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Effectiveness of the Miyawaki method in Mediterranean forest restoration programs

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Abstract In the 1980s, Professor Akira Miyawaki introduced a new and innovative reforestation approach in Japan with the challenge to restore indigenous ecosystems, and maintaining global environments, including disaster prevention and carbon dioxide (CO_2) mitigation. Here, natural vegetation successional stages (from bare soil to mature forest) are practically forced and reproduced, accelerating natural successional times. The Miyawaki method has been applied in the Far East, Malaysia, and South America; results have been very impressive, allowing quick environmental restorations of strongly degraded areas. However, these applications have always been made on sites characterized by high precipitation. The same method has never been used in a Mediterranean context distinguished by summer aridity and risk of desertification. A first test was carried out by the University of Tuscia, Department of Forest and Environment (DAF), 11 years ago in Sardinia (Italy) on an area where traditional reforestation methods had failed. For an appropriate Miyawaki application on this site, the original method was modified while maintaining its theoretical principles. Results obtained 2 and 11 years after planting are positive: having compared the traditional reforestation techniques, plant biodiversity using the Miyawaki method appears very high, and the new coenosis (plant community) was able to evolve without further operative support after planting. Therefore, the implementation of supplementary technique along with cost reduction might provide a new and innovative tool to foresters and ecological engineering experts for Mediterranean environmental reforestation program.

Keywords Ecological restoration ·
Potential natural vegetation · Ecotechnology ·
Reforestation practices comparison ·
Mediterranean environment

Introduction

Global climatic changes, together with recent rapid urbanization and industrialization, have been the main anthropogenic effects worldwide in destroying natural environments and increasing risk of desertification. They suggest the need for performing more environmental conservation activity, as well as using innovative environmental recovery activities. In the last two decades, scientists have developed new insights both in theoretical and in practical actions for restoration and reconstruction of natural ecosystems (Clewell and Aronson 2007; Falk et al. 2006; Jordan et al. 1987; Perrow and Davy 2002a, b; Soulé 1980; Miyawaki 1975, 1981). Natural restoration is strictly related to increased sustainability and includes rehabilitation of ecosystem functions, enlargement of specific ecosystems, and enhancement of biodiversity restoration (Stanturf John and Madsen 2004). At the ecological level, restoration is also defined as “an intentional activity that initiates or accelerates recovery of an ecosystem with respect to its health, integrity and sustainability” (Aronson et al. 2002).

Degraded plant communities are generally quite difficult or sometimes impossible to restore (Van Diggelen and Marrs 2003). More than 200 years of reforestation practice has demonstrated that forest recovery takes a very long

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time, frequently with unsatisfying results. Nowadays, it is possible to plant plantations of several species, but the transition from the simple plantation to a forest community able to evolve and sustain itself, according to the natural successional pattern, is still a rare event (for Italy, cf. Bellarosa et al. 1996). On the other hand, the mere superficial appearance of vegetation restoration should be avoided. It is essential to restore the natural vegetation using a combination of native species that conform to the potential trend of the habitat and to try to restore the whole specific ecosystem of a region (Miyawaki 1992).

In a natural forest cycle, as Clements (1916) described, annual plants on barren land are succeeded by perennial grass, sun-tolerant shrubs, light-demanding, fast-growing trees, and finally natural forests; each step may require decades, and the climax vegetation could be formed after two centuries or more (Connell and Slatyer 1977) (Fig. 1a). Currently, most forest reforestation programs adopt a scheme of planting one or more early successional species; after successful establishment, they are gradually replaced by intermediate species (either naturally or by planting), until late successional species arise. This pattern tries to simulate natural processes of ecological succession, from pioneer species to climax vegetation. However, it requires several silvicutural practices and normally takes a long time (Fig. 1b).

Taking several hundred years to complete the process of forest restoration is too long for us; because we live in a world where industry and urbanization are developing very rapidly, improvement of an alternative reforestation technique that reduces these times could be a useful tool (Miyawaki 1999). One reliable forest restoration method is the "native forests by native trees," based on the vegetation–ecological theories (Miyawaki 1993a, b, 1996, 1998b; Miyawaki and Golley 1993; Miyawaki et al. 1993; Padilla and Pugnaire 2006) proposed by Prof. Akira Miyawaki and applied first in Japan. According to this method, restoring native green environments, multilayer forests, and natural biocoenosis is possible, and well-developed ecosystems can be quickly established because of the simultaneous use of intermediate and late successional species in plantations (Fig. 1c). The Miyawaki method involves surveying the potential natural vegetation (sensu Tüxen 1956) of the area to be reforested and recovering topsoil to a depth of 20–30 cm by mixing the soil and a compost from organic materials, such as fallen leaves, mowed grass, etc. In this way, the time of the natural process of soil evolution, established by the vegetational succession itself, is reduced.

The potential natural vegetation indicates the potential capacity of the land, theoretically considered, as to which vegetation it can sustain (Miyawaki 1992). Tree species must be chosen from the forest communities of the region in order to restore multilayer natural or quasinatural forests. For a correct choice, based on reconstructing the potential natural vegetation, several analyses (e.g., phytosociological investigation) are required. Detection of the soil profile, topography, and land utilization can improve our grasp of the potential natural vegetation. After these field surveys, all intermediate and late successional species are mixed and densely planted, with as many companion species as possible (Kelty 2006; Miyawaki 1998a), and soil between them is mulched. Mulching is needed to prevent soil dryness, erosion on steep slopes even with heavy rainfall, weed growth, protect seedlings against cold, and as manure as materials decompose (Miyawaki 2004). In fact, biocoenotic relationships involve autoregulations between species, favoring a dynamic equilibrium and avoiding any further silvicultural practice and need no insecticides or herbicides (with some exceptions). Indeed, in the Miyawaki method, the principles of self-organized criticality and cooperation theories have been essentially applied (Bak et al. 1988; Callaway 1997; Camazine et al. 2003; Padilla and Pugnaire 2006; Sachs et al. 2004). It has

