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Can Artificial Plantings Resemble Natural Vegetation? Preliminary Evidence from a *Quercus robur* L. Stand in Mediterranean Italy †

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Abstract

The understorey vegetation of mature *Quercus robur* L. mixed forests (MF) was compared for richness and composition with that of natural forest gaps (FG) and of 30-year-old artificial *Q. robur* plantations (AF) in Mediterranean Italy. Richness was similar in AF and MF and was almost double in FG, due to the arrival of species from non-forest habitats, among which 14% were aliens. In these specific conditions, natural gap dynamics did not support forest recruitment, while AF hosted typical nemoral species, demonstrating that afforestation may be successful for nature restoration, provided that connectivity with natural systems is maintained for the supply of forest species propagules.

Keywords: aliens; English oak; phytosociology; restoration; richness; understorey flora

1. Introduction

The European Nature Restoration Law (n. 2024/1991) commits Member States to restore 20% of degraded habitats by 2030, and all ecosystems in need of restoration by 2050. As degraded ecosystems need much more time to restore their functionality compared to the imposed deadlines, all existing knowledge on past restoration actions and natural re-growth dynamics becomes crucial to predict the outcomes of future interventions.

Riparian mixed forests with *Quercus robur*, *Fraxinus* and *Ulmus* (code 91F0, European Habitat Directive n. 92/43) account for the most structurally, floristically and faunistically diverse of all European ecosystems, and deserve an outstanding position among the habitats in need of restoration [1]. More than ten tree species contribute to the canopy of these forests, with *Q. robur* becoming dominant in mature stands owing to its large size and longevity. The ground flora of riparian forests is also remarkably rich, comprising both species typical of floodplain forests and species associated with drier forest communities. Around 6000 years BP, *Q. robur* forests extended across prehistoric Europe [2], but human expansion progressively reduced and overexploited them for gaining farmland and timber. Today, they still have a wide geographical distribution but are highly fragmented and their conservation status is unfavourable-bad in most European regions [3–5]. Moreover, *Q. robur* recruitment is scarce, due to high acorn predation and sapling browsing [6], and because seedlings suffer from both drought and waterlogging stress [7,8].

In Mediterranean Italy, mixed forests dominated by *Q. robur* have an additional conservation value, as they represent extra-zonal relics of the forests that covered western

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Italy during the last Ice Age [2]. In Tuscany, highly fragmented remnants covering about 3000 ha survive [9,10]. Much of this area lies on the coast west of Pisa within the Migliarino, San Rossore, Massaciuccoli Regional Park (Nature 2000 Site 'Selva Pisana' IT5170002), surrounded by highly anthropized landscapes, including farmland, industries, and towns.

Over recent decades, the riparian forests of this site have declined markedly, with *Q. robur* being the most affected species. Treefall rates are high, and recruitment of most deciduous tree species is negligible, due to intense ungulate pressure and unfavourable environmental conditions. Indeed, in gaps created by treefall, the very sandy soils rapidly dry out and lose organic matter and nutrients through mineralization and leaching [11]. Consequently, the recently approved forest management plan has identified the conservation and regeneration of *Q. robur* as a priority, including large-scale planting.

In nature reserves, the target of restoration is not only preserving trees, but the entire plant communities. Thus, it is crucial to assess whether the ground flora associated with riparian forests will spontaneously colonize natural gaps or artificial plantations. A monospecific *Q. robur* plantation established at the edge of a mature forest about thirty years ago, on soil used for centuries as pasture and farmland, offered the unique opportunity of comparing, within the same site, the understory vegetation of mature forests with that which is developing under two contrasting forest recruitment approaches: natural regeneration and afforestation. The novelty of our study lies in investigating not only tree recruitment, but also the fate of the whole understory community.

In this study we tested whether the conservation or restoration of the understory vegetation typical of riparian forests could be effectively supported by either natural gap dynamics or by artificial plantations under coastal Mediterranean conditions. To do this, the understorey vegetation was recorded in three vegetation types: (i) a mature *Q. robur* mixed forest, (ii) canopy gaps created by natural treefall within mature forests, and (iii) a contiguous artificial *Q. robur* plantation established on former farmland. The species recorded in the three vegetation types were compared for floristic composition, diversity, life form, chorotype, ecological indicator values, and preferred habitat.

