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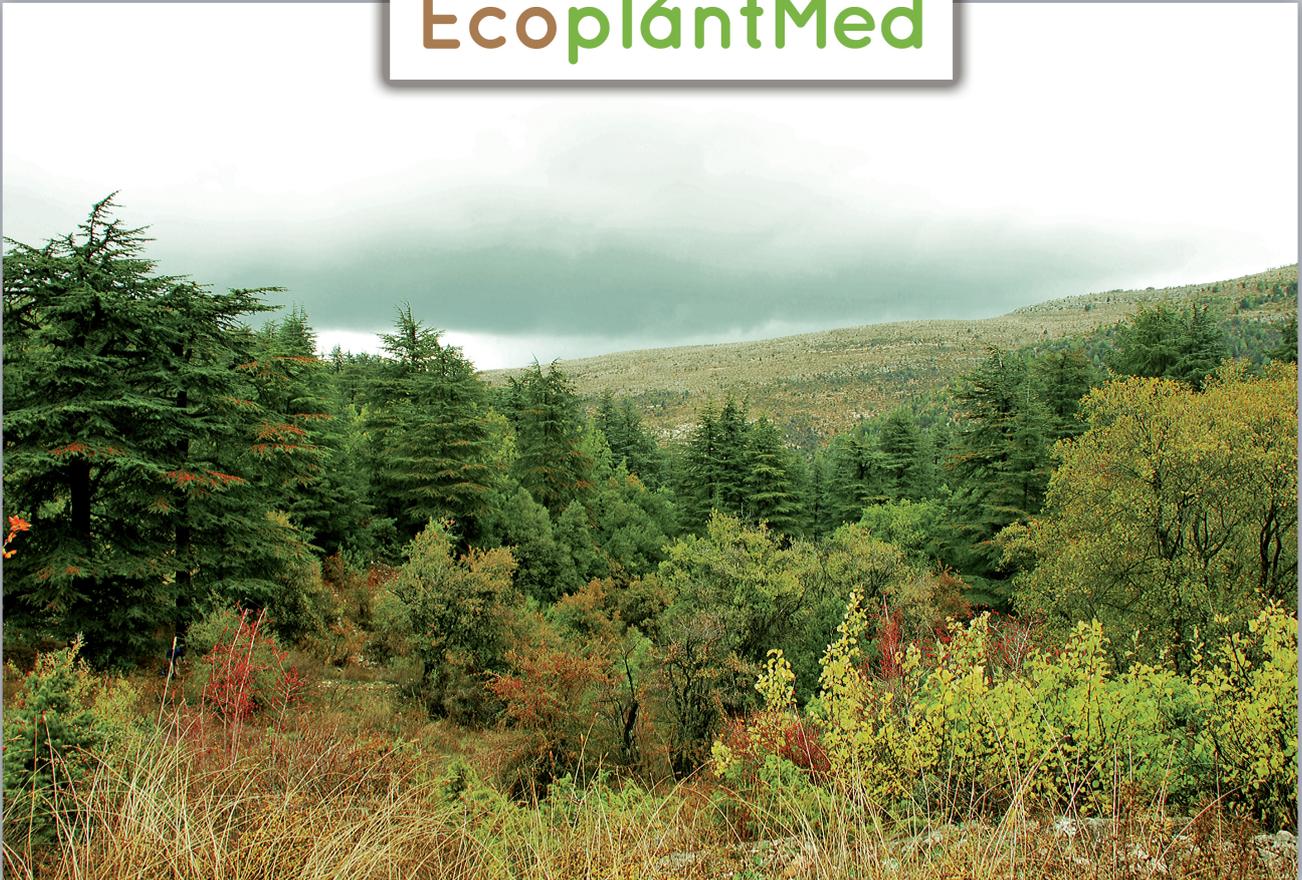
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Beech-wood restoration in the Gran Sasso and Monti della Laga National Park (central Apennines, Italy)

