangement of beech forests further promote this attribute.

Important differences are on the contrary detected in tree height variability by TH and $SVTI_{Htot}$ at Cansiglio. Here, values drop following the customary intervention and remain steady after the innovative practice. The steady pre-post condition is recurring at Mongiana for both interventions' criteria. The result in Cansiglio is explained by the higher stand age which ranked tree height arrangement into a thicker one-storied structure. Here, the customary intervention has harvested small to medium-sized stems (i.e. dominated up to a few sub-dominant trees) reducing the height range of standing crop (Roberts and Gilliam 1995). This result does not apply to the innovative criterion acting in the main crop layer made by co-dominant to dominant trees. The less-differentiated tree height layer into the younger stand of Mongiana allows only a slight record of both thinning practices.

Competition indexes (first quartile) are quite responsive - further to the expected reduction - to thinning theses (Brand and Magnussen 1988). They describe properly the targeted criterion of reducing tree competition in the dominant layer (Cansiglio-innovative), and in the neighborhood of a number of selected canopy trees (Mongiana-innovative), as well as the overall competition at stand level (customary thesis) at both sites. Response applies to low up to medium-high competition classes (Piutti and Cescatti 1997, Cescatti and Piutti 1998). Exception is made by customary criterion in Mongiana resulting vice versa into the prevailing reduction of inter-individual competition into medium-high and high classes, i.e. in the most dense patches of the less regular texture characterizing this forest.

Non-parametric statistics confirm the reduced sensitivity of stand structure indexes at this early-post intervention stage. Exception is made for the Aggregation Pattern index CE. The high sensitivity of tree competition indexes is also proved. As for crown-based indexes, the much higher figures of SCP and CC at Cansiglio compared to Mongiana describe a forest stand aged nearly twice Mongiana, much less dense and displaying a quite similar basal area (Fichtner et al. 2013b, Kimmins 1987). That means the establishment of the age-dependent crown interface made up of a more structured layer both in terms of coverage and overlapping, in spite of lower tree density.

Conclusions

The analysis highlighted the response ability of spatial and non-spatial tree diversity and competition indexes to describe the early manipulation following crown, selective and low-mixed thinning practices performed into two beech forests aged differently. The Aggregation index CE showed to be sensitive, moving towards a more regular tree

Table 7 – Crown-based indexes: mean values before and after thinning implementation. Cansiglio = CA; Mongiana = MO.

thesis	SCP before	SCP after	CC before	CC after
CA_innovative	115%	71%	90%	65%
CA_customary	90%	71%	79%	66%
MO_innovative	76%	51%	66%	46%
MO_customary	75%	60%	65%	54%

distribution at the more aged crop, independently of the applied criterion, and maintaining a random pattern at the younger and less homogeneous stand.

A slight or null sensitivity is showed by Diameter and Tree height differentiation, as well as by dbh and tree height variance, i.e. the other spatial and non-spatial tree diversity indexes tested. The condition here analyzed immediately after thinning practice will progressively change over time as a function of tree size differentiation following the applied practice. In fact, thinning makes available higher growing space to released trees, enhances stem radial growth and crown development, reduces symmetrical competition, in the perspective of differentiate further their next growth rate. The use of the above indexes becomes therefore more profitable and their response more consistent at intermediate steps between thinning practice.

All tree competition indexes tested HG, HG_{MOD} and BAL_{MOD}, recorded effectively the change in progress because they do register the different spatial arrangement following the intermediate removal and do not need any growth reaction to be established. As for crown-based indexes, they were able to differentiate thinning criteria much more than what recorded by mensurational parameters e.g. the difference in basal area removed.

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Technical note

A spatial model for sporadic tree species distribution in support of tree oriented silviculture

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Abstract - This technical note describes how a spatial model for sporadic tree species distribution in the territory of the Unione di Comuni Montana Colline Metallifere (UCMCM) was built using the Random Forest (RF) algorithm and 48 predictors, including reflectance values from ground cover – provided by satellite sensors – and ecological factors. The P.Pro.SPO.T. project - Policy and Protection of Sporadic tree species in Tuscany forest (LIFE 09 ENV/IT/000087) is currently carried out in this area with the purpose of initiating the implementation of tree oriented silviculture in the Tuscany forests. Tree oriented silviculture aims at obtaining both forest biodiversity protection and local production of valuable timber. After creating a map showing the probability of presence of sporadic tree species, it was possible to identify the most suitable areas for sporadic tree species which are under protection according to the regulation of the Tuscany Region. Using data and software provided free of charge, and applying the RF algorithm, distribution models could be developed in order to identify the most suitable areas for the application of tree oriented silviculture. This can provide a support to forestry planning that includes tree oriented silviculture, thus reducing its implementation cost.