2. Materials and Methods

2.1. Study Area

The riparian forests investigated in the present research are within the Regional Park of Migliarino, San Rossore, Massaciuccoli, located along the Tuscan coast (central Italy), at coordinates 43°43′ N and 10°16′ E. They extend on ancient dunes running parallel to the coastline, interspersed with small lagoons or bogs, and the soil consists of unconsolidated marine sediments and alluvial deposits of the rivers Arno and Serchio. They belong to the Mediterranean biogeographic region (Tyrrhenian coastal province), and according to the Köppen classification, the climate is typical Mediterranean with hot and dry summers (Csa). The long-term average mean annual maximum and minimum daily air temperatures are 20.2 °C and 9.5 °C, respectively, with an annual precipitation of 971 mm, mainly concentrated in autumn–winter. The photoperiod varies from 8 h and 46 min to 15 h and 14 min. In the year of the research, the temperature was close to the long-term averages, whereas rainfall was higher, 1536 mm, due to an additional rainy period in spring [12].

2.2. Experimental Design

The experimental design consisted of one factor (vegetation type) with three levels (MF, mature forest; FG, forest gap; AF, artificial forest) and five replicates. The three vegetation types were: MF, a 50-ha mixed forest dominated by over 200-year-old *Q. robur* trees; FG, gaps originated within MF by natural treefall started around 20 years ago; AF, a 36-ha monospecific plantation of *Q. robur* spaced 2.5 m × 2.5 m, which was established in 1995 on

an abandoned farmland bordering MF. In all vegetation types, investigations were carried out on five representative plots of 400 m^2 (20 m × 20 m), complying with the recommended range for deciduous forests and previously applied to classify the vegetation of MF [13]. Due to the great spatial heterogeneity of the mature forest, MF and FG plots were chosen in pairs close to each other. To assess within-plot frequency and diversity, in each plot, the occurrence of species was recorded in 16 sampling units of 0.25 m^2 (0.5 m × 0.5 m) set along the plot diagonals.

2.3. Measurement and Calculations

Data were collected between May and July 2025. In each plot, all understory species were recorded, including dried species and those in the vegetative stage. These were subsequently identified during surveys conducted in autumn and early spring. Cover/abundance of species was assessed following the method of Braun–Blanquet with indices transformed into an ordinal scale for further calculations [14]. In forest plots, trees (>2 m) were counted, identified, and their diameter measured. The tree layer of mature and artificial forests differed in tree density and size, and in species richness (Table 1), with a total of six species recoded in MF (*Q. robur*, *Fraxinus angustifolia*, *Ulmus minor*, *Carpinus betulus*, *Acer campestre*, and *Laurus nobilis*) and only one *U. minor* tree found in AF, besides *Q. robur*.

Table 1. Canopy characteristics in mature (MF) and artificial (AF) forest plots. Values are means ± standard error of five replicates.

Vegetation Type	Tree Density (*n* Plot^{-1})	Average Tree Size (Ø cm)	Canopy Richness (*n* Species Plot^{-1})
MF	5.6 ± 1.5	69.5 ± 6.9	3.2 ± 0.33
AF	11.4 ± 1.9	22.8 ± 1.0	1.2 ± 0.18

Species were identified following Pignatti [15] and assigned to Raunkiaer's life form, chorotype and preferred habitat. Scientific names were updated according to the Portal to the Flora of Italy 2025.1 [16] (Supplementary Materials, Table S1). The Ecological Indicator Values of Ellenberg (EIV) were adapted to the Italian flora, and indifferent species were weighted as species of mediocre conditions [17,18]. The considered ecological factors were light (L), temperature (T), continentality (C), soil moisture (U), soil pH (R), and soil nutrients (N). The EIVs relative to each vegetation type were calculated according to the ordinal method, i.e., weighting the EIVs of each species by their transformed cover/abundance [18].

Species frequency within plots (*SF*) was calculated as $SF = Qs/Q \times 100$, where *Qs* is the number of sampling units in which a given species occurred, irrespective of the number of individuals, and *Q* is the total number of sampling units per plot, i.e., 16 [19].

Understory floras were compared by means of richness, diversity, similarity, life form spectra, chorograms, ecograms, and preferred habitat of component species. Diversity within plots was assessed by means of the Shannon-Wiener Diversity Index (H'), the Pielou Evenness Index (J'), and the Simpson Dominance Index ($1 - D$), calculated following Smith and Wilson [20] (Supplementary Materials, Table S2).

The Sørensen Similarity Index (*IS*) was calculated as $IS = 2J/(a + b) \times 100$, where *a* and *b* are the numbers of species of the two communities to be compared, and *J* the number of shared species. The index ranges from 0 (completely different) to 100 (identical) [19].