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Abstract

Beech-wood (*Fagus sylvatica* L.) restoration in the Gran Sasso and Monti della Laga National Park (central Italy) started in 2001, in areas that were degraded by overgrazing and overexploitation, which had led to the fragmentation and degradation of the beech woods. The objectives of the ecological restoration were to reverse the fragmentation through the re-activation of the ecological functionality of the forest system. Some innovative criteria were introduced concerning the modification of the Miyawaki method, using a few tree species and involving a low mechanisation of all the planting and tending operations. In the experimental area, the vegetation restoration started with successional tree species that belonged to the same vegetation series, of the association *Actaeo spicatae-Fagetum sylvaticae*. The cultural tecnique followed the criteria of sustainability from the ecological, social and economic points of view. The results 14 years after the planting show: (i) *Prunus avium*, *Betula alba*, *Salix caprea* and *Populus tremula* as the tree species with greatest growth; (ii) High survival rates and good vitality status for all of the planted trees, except for some damage caused by wild herbivores (eating and stripping of the bark), and by recent snowfalls; and (iii) Some species fruiting (*Prunus avium*, *Acer pseudoplatanus*, *Sorbus aucuparia* and *Sorbus aria*), and evidence of relatively frequent natural regeneration. Analysis of the flora shows that the situation is still very similar to the initial conditions, with prevalence of species of secondary pastures dominated by *Brachypodium rupestre* (*Brometalia erectii*), and with the stand crown cover at 80%. On the contrary, where the stand crown cover had reached 100%, there were some nemoral species in the herbaceous layer, of *Fagetalia sylvaticae*. With these generally good results, this experience reveals some open aspects relating to enhancing forest restoration in protected areas, as the need for: (1) Control of the game population; (2) Identification of the local provenances of all of the species that are used in future forest restoration activities; (3) Production of nursery material of high quality; and (4) Initial stocking density >1100 ha^{-1}.

Key words: forest restoration, *Fagus sylvatica*, Italy, Miyawaki method, potential natural vegetation, planting system, protected areas.

Introduction

Akira Miyawaki, a Japanese phytosociologist, developed a method for active restoration of degraded sites that is based on the concept of the potential natural vegetation (Miyawaki, 1999; Miyawaki & Box, 2007). The aim of this method is to restore multi-species and multi-layered forests that are very "close" to the native forests.

Preliminary investigations of the field vegetation are carried out by the phytosociological approach to determine the correct choice of species, with an analysis of the soil profile and the morphology. Seeds of all intermediate and late successional species are then collected in nearby native forests (mainly from sacred groves), to grow the seedlings for the planting. After this, if necessary, 20 cm of soil can be carried-over and all of the species are mixed and planted at high density. Mulching is needed to prevent soil dryness, erosion on steep slopes (even with heavy rainfall), and weed growth, and to protect the seedlings against the cold.

No post-plantation silvicultural practices are applied.

In Italy, with its long history of human activity, the intense exploitation or complete forest destruction for agriculture and grazing has in many cases altered the original species composition and the natural environment. Thus, afforestation of bare land has been carried out since the 19th century, to prevent soil erosion. Over the last few decades, the abandonment of the agricultural land has resulted in further problems in Italian rural areas, as in many other European countries (Kirby & Watkins, 2015), which need to be approached from the social, economic and cultural points of view. Therefore, different options need to be considered: recovery of the land for new agricultural purposes (as suggested in some regions for new vineyards); and conservation of the historic rural landscapes (Agnoletti, 2010), to allow natural evolution (passive restoration), or to applying active restoration (reforestation).

Secondary succession through perennial grass, light-demanding shrubs, light-demanding fast-growing trees, and late successional trees would take about 200

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years (Miyawaki, 1999; Quezel & Medail, 2003; Mercurio, 2010). Therefore, for the final native forest to be restored in a relatively short time (i.e., a few decades) this requires human intervention.

Since the 1980s, the traditional techniques of afforestation have been revisited in Italy on the basis of new knowledge of forest ecosystem functioning and forest restoration techniques. This can be summarised and simplified as the principle of "consulting nature in the planting of forests". In particular, the Miyawaki method (Miyawaki, 1999; Miyawaki & Box, 2007) was taken into consideration in Italy by Mercurio *et al.* (2010) and Schirone & Vessella (2011).