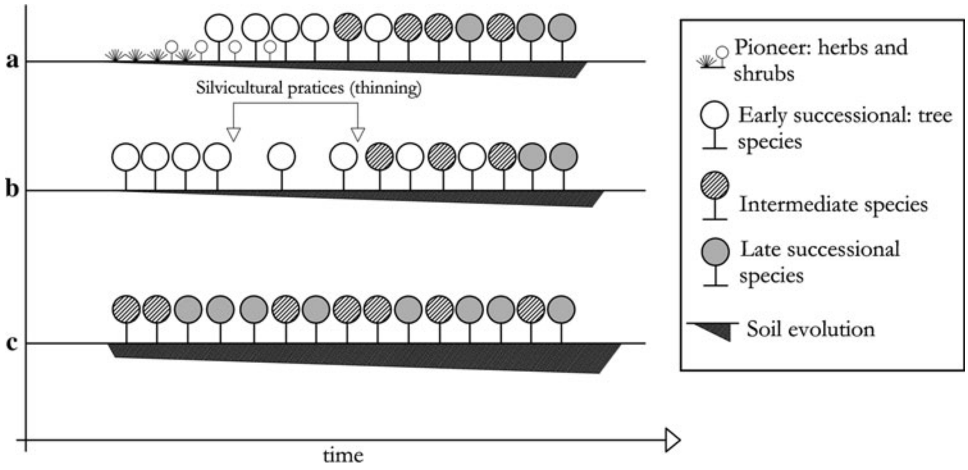

Fig. 1 Successional stages as would follow in natural conditions (**a**), adopting traditional reforestation methods (**b**) and the Miyawaki method (**c**)

been demonstrated that multilayer quasinatural forests can be built in 15–20 years in Japan and 40–50 years in Southeast Asia by ecological reforestation based on the system of natural forests. Results obtained by application of the Miyawaki method in about 550 locations in Japan, as well as in Malaysia, Southeast Asia, Brazil, Chile, and in some areas of China, were found to be successful, allowing quick environmental restorations of strongly degraded areas (Miyawaki 1989, Miyawaki 1999).

Until now, the Miyawaki method has been applied in countries characterized by cold-temperate and tropical climatic regimes, which do not experience summer aridity stress and potential risk of desertification (increased by global change). Thus, the Mediterranean context could be considered an interesting test to assure the effectiveness of such a method in other important biomes, even with high biodiversity hotspots. This paper represents the first test of reforestation practices in the Mediterranean Basin using the Miyawaki method. It also offers a comparison between traditional methods and the proposed one, because the test has been carried out on target sites where traditional reforestation approaches are widely used but have mostly failed.

Materials and methods

Experiment locations and descriptions

On May 1997, we planted two experimental plots at the Municipality of Pattada (North Sardinia) on sites 2 km from each other in a straight line (Fig. 2 shows approximate location of the fields using a Digital Elevation Model with ESRI ArcMap 9.1 GIS software). In this area, reforestation programs have been periodically conducted with traditional methods since 1905, mainly using *Pinus pinaster* Aiton (maritime pine), *Pinus halepensis* Miller (Aleppo pine), *Cedrus atlantica* (Endl.) Carrière (Atlas cedar), *Quercus suber* L. (cork oak), *Quercus pubescens* Willd. (downy oak), and *Castanea sativa* Miller (sweet chestnut). Techniques involved planting along countour lines after forming gradoni or terraces by subsoiling, or along the maximum slope with subsoiling and holes.

To test the Miyawaki method, an experimental plot (named site A) of 4,500 m^2 was established at Sos Vanzos close to an artificial lake at 760 m a.s.l. Plot preparation consisted of brush clearing and tillage in order to shape 13 strips 3.5 m wide (Fig. 3a shows the planting scheme with