2.4. Statistical Analysis

To test the effect of vegetation type on mean plot and sampling unit richness, and on plot diversity, data were arranged in a simple factorial design with five replicates and

subjected to analysis of variance (ANOVA). The normality of data and the homogeneity of variances were checked prior to analyses. Post hoc Tukey's test was used for comparison among treatments, and significantly different means were separated at the 0.05 probability level. All statistical analyses were performed with JMP Student Edition 18.2.0. (SAS Institute, Inc., Cary, NC, USA).

3. Results and Discussion

A total of 94 vascular plant species were identified. Vegetation types differed in overall richness, with 85% more species recorded in forest gaps (FG) than in mature (MF) and artificial forest (AF), 76 species compared to 40 and 42, respectively. The same ranking was found for the mean number of species per plot and per sampling unit, with the differences among vegetation types becoming lower with the decrease in size (Figure 1a,b). Forest plot richness falls within the range reported for these riparian forests, despite the possibility that we overlooked some early spring and autumn species [13].

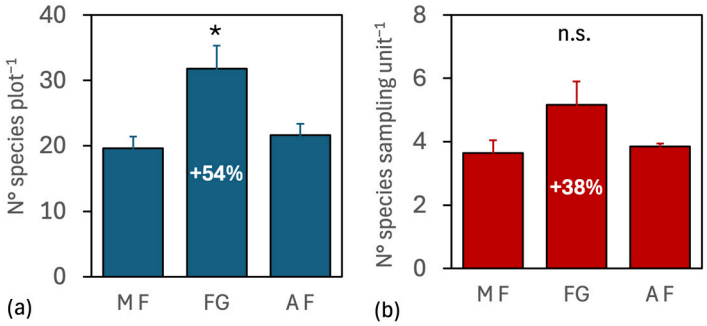

Figure 1. Mean richness: (**a**) in 400-m^2 plots; (**b**) in 0.25-m^2 sampling units. MF, mature forest; FG, forest gap; AF, artificial forest. * differs significantly at $p \leq 0.05$. n.s. not significant.

All analyzed diversity indices, Shannon–Wiener, Pielou, and reciprocal Simpson, displayed higher values in FG, but the differences to MF and AF were not significant (Table 2). Overall, figures pointed out a fairly good diversity and evenness in all vegetation types compared to values reported for other oak forests [21]. Moreover, the reciprocal Simpson index pointed out that no species exerted a dominant behaviour in FG.

Table 2. Diversity indices for the understory vegetation of the three vegetation types. Values are means ± standard error of five replicates. MF, mature forests; FG, forest gaps; AF, artificial forests. Means did not differ significantly at $p \leq 0.05$.

Vegetation Type	Shannon–Wiener Index	Pielou Evenness Index	Reciprocal Simpson Index
MF	2.31 ± 0.08	0.78 ± 0.03	0.67 ± 0.11
FG	2.70 ± 0.26	0.79 ± 0.08	0.93 ± 0.02
AF	2.24 ± 0.09	0.73 ± 0.01	0.87 ± 0.01

The Sørensen Index of Similarity highlighted that vegetation types differed in floristic composition, with MF sharing 58% of species with both AF and FG, whereas only 47% of species were shared by AF and FG. These patterns may be explained by the greater proximity of MF and FG plots, but also by the higher spatial heterogeneity typical of old oak forests that offers a great variety of niches which may also be suitable for non-forest species [22]. Twenty-two species were common to all vegetation types, representing approximately half the flora of forest understories (i.e., 55% MF, 52% AF) but less than one third that of gaps (29%). Moreover, 36 out of the 76 species (47%) recorded in FG were

exclusive to gaps. These patterns suggest that when forests are surrounded by farmland and other anthropized areas like in this site, gaps are easily colonized by foreign seeds and prompt the establishment of non-forest species stored in the soil seed bank [23,24].

Seedlings of the characteristic riparian forest species *Q. robur*, *F. angustifolia* and *U. minor* were detected in all three vegetation types (Table 3). As observed for overall richness, tree species richness was highest in FG and similar in MF and AF. *Fraxinus angustifolia* was the most frequent tree in all vegetation types. The overall frequency of tree seedlings was much higher in AF than in FG, suggesting that, in sandy soils under Mediterranean conditions, artificial forests may provide more favourable conditions for tree recruitment than forest gaps, in which full light exposure, impoverished soils, and greater fluctuation in temperature and humidity may impair seedling survival during summer, particularly for *Q. robur* [8,11]. However, also in AF, recruitment can not be considered effective, as seedlings rarely survived beyond the first year. We attributed this pattern to a combination of intense deer browsing, seed predation, and to increased fluctuations in the water regime [6–8,11].

