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The southernmost beech (Fagus sylvatica) forests of Europe (Mount Etna, Italy): ecology, structural stand-type diversity and management implications

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The southernmost beech (*Fagus sylvatica*) forests of Europe (Mount Etna, Italy): ecology, structural stand-type diversity and management implications

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Abstract
The southernmost European beech forests are located in the upper forest vegetation belt on Mount Etna volcano. Their stand-structural patterns were analysed to assess the effects of the site-ecological factors and previous management practices on the forest structure. Five main structural-silvicultural types were identified among the main beech forest types: coppice, high-mountain coppice (HMCo), high forest, coppice in conversion to high-forest and non-formal stand. A detailed stand-structural analysis was carried out through measured dendrometric parameters and derived structural characters linked to both the horizontal and the vertical profiles. Plant regeneration processes were also assessed, and several biodiversity indicators were calculated. The collected data indicate a high variability of beech stand structures in relation to the heterogeneity of the site-ecological characteristics as well as to the effects of both natural and anthropic disturbance factors. The occurrence of particular stand structures along the altitude gradient on Mount Etna is evident. It is especially visible in the multi-stemmed HMCos in relation to the changing, and increasingly limiting, ecological factors, although at higher altitudes historical anthropic actions (felling) also have had an influence. Inside the Mediterranean area, these stands highlight their ecological marginality, in terms of both latitude and altitude, especially regarding current climate change processes.

Keywords: *Southern European beech forests, structural diversity, forest type, silviculture type, marginal forest, Mediterranean range edge*

Introduction

The European beech (*Fagus sylvatica*) is one of the most important tree species of Europe, considering its distribution area and forest cover (Bohn et al. 2000), the variability in forest coenosis (Peters 1997; Rodwell et al. 2002), the forest types (Larsson 2001; Barbati et al. 2006), and the diversity in forest stand structures and management practices (Peters 1997; Larsson 2001; Del Favero 2008; Nocentini 2009; Wagner et al. 2010; Ziaco et al. 2012).

Forest management, and namely silviculture, can significantly influence the structural and compositional features of a forest stand. Traditional forest management has had an important impact on the current European beech stands resulting in the creation and maintenance of a wide spectrum of structural forms (Bengtsson et al. 2000), especially in Mediterranean areas (Ciancio et al. 2006, 2008; Coppini & Hermanin 2007; Nocentini 2009; Lombardi et al. 2012).

Many authors have carried out researches on beech stands, both in the northern and southern hemisphere (including other *Fagus* and *Nothofagus* species, respectively), in marginal ecological conditions and locations as well as in relation to the latitude and the altitude (e.g. Williams-Linera et al. 2000; Gea-Izquierdo et al. 2004; Shimano 2006; Guo & Werger 2010; Martínez-Pastur et al. 2012). Similarly different studies have been conducted on European beech stands, especially at their southern mountain-Mediterranean edge (Poli & Puzzolo 1999; Christensen et al. 2005; Peñuelas et al. 2007; Tsiripidis et al. 2007; Mercurio & Spampinato 2008; Manes et al. 2010; Papalexandris & Milios 2010). In these marginal locations, a typical middle-European species, such as the *F. sylvatica*, is particularly subject to the influence of current climate change processes, i.e. in terms of potential change-induced biome shift at their range edges (e.g. Peñuelas & Boada 2003; Pignatti 2011). Kramer et al. (2010)