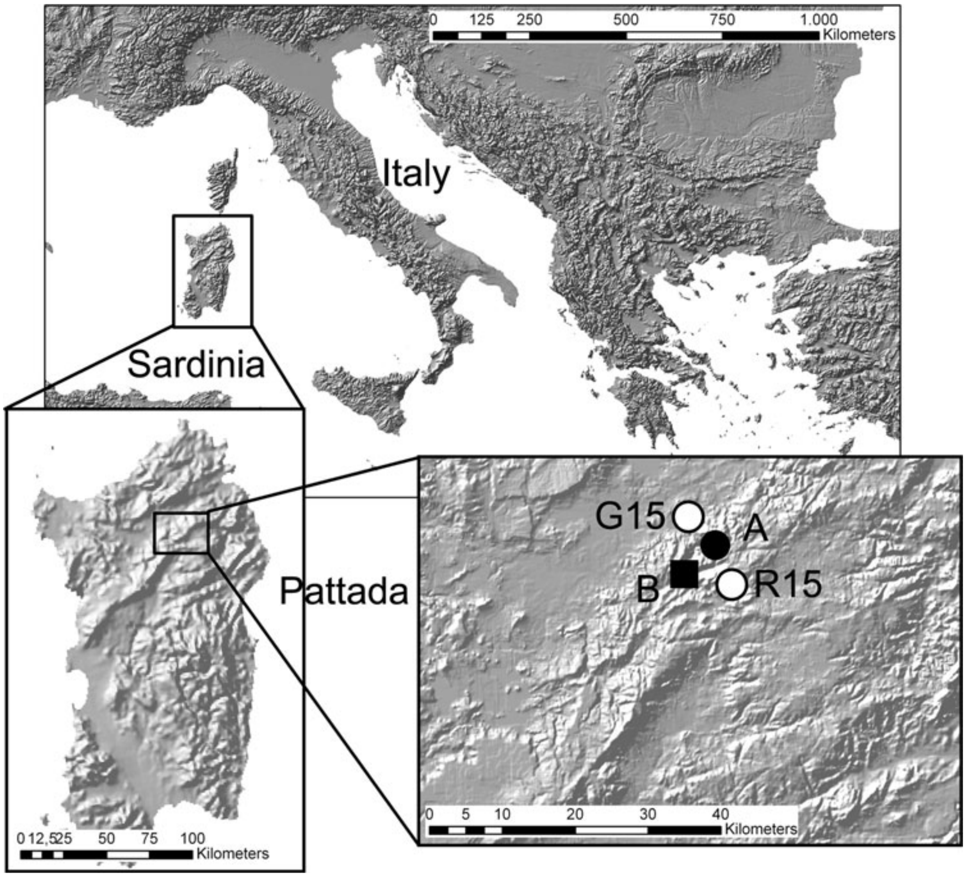

Fig. 2 Location of the study areas. *Black solid circle* and *square* indicate, respectively, site A and site B; *white solid circles* show reforested areas with traditional methods used as comparison

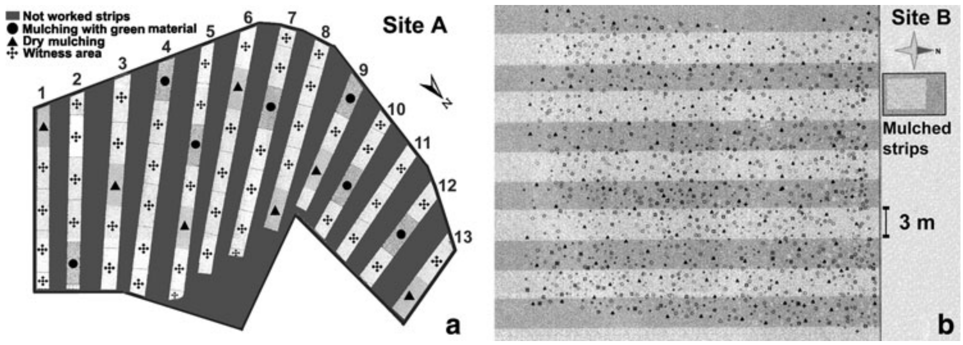

Fig. 3 Planting schemes of experimental fields. Different mulching operations in site A strips (**a**), mulched strips in site B with plant distribution (**b**)

Table 1 Site description (topographic, surrounding land cover and natural vegetation characteristics)

	Site A	Site B
Locality	Sos Vanzos	Uca de s'abba lughida
Coordinates	40°37′N; 9°11′E	40°36′N; 9°10′E
Altitude (m a.s.l.)	760	885
Surface (m^2)	4,500	1,000
Slope (degrees)	4	0
Aspect	NE	Flat
Geology	Granite	Granite
Soil	Lithic and Dystric Xerorthents	Lithic and Dystric Xerorthents
Land cover (%)		
Rocks	1	5
Bare layer	1	2
Litter layer	0	0
Herbaceous layer	60	93
Shrub layer	95	0
Arboreal layer	0	0
Mean height (cm)		
Herbaceous layer	10–25	30–40
Shrub layer	100–120	0
Arboreal layer	0	0

different mulching operations). Potted tree seedlings were planted at a density of approximately 8,600 plants/hectare. A second plot (site B) of 1,000 m^2 is near Uca de s'abba lughida at 885 m a.s.l. (Fig. 3b shows mulched strips and plant density used). The preparation was similar to site A but covered the entire plot. Here seedlings were planted at a density of approximately 21,000 plants/hectare ca.

A description of the natural environment was carried out before implantation in order to check the potential natural vegetation and to proceed with species selection. Table 1 shows the main site characteristics as results of the field survey, and Fig. 4 compares the Mediterranean climate pattern with others where the Miyawaki method was successful. The data refers to 21 years of records, and the Walter and Lieth 1960 diagrams were obtained using the *climatol* statistical package implemented in R 2.7.1 for Linux (Guijarro 2009). Phytosociological analysis was carried out and a check-list of spontaneous species, with percentage of presence, is reported in Table 2. From this investigation, it was assumed that a mixed forest with *Quercus ilex* L. (holm oak), *Quercus suber* L., *Quercus pubescens* Willd., and *Ilex aquifolium* L. (common holly) represented the natural potential vegetation for the area. On both plots, seeds were collected from nearby natural forest stands and germinated in four greenhouses owned by the Regional Forest Directorate of Sardinia. After two or three leaves had sprouted, seedlings were cultivated in plastic bags for 1 year. Table 3 shows the species used on site A and site B, selected according to the natural phytocoenoses. After planting, mulching with straw, green material (Navarro-Cerrillo et al. 2009) as *Trifolium subterraneum* L. (in site A), and sawdust (in sites A and B) were applied.

Several changes from the original Miyawaki method were introduced on sites A and B in order to better test its effectiveness to local environmental conditions. The first 20–30 cm of native soil was labored, and no new soil was