Table 3. Tree species recorded in the understorey of the three vegetation types. Frequency of given tree species and of tree seedlings in the 16 sampling units per plot. MF, mature forests; FG, forest gaps; AF, artificial forests. Values are means of five replicates. Means followed by the same letter within a column do not differ significantly at $p \leq 0.05$.

Vegetation Type	N° of Tree Species	Frequency (%)			
		Fraxinus angustifolia	*Quercus robur*	*Ulmus minor*	Tree Seedlings
MF	5	20.0 a	3.8 ab	18.8 a	63.8 ab
FG	10	30.0 a	2.5 b	7.5 a	47.5 b
AF	6	65.0 a	16.3 a	8.8 a	93.8 a

Life form spectra pointed out a markedly lower proportion of perennial hemicryptophytes in FG, to which corresponded an advantage of annual therophytes, that represented half of the exclusive FG species (Figure 2a). The high richness and the abundance of annuals indicate that gaps are dominated by pioneer vegetation rather than forest species. Because pioneer communities are usually restricted to the early stages of gap dynamics, their persistence after decades suggests weak ecological filtering in the study area [25]. Forests had similar life spectra, with AF displaying a slightly higher proportion of woody phanerophytes and hemicryptophytes and a lower proportion of geophytes compared to MF, which is in line with the different age of these forests [26].

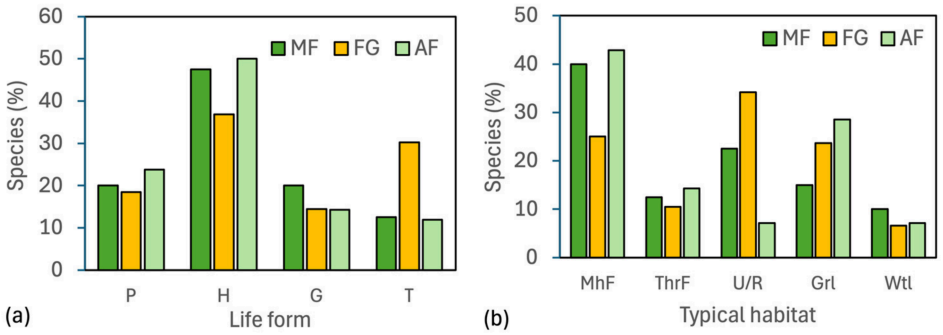

Figure 2. (**a**) Life form spectra and (**b**) proportion of typical habitat in the three vegetation types. MF, mature forest; FG, forest gap; AF, artificial forest. Life form acronyms: P, Phanerophytes; H, Hemicryptophytes; G, Geophytes; T, Therophytes. Habitat acronyms: MhF, Meso-hygrophilous forest; ThF, Thermophilic forest; U/R, Uncoltivated land/ruderal sites; Grl, Grassland; Wtl, Wetland.

Ecograms evidenced that light-demanding species were more represented in FG and species related to higher soil moisture in MF (Figure 3a), which reflects the differences in light and soil moisture recorded under the tree canopy and in the gaps [11]. While initial shifts towards heliophilous and thermophilous species are known consequences of gap formation, less attention has been devoted to assessing whether these changes will be temporary or permanent [27,28]. In the study area, forests grow on old sand dunes, and once the canopy is removed, the increase in solar radiation and temperature favours mineralization and nutrient leaching, reducing soil fertility and water retention [11,29]. These changes in soil conditions hinder the establishment and survival of forest seedlings and understory nemorals, and favour opportunistic colonizers, which may lead to alternative successional trajectories rather than effective forest regeneration. Conversely, the overlapping MF and AF ecograms suggest that, although structurally different from mature stands, artificial plantations seem to offer similar ecological conditions in the understory, which is also confirmed by the higher frequency of tree seedlings compared to FG (Figure 3b, Table 3).

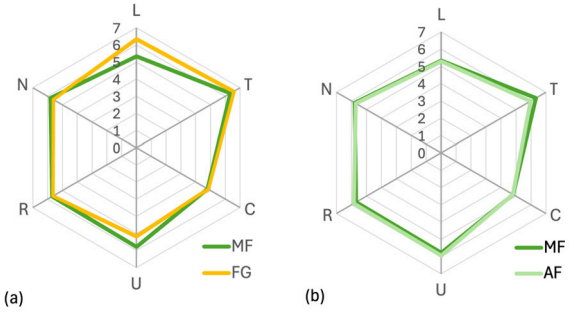

Figure 3. Ellenberg indicator values for the three vegetation types: (**a**) MF, mature forest; FG, forest gap. (**b**) MF, mature forest; AF, artificial forest. L, light; T, temperature; C, continentality; U, soil moisture; R, soil pH; N, soil nutrients.