Here we present the results after 14 years of active forest restoration through a modification of the original Miyawaki method, which used a few tree species at low densities, and involved low-level mechanisation for all of the planting and tending operations. In addition to structural analyses, floristic and vegetation surveys were carried out, which were aimed at assessing the current dynamics, especially for the herbaceous and shrub layers.

Materials and Methods

Study area

The study was conducted in the Valle del Bove, Campotosto (AQ), in the Gran Sasso and Monti della Laga National Park (the upper valley of the Vomano River) in central Italy (1480-1560 m a.s.l.; north to northeast aspects; slope 25% to 40%). The mean annual precipitation was 1047 mm, with summer precipitation of 163 mm, and without any dry period. The snow co-

ver usually extended from November to March/ April. The mean annual temperature was 7.18 °C, with the mean temperatures of the coldest month of -2.58 °C, and the warmest month of 18.08 °C. According to the bioclimatic classification of Rivas-Martínez (Rivas-Martínez *et al.*, 2011), the thermopluviometric station of Campotosto (1430 m a.s.l.) belongs to the temperate macroclimate. The predominant bedrock is flysch. The soils were classified as Typic Haploxerept (Soil Survey Staff, 2003), were of silt loam, and were acidic and deep (> 60 cm).

The natural beech woods are referred to the association *Actaeo spicatae-Fagetum sylvaticae* (Biondi *et al.*, 2008). This association includes the beech woods of the upper supratemperate bioclimatic belt that grow on the formation of Gran Sasso/Laga Flysch. These woods grow on deep and acid soils, and they can be considered the potential natural vegetation in the territory under investigation. This association is included within the suballiance *Veronico urticifoliae-Fagenion sylvaticae* (Di Pietro, 2007), which includes the acidophilous and sub-acidophilous beech woods in the central Apennines, and within the alliance *Aremonio agrimonoidis-Fagion sylvaticae* (*Fagetalia sylvaticae*, *Querco roboris-Fagetea sylvaticae*).

These beech woods can be considered the most evolved vegetation in the series of the central-Apennine, microthermic, acidophilous, climatophilous beech woods of the upper supratemperate bioclimatic belt (*Actaeo spicatae-Fageto sylvaticae sigmetum*). These woodlands are dynamically linked with the mantle communities of *Juniperus communis* subsp. *communis* and *Cytisus scoparius*, pastures of *Brachypodium*
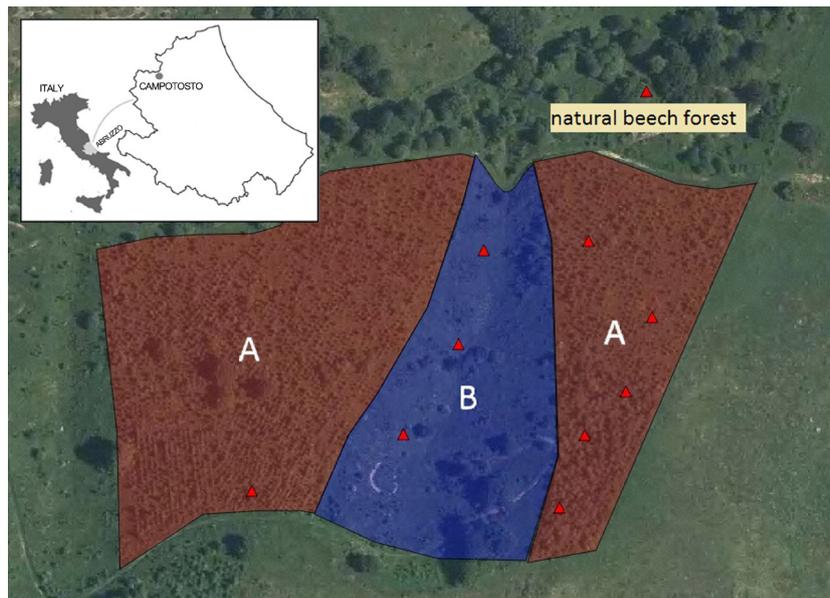