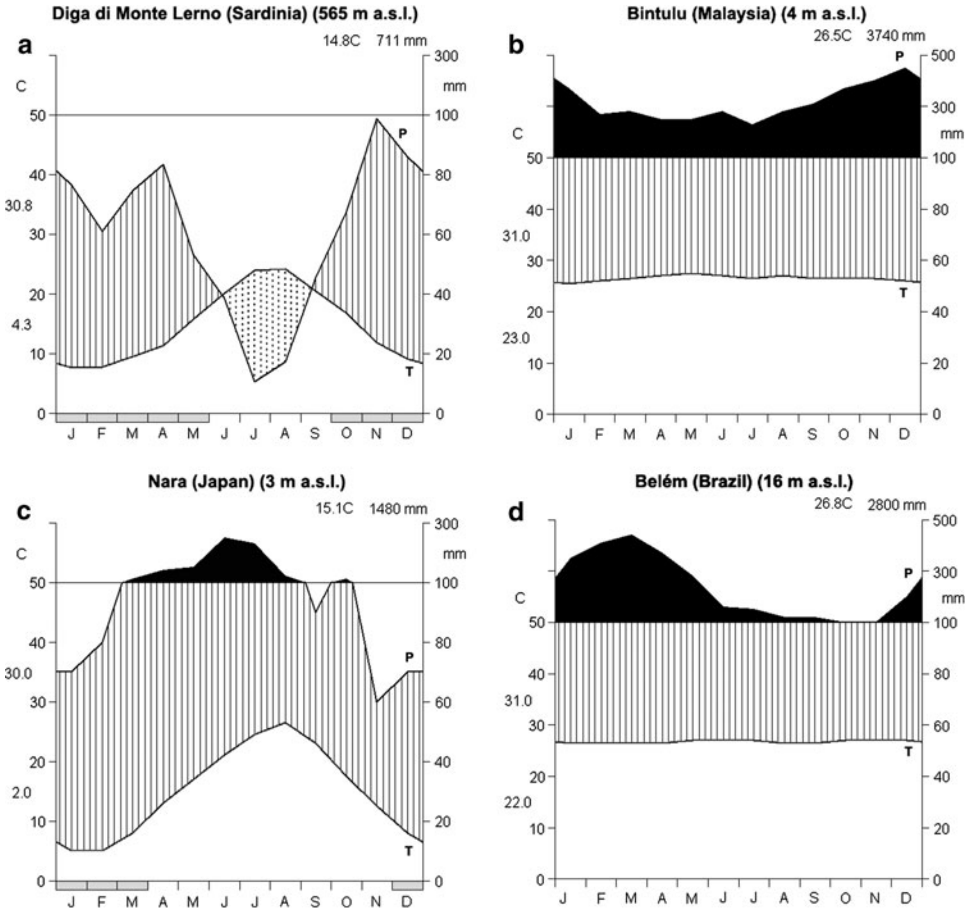

Fig. 4 Climate diagrams according to Walter and Lieth 1960. Diga di Monte Lerno in Sardinia (closed to Pattada) shows typical Mediterranean climate pattern (**a**); Bintulu (Malaysia), Nara (Japan), and Belém (Brazil) climate patterns, where the Miyawaki method has been successfully applied (**b**–**d**). *T* and *P* indicate temperature curve and precipitation time series. *Grey* rectangles on *x*-axis show probable frost months (when monthly values are ≤0°C)

added; some autochthonous early-successional species (e.g. *Pinus pinaster* L. and shrubs) were planted together with late-successional ones to improve plant community resilience (Castro et al. 2002, 2004; Gómez-Aparicio et al. 2004; Lortie et al. 2004); mulching was provided using different types of material, as mentioned above, instead of using only straw.

Data collection and analysis

To estimate the efficiency of this adapted Miyawaki method to Mediterranean environments, as well as the relationships in terms of interspecific competition, three surveys were performed in both experimental plots: in September 1998, April 1999 and, 10 years later, March 2009. GPS plant position, height (*h*) and DBH (diameter at breast height) >3 cm were collected for each individual. Moreover, mortality percentage trend and relative frequency (defined as number of individuals from each species by total number of plants) were computed. Comparisons were done with two nearby coeval sites where traditional reforestation techniques were applied to better understand the differences in plants growth, forest composition, and vegetation cover in percentage. The first one (conventionally named R15, 452 m^2) is a 15-year-old stand north of site A in a flat area, with *Pinus pinaster* L. and *Quercus ilex* L. planted in holes, with a spontaneous shrub layer of *Arbutus unedo* L., *Phyllirea latifolia* L., and *Erica arborea* L.; a conventional 12-m-radius sampling area was selected for recording height and diameter of all plants. The other plot (named G15, 400 m^2) with the same age of R15, approximately east of site B, belongs to a gradoni reforested site with *Pinus pinaster* L., *Quercus ilex* L., *Rosmarinus officinalis* L., and the natural presence of *Arbutus unedo* L., *Phyllirea latifolia* L. and *Erica arborea* L. In this case, due to the position of the site, i.e., along the mountainside with slope greater than 30%, a 4 × 100-m transect was set up following the contour line.

Results

Comparison between experimental plots

After planting on May 1997, plots were monitored and percent mortality was calculated for each species. On site A, 1,450 of 1,723 plants survived 1 year after planting; after 2 years, this number was reduced to 1,327, and after

Table 2 Major spontaneous species composition outside experimental fields according to Braun-Blanquet (1928)

Species	Site A			Site B		
	A	B	C	A	B	C
Allium roseum L.						+
Anagallis arvensis L.						+
Anthemis arvensis L.						+
Anthoxanthum odoratum L.						+
Aphanes bonifaciensis (Buser) Holub						+
Arbutus unedo L.		2	+			
Artemisia sp.		+				
Asphodelus microcarpus Salzm. et Viv.			1			+
Avena barbata L.						3
Briza maxima L.			2			2
Briza minor L.			1			
Bromus hordaceus L.						3
Bromus sp.						+
Cerastium sp.						+
Cistus incanus L.		+	+			
Cistus monspeliensis L.		2	+			
Cistus salvifolius L.		3	+			
Crepis sp.						+
Cynosurus cristatus L.			+			1
Cytisus villosus Pourret		+	+			
Daphne gnidium L.		1	+			
Delphinium halteratum S. et S.			+			
Echium vulgare L.						+
Erica arborea L.		3	+			
Erica scoparia L.		4	+			
Erodium botryus (Cav.) Bertol.						1
Genista corsica (Loisel.) DC.		3	+			
Geranium columbinum L.						+
Geranium molle L.						1
Halimium halmifolium (L.) Willk.		2	+			
Helianthemun sp.			+			
Hypericum perforatum L. subsp *veronense* (Schrank) Fröhlich			+			
Lathyrus angulatus L.			+			
Lavandula stoechas L.		1	+			
Linum bienne Miller			+			
Lotus subbiflorus Lag.			+			1
Lupinus micranthus Guss.			+			
Ornithopus compressus L.			+			
Pancratium illyricum L.						+
Phyllirea angustifolia L.		2	+			
Plantago lanceolata L.			+			+
Polygala vulgaris L.			+			
Ranunculus flabellatus Desf.			+			2
Rumex acetostella L.						+
Sanguisorba minor Scop.			3			
Sedum caeruleum L.						+
Sedum stellatum L.						+