Keywords - sporadic tree species, distribution, tree oriented silviculture, forest biodiversity, random forests, GRASS GIS

Introduction

Mori et al. (2007) and Pelleri et al. (2010) proposed and initiated the implementation of tree oriented silviculture in the woods of Tuscany. The P.Pro.Spo.T. project - Policy and Protection of Sporadic tree species in Tuscany forests (LIFE 09 ENV/IT/000087) - takes currently place in the "Colline Metallifere" area (southern Tuscany). This project includes demonstration areas about tree oriented silviculture, a technique in which target trees are identified and optimal conditions for their growth are created through different measures.

Investments in the application of tree oriented silviculture - favouring sporadic tree species - can realistically expect a financial return only in wooded areas whose ecological and microclimatic conditions are highly suitable for such species.

This technical note shows that it is possible to build cost-effective probabilistic models related to the presence of sporadic tree species. These models can be used to identify which forest areas are the most suitable for the application of tree oriented silviculture, thus supporting field sampling aimed at forest planning.

Materials and Methods

We developed the model using as reference the raster map of the forest areas in which the Unione di Comuni Montana Colline Metallifere (UCMCM) is responsible for forestry. The P.Pro.SPO.T. project takes place in this territory and includes demonstration areas. The 100 m resolution raster map - derived from Corine Land Cover (CLC) 2006 - covers 525.2 km^2 of forest area. The distribution model refers to the sporadic tree species which are under protection according to the article 12 of the *Regolamento Forestale della Toscana* (regional forestry regulation) 48/2003, which implements the Legge Forestale della Toscana (Tuscany regional law) 39/2000. These species can provide valuable timber and include for example *Acer* sp., *Fraxinus excelsior*, *Fraxinus oxycarpa*, *Tilia* sp., *Pyrus* sp., *Malus* sp., *Sorbus* sp., *Ilex aquifolium*, *Taxus baccata*, *Prunus avium.*

The model calculates - on the basis of 48 predictors - the degree of ecological suitability of the forest land for the sporadic tree species and it expresses their probability of presence in wooded areas. We used the Random Forest (RF) algorithm (Breiman 2001, Liaw and Wiener 2002), which is a variant of the Classification And Regression Trees (CART) algorithm. The RF algorithm classifies objects using predictors. Compared to other traditional methods, this system can be used to approximate any unknown function, even if it is nonlinear and involves complex interactions (Strobl et al. 2009). RF models split data into homogeneous groups using the infor-

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mation provided for their training and can even deal with highly correlated predictor variables (Strobl et al. 2008). They use an ensemble of classification (or regression) trees that are calculated on random subsets of the data, using a subset of randomly restricted and selected predictors for each split in each classification tree (Strobl et al. 2008). RF models are implemented in the homonym library of R (R Development Core Team 2013), an open source software environment for statistical analysis. This procedure can be interfaced with the GRASS (Geographic Resources Analysis Support System) software (GRASS Development Team 2012) on Windows, Mac OS X and GNU/Linux systems using the spgrass6 library. The model for the sporadic tree species probability of presence was built using the data collected in 83 plots established in 1993, when the Tuscany Forest Inventory was conducted (Regione Toscana 1998). 80% of the data sets were used for training the RF model, 20% were used for model validation. The 80/20 proportion is widely used for splitting data sets in machine learning algorithm applications according to the Pareto principle, which states that, for many events, 80% of the effects come from 20% of the causes (Boslaugh and Watters 2008). That is why we considered 20% of the data as an appropriate proportion for the validation set.

We tested other methods - the k-nearest neighbors (k-NN) algorithm and the artificial neural networks (ANN) - with the same data set, in order to compare them with the RF method. The k-NN algorithm is a non-parametric method for classification and regression that predicts objects values or class memberships, based on the k closest training examples in the feature multidimensional space (Cunningham and Delaney 2007). ANN are computational models inspired by the brain of animals, which are capable of learning and pattern recognition. They are usually presented as systems of interconnected neurons which can compute values from inputs by feeding information through the network (Anil K. Jain et al. 1996).

We used the k-NN method as implemented in the KKNN (Schliep and Hechenbichler 2013) and the KNNFLEX (Dunlap Brooks 2007) R libraries. The data set was divided to compare the RF algorithm with the k-NN and the ANN methods. The RF method itself does not require a cross-validation: an unbiased estimate of the test set error is calculated internally during the run (Breiman 1996) as follows. Each tree is constructed using a different bootstrap sample from the original data. About one-third of the cases are left out of the bootstrap sample and not used in the construction of the k^{th} tree. Each case left out in the construction of the k^{th} tree is used in the k^{th} tree to get a classification. In this way, a test set classification is obtained for each case in about one-third of the trees. At the end of the run, if "j" is the class that got most of the votes every time case "n" was out-of-the-bag (OOB), the proportion of times that "j" is not equal to the true class of "n" averaged over all cases is the OOB error estimate. Through this process, we can also get an indirect estimation of the classification accuracy.