Fig. 1 - Study area within Italy. Campotosto in the Gran Sasso and Monti della Laga National Park, and satellite view of Sites A and B and the nearby natural beech forest. Locations of the phytosociological surveys in the study areas are shown as red triangles.

rupestre, *Sesleria nitida* and *Astragalus sempervirens* (*Phleo ambigui-Bromion erecti*), and grasslands of *Cynosurus cristatus* and *Trifolium repens* (*Cynosurion cristati*) in the sites with deep soil.

Chain relationships have been established with the series of central-Apennine, thermophilous, climatophilous and acidophilous beech woods that belong to the low supratemperate bioclimatic belt (*Potentillo micranthae-Fageto sylvaticae sigmetum*) (Biondi *et al*., 2008), and in the upper supratemperate bioclimatic belt, with the series of mountain dwarf juniper (*Juniperus communis* var. *saxatilis*) and high mountain dwarf bilberry (*Vaccinium myrtillus*) shrubs.

Planting techniques

Following Mercurio (2001, 2010), two criteria guided these forest restoration procedures:

– To use the native tree species chosen after field investigations in the area, according to the phytosociological approach, and thus to speed up the natural dynamics to provide the so-called "potential natural vegetation", which was not regarded as an absolute datum, but as a simple reference point.

– To reduce the impact of the traditional geometric plantations that are used to promote the mechanisation of all cultural operations, such as ploughing and cleaning. For this, arrangements of curved rows (Lucas, 1991) and clusters (Schoenenberger, 2001; Twedt, 2006) were applied.

Two different planting techniques were adapted for two different sites, in relation to the soil inclination:

1. *Site A*, with slope <25% and a flat morphology. The soil preparation was full deep cultivation (ploughing) to 70 cm in depth, and the seedlings were arranged in curved rows (spacing: 2 m between seedlings along rows; 3 m between rows). This reduced the planting costs and the following tending operations. With the stocking at 1100-1600 plants ha⁻¹, the tree species composition was:

(a) Early successional species (equal percentages of each species): goat willow (*Salix caprea* L.), birch (*Betula alba* L.), aspen (*Populus tremula* L.), rowan (*Sorbus aucuparia* L.), whitebeam (*Sorbus aria* Crantz.), wild cherry (*Prunus avium* L.) and sycamore (*Acer pseudoplatanus* L.);

(b) Late successional species: 70% beech (*Fagus sylvatica* L.) and 30% Norway maple (*Acer platanoides* L.), ash (*Fraxinus excelsior* L.), lime (*Tilia cordata* Mill.), silver fir (*Abies alba* Mill.), and yew (*Taxus baccata* L.).

2. *Site B*, with slope >25% and a rough morphology. The soil preparation was for holes, with seedlings arranged in clusters (spacing: 2 m between seedlings inside clusters; 4 m between clusters). This approach was more suitable to steep slopes in mountain areas with complex orography. The aim was the creation of spatially non-uniform and more diverse stands that are more resistant to pathogens, herbivores and climatic hazards, while avoiding soil erosion caused by more aggressive techniques that eliminate the shrub cover using heavy machinery. The tree species composition was the same as for Site A, but the stocking was 400 plants ha⁻¹.

In both cases, 1-2-year-old bare root seedlings were used. The planting was carried out in the spring of 2001. The tending operations involved fencing off the entire afforested area with 1.25-m-high wire mesh, replacement (beating up) of seedling failures, and manual cultivation around the seedlings.

Data collection

Randomised samples of 30 individuals of each tree species were used to analyse the dendrometric and dendrological aspects, diameters at breast height, total heights, crown cover, and damage by herbivores and snow. The different tree species were surveyed during the winter of 2015.