Table 2 continued

Species	Site A			Site B		
	A	B	C	A	B	C
Senecio vulgaris L.						+
Serapias lingua L.						+
Sheradia arvensis L.						+
Silene gallica L.						+
Silene sp.						1
Stachys glutinosa L.			+			
Trifolium strictum L.						+
Trifolium subterraneum L.						1
Tuberaria guttata (L.) Fourr.			+			+
Vicia sp.			+			
Vicia tenuissima (Bieb) Sch. et Th.			+			
Viola corsica Nyman subsp *limbarae* Merxm. et Lippert			2			
Vulpia muralis (Kunth) Nees			+			4

A Arboreal, *B* shrub, *C* herbaceous layers. Abundance of each species is represented by six class coverage [<1% (+); 1–20% (1); 20–40% (2); 40–60% (3); 60–80% (4); 80–100% (5)]

12 years, 672 individuals were still alive (mortality rates equal to 15.84%, 22.98%, and 61%, respectively). Site B showed higher rates of mortality except from the first survey: in 1998, the number of plants that had survived was 1,920; the next year we counted 1,385, and in 2009 there were 336, with mortality percentages of 10.24%, 35.25%, and 84.29%, respectively. Note that in site A, 20 species survived but *Salvia officinalis* L., a shrub species of secondary importance, did not. On site B, a significant loss of subordinate species has occurred since 1999, and a consequent decrease of plant diversity (nine species of 23) was observed. The main forest species survived, i.e., maritime pine and the oak group, thus maintaining the possibility of achieving intermediate and terminal vegetation stages. Moreover, the presence of *Prunus spinosa* L. was observed as an autochthonous species. It has to be kept in mind that on the same site, other reforestation programs with traditional methods still failed, mainly due to a relevant water stagnation. Compared with site A, the success obtained on site B was less evident, as confirmed by Fig. 5, where histograms of mortality percentages are reported.

Further comparisons regard the role played by each species in the plant community as a result of interspecific competition and natural evolution of vegetation (Padilla and Pugnaire 2006). By monitoring the number and height of individuals per species, it was possible to analyze their position in terms of relevance within the experimental plots. A K index defined as $h \times v$ shows a quali-quantitative picture of vegetation dynamism, pointing out which species constitute both the upper layer and the understory. Comparisons were possible between sites A and B, as illustrated in Fig. 6 and Table 4. Diameter was not considered as a parameter for comparison because most species, except for maritime pine, showed mean DBH values <3 cm.

On both plots, the role of *Pinus pinaster* L. is undoubtedly the dominant representative of the early-successional species. Mean height was 433.24 cm on site A, around 2.5 times greater than cork oak (the second species in order of significance), whereas a mean of 325.5 cm was registered on site B where it towers above the remaining species. Also, the K index values for *Pinus pinaster* are much higher than the other species, emphasizing the importance of this species on both plots. In fact, K refers to an overstory layer distinguished only by this species, as abundant and relevant in terms of number of individuals and growth performance. Because of its ability to establish in such ecological contexts, maritime pine is also found in other traditional reforestation programs all over Sardinia. Some differences in biodiversity richness of the experimental plots were recorded within the forest understory: on site A, the oak group is present with holm, pubescent, and cork oak, along with their secondary early successional species, such as *Spartium junceum* L., *Arbutus unedo* L., and *Rosmarinus officinalis* L., whreas on site B, intermediate species are represented only by cork oak and holm oak in a simpler plant community.

Comparison of the Miyawaki method with traditional reforestation techniques

Estimating the effectiveness of the Miyawaki method needs a comparison with other reforestation practices traditionally applied on the same ecological context, mainly focused on growth performance of selected species. Table 5 describes the species composition of two selected plots with traditional reforestation techniques as result of test areas performed, in comparison with the Miyawaki ones. It is important to note that the majority of reforested sites in the area have been planned using traditional techniques; thus, the plots we have selected for comparison should be considered as a significant sample of a wider scenario.

Table 3 List of selected species planted in Miyawaki experimental fields (total number of individuals per plot and relative percentage)