The RF algorithm was selected because it performed the best classification accuracy, calculated through the confusion matrix (a table where each column represents the instances in a predicted class, while each row represents the instances in an actual class).

In order to assess the directional variability of the predictors, we calculated 48 raster maps using the statistics of minimum, maximum and standard deviation, which are calculated using a 3 x 3 cell neighborhood in each input layer.

The RF algorithm was applied to a database that was obtained by extracting values from the digital maps of predictors in the locations of the forest inventory plots. These values were then added to the data regarding the presence of sporadic tree species, derived from regional forest inventory. These data were used to build a model which describe the presence of sporadic tree species.

We built the model using 500 classification trees. According to the RF method, each classification tree provides a classification and it is said that the tree "votes" for that class. The algorithm chooses the classification that gets the majority of the votes (Emmert-Streib and Dehmer 2010). Different numbers of trees were tested as well, showing no statistically significant differences in the classification accuracy. After that, we applied the model to the predictors' raster maps, obtaining a map showing the probability of presence of the sporadic tree species. The resulting raster map was processed by reclassifying the values from 0 to 0.5 as 0 (1st class) and the values from 0.51 to 1 as 1 (2nd class). The areas with a higher probability of presence (2nd class) were considered the most suitable for the application of tree oriented silviculture. We chose a reclassification with 0.5 as threshold because we wanted to adopt very selective criteria in the identification of the areas that are suitable for the tree oriented forestry application.

Reflectance values (Landsat 7 ETM+ 1, 2, 3, 4, 5, 6 bands)

We used the reflectance values provided by a Landsat 7 ETM+ scene for the spectral bands 1, 2, 3 and 4 (red and near IR), 5, and 6. Particularly red and infrared values express the absorption of radiation in the wavelengths used by the photosynthesis and describe the functionality of ecosystems. The Landsat scenes of 2006 are available at the URL http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp. A principal component analysis was conducted using the i.pca module of GRASS software.

Normalized Difference Vegetation Index (NDVI)

This index - calculated through the equation [1] using the reflectance values of bands 3 and 4 provided with Landsat 7 ETM+ - assesses the absorption of photosynthetically active solar radiation and describes the ecological functionality of forest ecosystems (Lloyd 1990).

$$\text{NDVI} = (\text{band } 4 - \text{band } 3) / (\text{band } 4 + \text{band } 3) \qquad [1]$$

Altitude, slope, aspect

The terrain morphology influences many ecological factors. Altitude, exposition and slope are the driving factors determining the sliding velocity of water on the ground surface, the prevailing winds and the available solar radiation. Maps of slope and aspect were derived from a DTM (Digital Terrain Model). The DTM has a 90 m resolution and is provided by the Consortium for Spatial Information http://srtm.csi.cgiar.org. Elevation data were collected during the SRTM (Shuttle Radar Topography Mission), which provided data on a global scale to generate a high-resolution digital topographic database of the Earth. The SRTM consisted of a radar system that flew aboard the Space Shuttle Endeavour during an 11-day mission in February 2000. Despite the availability of DTMs with a higher resolution, we chose to use this one because we considered a 100 m resolution to be adequately precise for the purposes of the present work. We resampled the 90 m resolution SRTM DTM to 100 m resolution using the GRASS GIS software (nearest neighbor resampling).

Surface water accumulation

The calculation of the accumulation of water flows was performed using the GRASS software. This software provides an output map in which the absolute value of each cell represents the amount of overland flow that moves across the cell coming from cells at higher altitudes. The areas with greater water availability were identified calculating the logarithm of accumulation. Due to the wide extension of the study area, the flow accumulation values have a very wide range. Therefore we chose to calculate the logarithm of the flow accumulation (Catani et al. 2013).

Average annual precipitation

The average annual precipitation map was obtained by interpolation using the rainfall data of the Regional Hydrological Service (www.sir.toscana.it). These data were recorded in 59 stations in the provinces of Grosseto and Siena and refers to the years between 1919 and 2005. Unfortunately, the availability of these data was not homogeneous and we therefore we selected only the stations reporting data from at least 10 consecutive recent years. We derived the values of average annual precipitation and provided the coordinates of the stations in order to create a georeferenced database in vector format.

The interpolation was conducted using the Universal Kriging method with elevation (provided by SRTM DTM) as external drift, implemented in the gstat library (Pebesma and Edzer 2004) of R software. The Universal Kriging method was used because it performed better compared to other methods that have been proved to be useful at regional scale for bioclimatic data interpolation (Attorre et al. 2007). We verified the normal distribution and the absence of autocorrelation of the errors. The variogram model we chose was exponential and the interpolation was performed using a range of 30 km.