The vegetation study in these restored areas was conducted using the phytosociological approach (Braun-Blanquet, 1964; Géhu & Rivas-Martinez, 1981), updated according to the latest interpretations. The reference for the single *taxa* nomenclature was the checklist of the Italian vascular flora (Conti *et al*., 2005; 2007). Ten phytosociological surveys were carried out in these study areas during the summer of 2015. From this phytosociological survey, Table 1 was drawn up. Surveys 1 to 6 were performed in the restored area with slope <25% (Site A), and surveys 7 to 9 were performed in the restored area with slope >25% (Site B); survey 10 was taken in a close-by natural beech wood.

For the distributions of the species between the different phytosociological categories, the percentages of the species of each phytosociological category were also calculated in terms of the total of the species present.

Results and discussion

After 14 years, all of the planted trees showed high survival rates and good vitality status. The exact height measurements were compromised by the frequent snow damage. However, 85% of the trees of Site A were higher than those of Site B, which reveals the importance of complete soil preparation. Indeed, all of the plants had benefited from the more favourable soil conditions, such as for water and nutrients.

The highest tree species were those that are light-demanding or early successional, such as birch (8.7 m), aspen (8.4 m), wild cherry (6.7 m), and goat willow (6.6 m). These had grown rapidly in height and formed an upper canopy stratum, unlike the late successional species. Indeed, these latter species showed lower
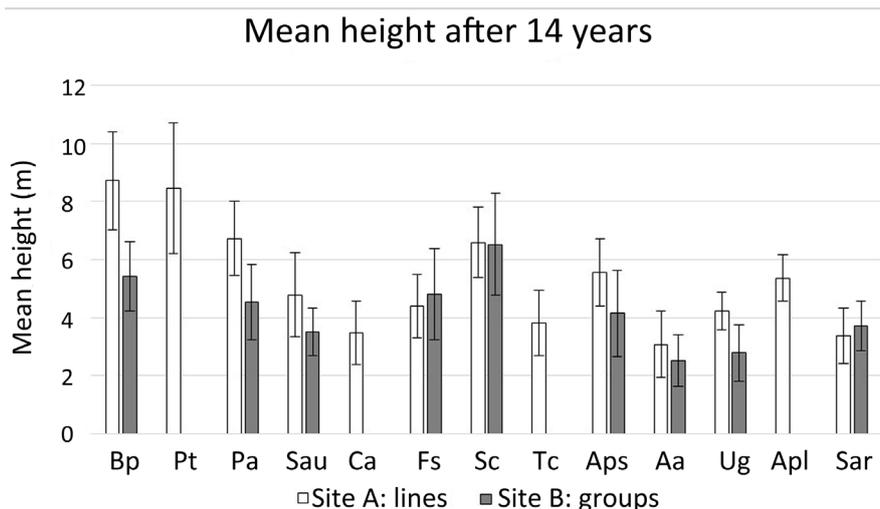
Fig. 2 - Mean heights (±SD) of the tree species after 14 years. Bp: *Betula pendula*, Pt: *Populus tremula*, Pa: *Prunus avium*, Sau: *Sorbus aucuparia*, Ca: *Corylus avellana*, Fs: *Fagus sylvatica*, Sc: *Salix caprea*, Tc: *Tilia cordata*, Aps: *Acer pseudoplatanus*, Aa: *Abies alba*, Ug: *Ulmus glabra*, Apl: *Acer platanoides*, Sar: *Sorbus aria*.

heights: beech (4.6 m), lime (3.8 m), and silver fir (2.8 m), while yew had disappeared (Fig. 2). Intermediate heights were recorded for *Acer*, *Ulmus* and *Sorbus* trees. Some species were fruiting (e.g., *Prunus avium*, *Acer pseudoplatanus*, *Betula alba*, *Sorbus aucuparia*, *Sorbus aria*), and advanced natural regeneration of these species was quite frequent.

Experience using late-successional broadleaved trees in the restoration of beech woods is very rare, but sometimes this can be successful (Legard & Davis, 2004) if the restored site has good soil conditions, as in this case study. More frequently pines and/or other pioneer species have been used mainly for degraded sites (Girona Garcìa *et al*., 2015; Popović & Ćirković-Mitrović, 2016), which facilitates the introduction of late-successional hardwoods (Ivetić & Devetaković, 2016); however, these different situations are not comparable with this case study.