Species	Acronym	Site A		Site B	
		n	%	*n*	%
Acer monspessulanum L.	AM	21	1.22	30	1.40
Arbutus unedo L.	AU	50	2.90	11	0.51
Castanea sativa Mill.	CS	42	2.44	–	–
Celtis australis L.	CA	22	1.28	37	1.73
Fraxinus ornus L.	FO	8	0.46	9	0.42
Ilex aquifolium L.	IA	112	6.50	125	5.84
Juniperus oxicedrus L.	JO	–	–	45	2.10
Laurus nobilis L.	LN	22	1.28	19	0.89
Ligustrum vulgare L.	LV	126	7.31	13	0.61
Malus domestica Borkh.	MD	21	1.22	19	0.89
Myrtus communis L.	MC	19	1.10	95	4.44
Phyllirea angustifolia L.	PA	1	0.06	–	–
Phyllirea latifolia L.	PL	–	–	203	9.49
Pinus pinaster L.	PP	273	15.84	155	7.25
Pyrus communis L.	PC	19	1.10	22	1.03
Quercus ilex L.	QI	300	17.41	394	18.42
Quercus pubescens Willd.	QP	268	15.55	93	4.35
Quercus suber L.	QS	11	0.64	621	29.03
Rosmarinus officinalis L.	RO	23	1.33	23	1.08
Salvia officinalis L.	SO	5	0.29	4	0.19
Sorbus torminalis (L.) Crantz	ST	18	1.04	24	1.12
Spartium junceum L.	SJ	53	3.08	21	0.98
Taxus baccata L.	TB	251	14.57	126	5.89
Thymus vulgaris L.	TV	–	–	24	1.12
Viburnum tinus L.	VT	58	3.37	26	1.22
Total		1723	100.00	2139	100.00

Both R15 and G15 show an abundant presence of spontaneous shrub species, including *Arbutus unedo*, *Erica arborea*, and *Phyllirea latifolia*, whereas maritime pine forms the overstory layer with a density of 242 plants/ha in R15 and 175 plants/ha in G15 instead of 1,040 and 800 plants/ha recorded on sites A and B. The vegetation structure is simple in both cases, and associated planted species are represented only by holm oak (354 and 200 plants/ha, respectively) and other secondary species, such as *Rosmarinus officinalis* and *Cedrus atlantica* (a nonautochthonous species used on G15). Except for *Pinus pinaster*, the growth performance of secondary species, measured by plant density and mean height (including holm oak), is severely influenced by the massive presence of spontaneous shrub species that apply a strong competition. Shared investigated species reveal different vegetative condition and growth performance depending on local constraints. Mean and theoretical annual increase of height (Fig. 7) indicate a good affirmation of maritime pine on site A, site B, and G15, whereas on R15, it suffers competition by *Arbutus unedo*, partially balanced by difference in density species (44 plants/ha of *Arbutus unedo* against 242 plants/ha of *Pinus pinaster*). Although mean height of species common to all study areas does not differ significantly, plant density on site A is around four times higher than on R15 and five times on G15, whereas on site B, maritime pine densities are 3 and 4.5 times higher than on traditional reforested plots were observed.

Discussion and conclusions

A large debate concerning naturalistic silviculture, naturalization of degraded forests, and landscape restoration

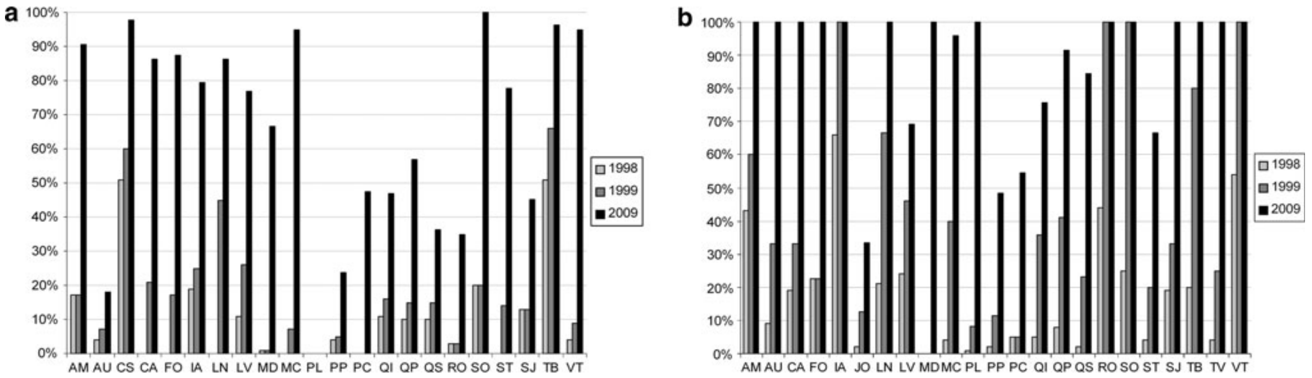

Fig. 5 Mortality rates in experimental fields. Percentage measured during three surveys for each species on site A (**a**); result on site B (**b**). *X*-axis labels refer to the acronyms in Table 3

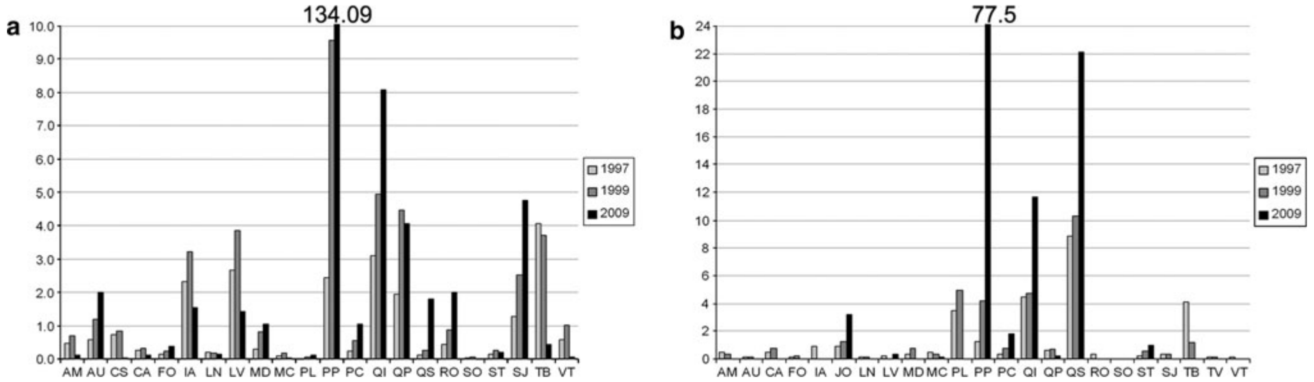

Fig. 6 *K* index recorded during field surveys in site A (histogram **a**) and site B (histogram **b**) as key index of interspecific competition and species relevance within coenosis. Values for maritime pine are shown up to the *black bar* to better represent the other values using an appropriate *y*-axis scale. *X*-axis labels refer to the acronyms in Table 3