Results

The ACC (accuracy) of the different models was calculated using the cross-validation confusion matrix. The RF method predicted with an ACC of 0.72; the best result using the k-NN algorithm was an ACC of 0.58. The ANN predicted with a maximum ACC of 0.64.

A result map showing the probability of presence of sporadic tree species (Fig. 1) was created applying the model built with the RF algorithm to the predictors' raster maps. The probability of presence of sporadic trees species in the result map (obtained applying the model built with the RF method) varies between 0.12 and 0.88. The areas with a probability of presence from 51% to 100% (2^{nd} class) cover a surface of 3,255 ha: 1,560 ha belong to the Tuscany Region properties, the remaining areas are private

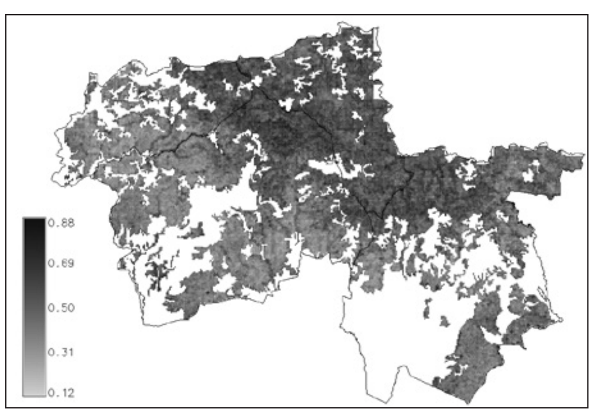

Figure 1 - Raster map on the probability of presence of sporadic tree species in the UCMCM territory, built using the RF algorithm.

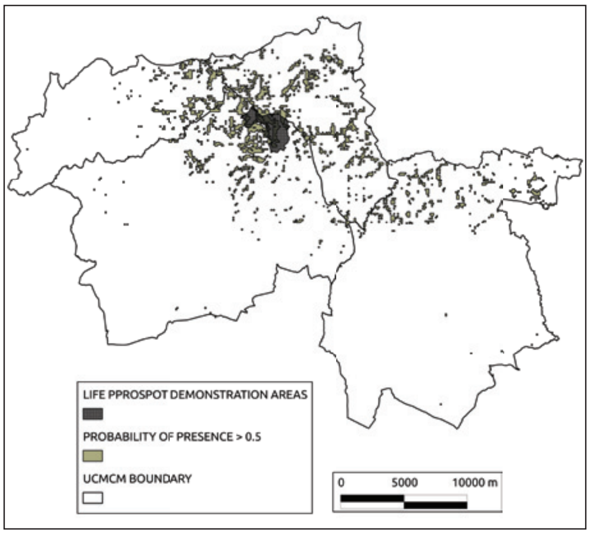

Figure 2 - Distribution of wooded areas where the probability of presence of sporadic tree species is from 51% to 100%. These surfaces include a large part of LIFE+ P.Pro.Spo.T. demonstration areas.

properties, mainly located in mesic deciduous hardwood forests. In addition, most of the forests chosen as demonstration areas for the P.Pro.Spo.T. project fall within the "high probability of presence" surfaces identified through the model (Fig. 2).

The terrains situated in low altitude areas and presenting a high probability of presence of sporadic tree species are located along the main watercourses and/or are exposed to the North.

Discussion

In the construction of the model of distribution of sporadic tree species, the RF algorithm performed better in terms of classification accuracy compared to the other non-parametric methods used (k-NN and ANN). The problem we examined - the modelling of the distribution of a set of sporadic tree species with different ecological characteristics - appeared to be a very complex matter. For this reason, we consider the results obtained with the k-NN and ANN methods satisfactory as well and useful for the development of the model. It is our opinion that the better performance of the RF algorithm depends on the logical and mathematical features of this method, which do not perform only a single classification during the model building, but rather a large number of classifications (500 in the basic configuration). Furthermore, the classification is conducted with the automatic selection of a random sample containing about 70% of the data, using a subset of randomly restricted and selected predictors for each split in each classification tree. This allows the comparison of all the 500 or more different and independent classifications, assuring the selection of the most correct one in each case.

Conclusions

Building a spatial model using the RF algorithm we identified a surface of 3,255 ha - within the UCMCM wooded area - where the probability of presence of sporadic tree species is greater than 50%. This model provides useful information for forest planning both on private and public properties. For instance, it is possible to identify suitable areas for the application of tree oriented silviculture corresponding to over 6% of the forest surfaces where the UCMCM is the competent authority. This model is built using data and software provided free of charge and it can support low cost forest planning including tree oriented silviculture. It allows to overcome the need for preliminary field investigations aimed at verifying the presence and the possibility of diffusion of sporadic tree species, thus reducing the cost of forest planning aimed at the application of tree oriented silviculture.

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