Species of *Fagetalia sylvaticae* and mesophilous forests were present in large numbers in the first group of surveys, where the tree species planted with the higher density had secured the soil cover that is more appropriate for the nemoral herbaceous species. These species included *Poa nemoralis*, *Brachypodium sylvaticum*, *Veronica chamaedrys*, *Senecio ovatus*, *Geum urbanum*, *Scrophularia scopolii*, *Geranium nodosum*, *Epilobium montanum*, *Festuca heterophylla*, *Potentilla micrantha* and *Melica uniflora*.

In surveys 7 to 9 (Site B), the situation of the herbaceous layer had not yet evolved, with the prevalence of the typical pasture species.

In the restored stands, there were also various nitrophilous-ruderal species, although with low values of cover, and these were, however, subordinate to the species of the pastures with *Brachypodium* (Fig. 3).

Conclusions

According to the scientific evidence that has resulted from this experience, some particular points can be noted:

- The analysis of the flora shows that the situation is still very similar to the initial conditions, with the prevalence of species of secondary pastures dominated by *Brachypodium rupestre* (*Brometalia erectii*) when the stand crown cover was 80% or less (for slopes >25%). On the contrary, when the stand crown cover reached 100% (for slopes <25%) in the herb layer, there were some nemoral species of *Fagetalia sylvaticae*.

- The differences in the tree species growth suggest that restoration efforts should be carried out at different times: initially with early successional species, as the "nurse crop", and then with planting of late-succes-

PERCENTAGE DISTRIBUTION OF SPECIES BETWEEN THE DIFFERENT CATEGORIES
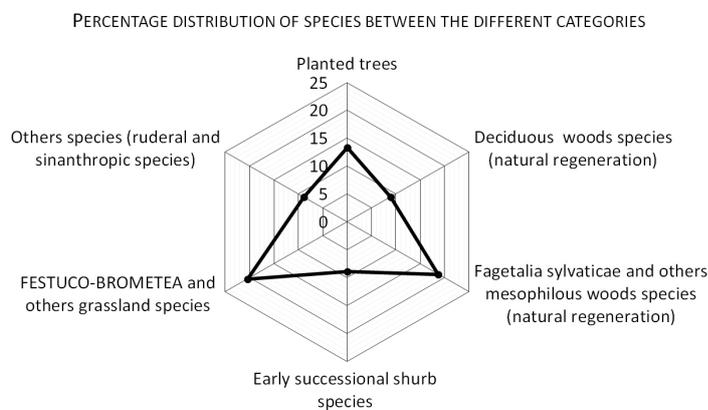
Fig. 3 - Percentage distributions of the species between the different phytosociological categories.

Tab. 1 - Phytosociological surveys for site A and site B.