Table 4 Total number of individuals per plot (*n*), mean height (*h*) and standard deviation (SD) in cm, relative frequency in percentage (*v* %), and *K* index of each species within both experimental fields 12 years after planting

Species	Site A				Site B			
	n	*h* ± (SD)	*v* (%)	*K*	*n*	*h* ± (SD)	*v* (%)	*K*
Acer monspessulanum L.	2	40.00 ± (14.14)	0.30	0.12	0	0	0	0
Arbutus unedo L.	41	32.68 ± (4.15)	6.10	1.99	0	0	0	0
Castanea sativa Mill.	1	10	0.15	0.015	–	–	–	–
Celtis australis L.	3	26.67 ± (28.86)	0.45	0.12	0	0	0	0
Fraxinus ornus L.	1	250	0.15	0.375	0	0	0	0
Ilex aquifolium L.	23	45.22 ± (30.57)	3.42	1.54	0	0	0	0
Juniperus oxicedrus L.	–	–	–	–	30	36.15 ± (18.5)	8.93	3.23
Laurus nobilis L.	3	30.00 ± (17.32)	0.45	0.135	0	0	0	0
Ligustrum vulgare L.	29	32.76 ± (52.64)	4.32	1.41	4	30 ± (8.16)	1.19	0.36
Malus domestica Borkh.	7	100 ± (45.46)	1.04	1.04	0	0	0	0
Myrtus communis L.	1	10	0.15	0.015	4	10 ± (1.41)	1.19	0.12
Phyllirea angustifolia L.	1	70	0.15	0.10	–	–	–	–
Phyllirea latifolia L.	–	–	–	–	0	0	0	0
Pinus pinaster L.	208	433.24 ± (143.6)	30.95	134.09	80	325.5 ± (38.59)	23.81	77.5
Pyrus communis L.	10	71 ± (65.06)	1.49	1.06	10	60 ± (61.23)	2.98	1.79
Quercus ilex L.	159	34.15 ± (32.11)	23.66	8.08	96	40.83 ± (36.22)	28.57	11.66
Quercus pubescens Willd.	116	23.62 ± (27.55)	17.26	4.08	8	10 ± (5.34)	2.38	0.24
Quercus suber L.	7	174.29 ± (49.61)	1.04	1.81	96	77.5 ± (51.94)	28.57	22.14
Rosmarinus officinalis L.	15	89.33 ± (33.9)	2.23	1.99	0	0	0	0
Salvia officinalis L.	0	0	0	0	0	0	0	0
Sorbus torminalis (L.) Crantz	4	35 ± (50)	0.60	0.21	8	40 ± (12.9)	2.38	0.95
Spartium junceum L.	29	110.69 ± (62.16)	4.32	4.78	0	0	0	0
Taxus baccata L.	9	33.33 ± (38.08)	1.34	0.45	0	0	0	0
Thymus vulgaris L.	–	–	–	–	0	0	0	0
Viburnum tinus L.	3	10 ± 0	0.45	0.045	0	0	0	0

Dashes indicate species not planted, and *zero values* refer to planted species that did not survive in 2009

has recently arisen (de Dios et al. 2007; Falk et al. 2006; Jordan et al. 1987; Perrow and Davy 2002a; Romano 1986; Van Andel and Aronson 2006; Walker and del Moral 2003), that provides interesting theoretical principles that can be tested through practical actions (Clewell and Aronson 2007; Padilla and Pugnaire 2006; Perrow and

Table 5 Description of species on the traditional reforestation plots and comparison with the Miyawaki ones

Name of species	Number/plot				Relative frequency [ν (%)]				Height ± standard deviation (SD)				Number of individuals/ha			
	R15	G15	A	B	R15	G15	A	B	R15	G15	A	B	R15	G15	A	B
Arbutus unedo L.	**2**	**80**	41	0	2.38	30.3	6.1	0	500 ± (35.75)$^{G15; A}$	110 ± (20.6)$^{R15; A}$	32.68 ± (4.15)$^{G15; R15}$	0	44	2000	205	0
Cedrus atlantica Endl.	–	6	–	–	–	2.27	–	–	–	162 ± (54.64)	–	–	–	150	–	–
Erica arborea L.	**45**	**65**	–	–	53.56	24.62	–	–	115 ± (12.78)^{G15}	130 ± (18.6)^{R15}	–	–	995	1625	–	–
Pinus pinaster L.	11	7	208	80	13.08	2.65	30.95	23.81	376.36 ± (72.97)^{B}	425.71 ± (25.07)^{B}	433.24 ± (143.6)^{B}	325.5 ± (38.59)$^{R15; G15;A}$	242	175	1040	800
Phyllirea latifolia L.	**10**	**95**	–	0	11.9	35.98	–	0	100 ± (15.5)^{G15}	140 ± (20.34)^{R15}	–	0	221	2375	–	0
Quercus ilex L.	11	7	159	96	19.08	3.03	23.66	28.57	69.37 ± (23.26)$^{G15;A;B}$	146.25 ± (38.15)$^{R15;A;B}$	34.15 ± (32.11)$^{R15;G15}$	40.83 ± (36.22)$^{R15;G15}$	242	175	795	960
Rosmarinus officinalis L.	–	3	15	0	–	1.14	2.23	0	–	80 ± (14.92)	89.33 ± (33.9)	0	–	75	75	0

Bolded numerals in Number/plot column (number of plants/plot) show the values of unplanted species, superscript symbols in each row indicate significant pairwise tests at 0.05 alpha probability level

Davy 2002b; Vallauri and Chauvin 1997). In the Mediterranean Basin, the environment has been modified and exploited by humans over the course of thousands of years. In particular, forests have experienced many processes that have led to degradation and consequent soil loss as reported since the fourth century B.C. by Plato in Critias. Also, because of these age-old anthropogenic impacts, in the last two centuries, all reforestation methods adopted in Mediterranean countries demonstrated that a long time is need to get a complete environmental restoration.