The distribution of chorotypes on chorograms showed similar patterns in mature and artificial forests, with only a slightly higher proportion of Cosmopolitan and Eurasiatic types in MF (Figure 4a,c). In contrast, the chorogram of FG differed greatly in shape for the markedly higher presence of Euri-Mediterranean and especially Cosmopolitan/Alien species (Figure 4b). Aliens represented 2.5% of the understory vegetation in both forests, but 8% in gaps, suggesting that the stability of these forests is highly vulnerable to disturbance and that canopy openings may favour the replacement of nemoral species by opportunistic colonizers from surrounding anthropogenic habitats [24,25].

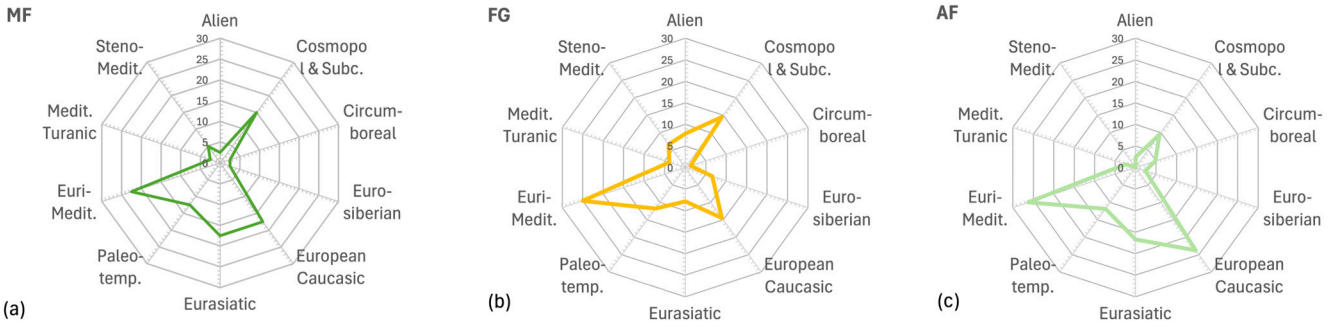

Figure 4. Distribution of chorotypes for the three vegetation types: (**a**) MF, mature forest; (**b**) FG, forest gap; (**c**) AF, artificial forest.

The understory of mature and artificial forests consisted of more than half of species typical of meso-hygrophilous or thermophilic forest habitats, 53% and 57% respectively, but only of 37% in FG (Figure 2b). Common ruderals and species typical of abandoned

land represented 34% of the vegetation in FG, 23% in MF, and only 7% in AF. The greater abundance of opportunistic colonizers and Cosmopolitan species in MF than in AF suggests higher disturbance in the mature forest, likely associated with treefall and gap formation. These findings raise concerns about the vulnerability to invasion of fragmented relics of old-growth riparian forests under Mediterranean pedoclimatic conditions, a factor that should be considered in the conservation of these highly biodiverse habitats [22]. In contrast, lower disturbance and a denser canopy appeared to protect the artificial plantation from the arrival and establishment of alien species and the higher proportion of grassland species likely reflects its former use as pasture and farmland.

4. Conclusions

Our research proves that natural gap dynamics were not effective for the conservation of the nemoral ground flora in the pedoclimatic conditions of the study area, which is characterized by sandy soils, high temperatures, high, though variable, humidity, and by high anthropic pressure favouring the arrival of seeds from farmland and ruderal areas. Otherwise, the artificial *Q. robur* plantation, still structurally poor but connected with the mature forest for zoochorous dispersal, offered a good refuge for the typical understory species of riparian forests and also for tree seedlings.

Though these data are preliminary, because early spring species including typical nemorals may have been overlooked, they add fundamental knowledge for planning forest restoration actions in the Mediterranean region.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/blsf2026062009/s1, Table S1: Species recorded in all vegetation types over the research, characterized for botanical family, Raunkiaer's life form, and chorotype; Table S2: Equations used for the calculation of diversity indices. The occurrence of species in the 16 sampling units (0.25 m^2) of one plot was used as a proxy of individuals, because the count of plant individuals is difficult, when not impossible, especially for grasses. For the index H' higher values indicate greater diversity. The indices J' and $1 - D$ range from 0 to 1, with 1 corresponding to highest diversity (J') or the complete absence of a dominant species ($1 - D$).

Author Contributions: Conceptualization, formal analysis, resources, writing—original draft preparation, project administration, I.A.; methodology, I.A. and S.P.; software, data curation, I.A. and R.L.; validation, I.A., R.L. and S.P.; investigation, visualization, R.L.; writing—review and editing, supervision, S.P. All authors have read and agreed to the published version of the manuscript.

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