	SITE A slope <25%						SITE B slope >25%			Natural beechwoods
Rel. n.	1	2	3	4	5	6	7	8	9	10
Exposure	NO	NO	NO	NO	NE	NNO	NE	NE	NE	N
Altitude m a.s.l.	1544	1535	1527	1520	1547	1506	1507	1529	1538	1490
Coverage %	65	60	95	80	80	85	40	60	40	90
Area m^2	70	50	50	80	100	60	50	40	100	200
Planted trees										
Fagus sylvatica L.	1	.	.	3	4	3	2	2	3	.
Sorbus aucuparia L.	2	2	2	1	2	+	.	1	2	.
Acer pseudoplatanus L.	.	.	.	2	2	.	1	2	1	.
Prunus aviumL.	2	1	3	.	.	.	.	.	.	.
Sorbus aria (L.) Crantz	2	.	2	.	.	.	.	.	+	.
Ulmus glabra Huds.	.	.	.	+	1	.	+	.	.	.
Salix caprea L.	.	3	.	2	.	3	.	.	.	.
Corylus avellana L.	2	2	.	.	+	.	.	.	.	.
Betula pendula Roth	2	.	3	.	.	.	.	.	.	.
Abies alba Mill.	.	.	.	.	.	+	+	.	.	.
Tilia cordata Mill.	+	.	.	.	.	.	.	.	.	.
Populus tremula L.	.	.	.	.	.	2	.	.	.	.
Acer platanoidesL.	.	.	.	.	.	.	2	.	.	.
Actaeo spicatae-Fagetum sylvaticae and superior syntaxa (natural regeneration)										
Fagus sylvatica L.	.	.	+	.	.	.	.	.	.	5
Poa nemoralis L.	1	.	.	1	1	.	.	1	1	+
Brachypodium sylvaticum (Huds.) P. Beauv.	.	.	1	.	1	2	.	.	1	2
Veronica chamaedrys L.	1	.	+	.	.	1	.	.	1	.
Sorbus aucuparia L.	.	.	2	1	1	.	.	.	.	.
Senecio ovatus (G. Gaertn., B. Mey. & Scherb.) Willd.	.	.	+	2	.	1	.	.	.	1
Scrophularia scopolii Hoppe	+	+	.	.	.	.	.	+	.	.
Potentilla micrantha Ramond ex DC.	.	.	.	.	+	.	.	.	.	1
Geum urbanum L.	+	1	.	.	.	.	.	.	.	+
Popolus alba L.	2	1	1	.	.	.	.	.	.	.
Prunus aviumL.	1	.	1	.	.	.	.	.	.	.
Geranium nodosum L.	.	.	.	1	.	.	.	1	.	2
Epilobium montanum L.	.	.	+	.	.	.	.	.	.	+
Festuca heterophylla Lam.	.	.	.	.	1	.	.	.	.	1
Melica uniflora Retz.	.	.	.	.	1	.	.	.	.	.
Fraxinus ornus L.	.	.	.	.	+	.	.	.	.	.
Ulmus minor Mill.	.	.	.	.	.	+	.	.	.	.
Anemone apennina L.	.	.	.	.	.	.	.	.	.	1
Cardamine bulbifera (L.) Crantz	.	.	.	.	.	.	.	.	.	1
Pyrola minor L.	.	.	.	.	.	.	.	.	.	1
Ranunculus lanuginosus L.	.	.	.	.	.	.	.	.	.	1
Hieracium murorum L.	.	.	.	.	.	.	.	.	.	1
Pulmonaria hirta subsp. apennina (Cristof. & Puppi) Peruzzi	.	.	.	.	.	.	.	.	.	1
Viola reichenbachiana Jord. ex Boreau	.	.	.	.	.	.	.	.	.	+
Athyrium filix-femina (L.) Roth	.	.	.	.	.	.	.	.	.	+
Anthriscus nemorosa (M. Bieb.) Spreng.	.	.	.	.	.	.	.	.	.	+
Daphne mezereum L.	.	.	.	.	.	.	.	.	.	+
Euphorbia amygdaloides L.	.	.	.	.	.	.	.	.	.	+
Acer pseudoplatanus L.	.	.	.	.	.	.	.	.	.	+

Early successional shurb species

Cytisus scoparius (L.) Link	1	1	1	1	1	1	2	3	3	.
Rubus idaeus L.	4	3	3	3	3	4	4	2	.	.
Vaccinium myrtillus L.	.	.	.	.	.	+	.	.	1	3
Corylus avellana L.	1	+	+	.	.	.	.	.	.	.
Salix caprea L.		1		.	.	.	.	.	.	.
Rosa canina L. group	.	.	.	.	1	.	.	.	2	.
Crataegus laevigata (Poir.) DC.	.	.	.	.	.	.	.	.	2	.
Juniperus communis L.	.	.	.	.	.	.	.	.	.	+
Ribes alpinum L.	.	.	.	.	.	.	.	.	.	+
Crataegus monogyna Jacq.	.	.	.	.	.	.	.	.	.	+
Prunus spinosa	+	.	.	.	.	.	.	.	.	.