The Miyawaki method could offer a quicker and more effective reforestation approach in the Mediterranean environment, adopting naturalistic theoretical principles not previously tested in Mediterranean Europe, which has the additional challenge of a seasonal climate characterized by summer aridity compounded in several cases by winter cold, and also by thin soils. Here we provide a comparison between the Miyawaki method and two other reforestation methods (gradoni and holes) traditionally applied in Mediterranean countries. The results showed a more rapid development of trees on the Miyawaki plots, in particular, early-successional species. The benefits over previous methods are remarkable and comparable with those obtained by Miyawaki in Asia and South America. At the same time, some of the changes made in this study to better fit the method to the Mediterranean environment seem to be particularly useful. First, we used tillage to improve soil water storage over the winter and reduce water stress during the summer. Summer aridity implies the soil would be able to stock winter rainfalls in order to allow the plants avoiding water stress of the next season. This outcome has been achieved using tillage; such action is necessary and should be enough, even if it would be possible to get a better performance by adding compost or local soil. Mulching with green material does not seem effective (Navarro-Cerrillo et al. 2009), whereas mulching with dry material has been useful. Moreover, avoiding clearing all brush is opportune for the Mediterranean environment, in contrast with some studies (cf. Bernetti 1995; Goor and Barney 1968; Metro et al. 1978; Molina et al. 1989; Weber 1977), as well as adopting the plantation in worked strips. Nowadays, benefits of this method are acknowledged by several authors (cf. Schirone et al. 2004).

In the Mediterranean scenario, adding some early successional species to the intermediate- and late-successional ones was very useful. This solution was already tested by Miyawaki and Abe in Brazil (2004), even if no benefits were recorded. Considering the results of our work, early-successional species might have been used in an excessive number, thus applying negative competition on the intermediate- and late-successional stages. Therefore, the number of plants should be reduced in future works, and the optimal plant density will have to be tested. In any case,

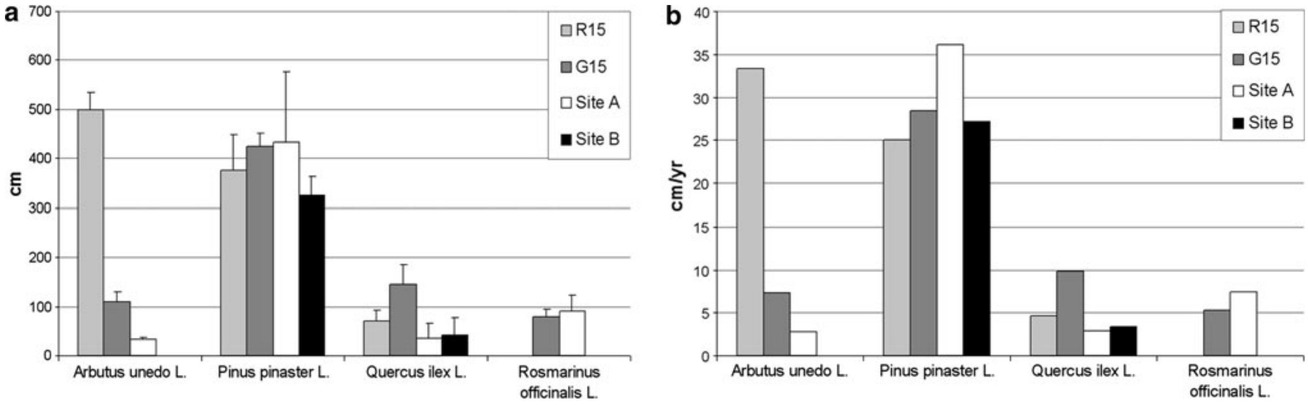

Fig. 7 Mean (**a**) and theoretical annual increase (**b**) of height for the common species on Miyawaki and traditional plantings

results support the effectiveness of alternative applicable approaches in the Mediterranean area. In fact, low plant density has been traditionally retained as appropriate in arid and semiarid environments in order to avoid competition for water resources between plants (Caramalli 1973; Bernetti 1995), but it is now evident that cooperative processes, e.g., mutual shading, prevail over competitive processes (Callaway 1997). High plant density also reduces the impact of acorn predators, thus encouraging oak regeneration, i.e., the main late-successional forest species in Mediterranean environments (Gómez et al. 2003). In addition, excellent plant stock remains fundamental for planting success in harsh environments (Palacios et al. 2009).

Finally, these results could offer a chance to introduce a new method into the Mediterranean context that is able to reduce the time for a complete environmental restoration. An economic analysis might be performed to estimate the costs of postplanting silvicultural practices with traditional reforestation methods and compare them with the Miyawaki method. Indeed, labor need is high, and planting costs are quite expensive because of the high plant density required. On the other hand, no human care, such as weeding or thinning, is needed after planting, and undergrowth with late-successional species are immediately on site (Miyawaki 1998a, Miyawaki 1999). If this new approach turns out to be more expensive, then it will be important to take measures to make it economically advantageous. In any case, if the high costs of the Miyawaki method were still not competitive with the traditional techniques on a large scale, the forest quality achieved would make it a noteworthy tool for protected areas and natural parks (Reque 2008), where traditional plantings are not easily accepted because of their aesthetic and ecological impacts.

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