Festuco-Brometea and others grassland species

Brachypodium rupestre (Host) Roem. & Schult.	3	4	3	4	3	3	3	4	4	.
Agrostis capillaris L.	1	1	2	2	1	1	1	+	2	.
Trifolium medium L.	3	3	2	2	1	1	.	.	2	.
Rumex acetosa L.	1	+	.	1	.	.	.	.	1	.
Hypericum perforatum L.	1	.	.	1	+	.	.	+	.	.
Valeriana officinalis L.	1	.	.	+	.	.	.	.	+	.
Lathyrus pratensis L.	.	+	.	.	.	+	.	.	2	.
Phleum bertolonii DC.	+	.	.	+	.	.	.	.	.	.
Briza media L.	+	.	.	.	.	.	.	.	1	.
Bupleurum falcatum L. cernuum (Ten.) Arcang.	+	.	.	.	.	.	.	.	+	.
Campanula rapunculus L.	.	.	.	+	+	.	.	.	.	.
Carlina acaulis subsp. caulescens (Lam.) Schübl. & G. Martens	.	.	.	.	1	.	.	.	1	.
Digitalis ferruginea L.	.	.	.	.	+	.	.	.	1	.
Campanula glomerata L.	.	+	.	.	.	.	.	.	.	.
Festuca sp.	.	+	.	.	.	.	.	.	.	.
Helianthemum nummularium (L.) Mill.	.	+	.	.	.	.	.	.	.	.
Potentilla reptans L.	.	.	+	.	.	.	.	.	.	.
Galium verum L.	.	.	.	+	.	.	.	.	.	.
Tragopogon porrifolius L.	.	.	.	+	.	.	.	.	.	.
Vicia cracca L.	.	.	.	.	.	+	.	.	.	.
Silene otites (L.) Wibel	.	.	.	.	.	.	.	+	.	.
Plantago lanceolata l.	.	.	.	.	+	.	.	.	.	.
Verbascum longifolium Ten.	.	.	.	.	+	.	.	.	.	.

Others species (ruderal and sinanthropic species)

Chaerophyllum aureum L.	1	+	+	1	.	1	1	+	+	.
Dactylis glomerata L.	1	+	+	1	1	.	1	.	.	.
Cruciata glabra (L.) Ehrend.	.	.	1	.	+	+	.	.	1	.
Cirsium tenoreanum Petr.	1	+	.	+	.	.	.	.	.	.
Cirsium arvense (L.) Scop.	.	+	+	+	.	.	.	.	.	.
Daucus carota L.	1	.	.	+	.	.	.	.	.	.
Galium aparine L.	+	.	.	.	.	.	.	.	+	.
Geranium dissectum L.	+	.	.	.	.	.	.	.	.	.
Cirsium vulgare (Savi) Ten.	.	.	.	.	.	.	.	1	.	.
Urtica dioica L.	.	.	.	.	.	.	.	.	1	.

sional species.

  - In comparisons with other conifer afforestation of the central Apennines (Gratani *et al*., 1994; Ottaviani *et al*., 2015), the use of broadleaves trees and shrubs that represent the potential natural vegetation of the area with flysch parent material, and the initial high density of planting, promoted more rapid natural dynamics of the herb layer. Thus, in a few decades, this tends to assume a more nemoral floristic composition.

  Furthermore other conclusions can be deduced here, such as:

  - The use of mixed tree species allows complemen-

tary resource use (i.e., light, water, nutrients) among species that have different levels of canopy and root development. Furthermore, afforestation with mixed species enhanced the ecological resilience, promoted conservation of biological diversity, reduced pathogen attacks, and represents an important preventive measure to cope with climate change effects.

- The initial stocking of 400 trees ha⁻¹ with localised soil preparation (i.e., Site B) was less effective for rapid soil cover and vegetation dynamics; in these cases, the minimal initial stocking density of 1100 trees ha⁻¹ (Site A) is recommended.

- On steeper slopes, it might be useful to favour the natural dynamics, and so afforestation can be limited only to the flatter areas, or in soils with inclination <30%.

- The success and retention of the afforestation in protected areas can be promoted by reductions in the game population.

Acknowledgments

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