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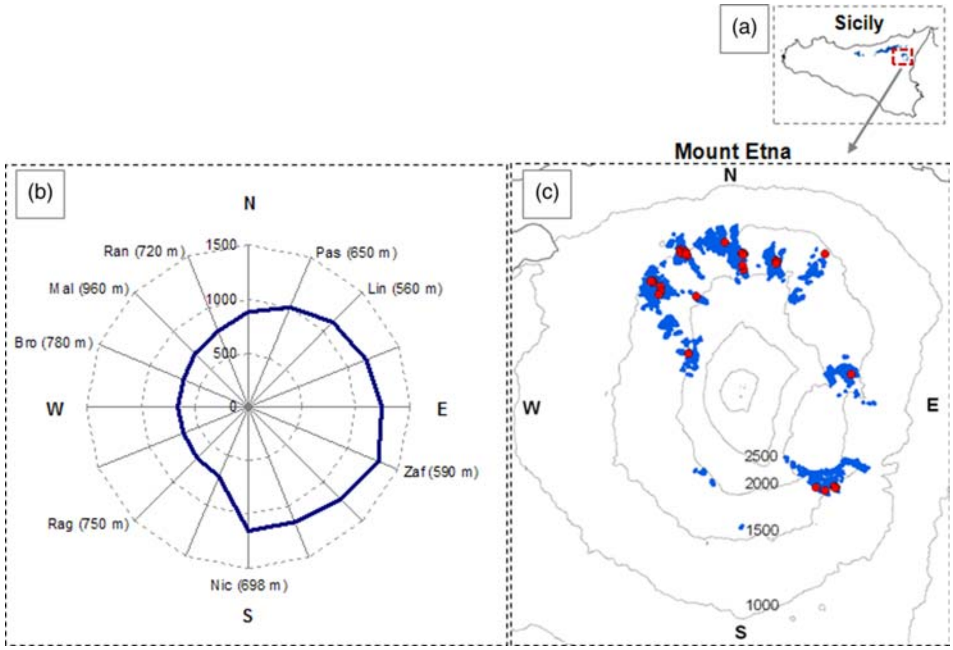

Figure 1. Distribution of *F. sylvatica* in Sicily (a) and spatial relation between: (b) mean annual precipitation (bold line) around Mount Etna (within the altitude belt of 500–1000 m asl.) and (c) beech forest cover within the mountain vegetation belt (contours from 1000 to 3000 m asl. are shown each 500 m); sample plots are displayed by location points (c). (The legend of the pluviometric stations reported in (b): Ran, Randazzo; Pas, Passopisciaro; Lin, Linguaglossa; Zaf, Zafferana; Nic, Nicolosi; Rag, Ragalna; Bro, Bronte; Mal, Maletto; the altitude of each pluviometric station is reported mentioned within parentheses).

outlined future projections of the European beech geographic distribution, showing a northward shift of the southern limit and a northward extension of the northern one.

Stand-structural patterns and the related management practices in European beech forests are very important aspects for the conservation of these forest covers in critical ecological conditions. In this study, the ecological, structural and silvicultural characterization of the southernmost European beech forests, located on Mount Etna (Sicily) (Figure 1(a)–(c)), was carried out with the aim of describing forest stand types and their significant ecological-management implications.

Materials and methods

The study area: an environmental-ecological frame

The Mount Etna beech forests are of particular phytogeographic and ecological interest because they are located at the southernmost limit of the entire European distribution area of the species (Pignatti 1998; Pott 2000).

Usually, beech plants grow in the most well-developed edaphic conditions, such as on Andic Brown Soils. However, on Mount Etna these soils are subject to frequent renewal due to the pyroclastic activity of the volcano.

Within the study area, average annual precipitation usually exceeds 1400 mm, with typical Mediterranean summer drought. However, the precipitations pattern changes irregularly according to the altitude and the volcano slope (Figure 1(b)).

On Mount Etna, the Mountain-Mediterranean vegetation belt is characterized by broadleaf deciduous forests of *F. sylvatica* and *Betula aetnensis* and by pine forests of *Pinus laricio.*

Presently, beech forests on Mount Etna cover an area of 1189 ha with scattered distribution due to destructive action of lava flows and to historical effects of human activities (Figure 1(c)).

The lowest altitude limit for beech is reported at 800 m asl. on the *Valle S. Giacomo* on the eastern Volcano slope; while, on the north-western volcano slope, isolated beech trees and small stands are recorded up to 2200 m asl. (Figure 1(c)) (Poli Marchese & Patti 2000).

The beech forest coenosis of Mount Etna has been often considered as impoverished aspects of *Aquifolio-Fagetum*. More recently, Brullo et al. (1999) highlighted the floristic autonomy of Mount Etna beech stands and they included those of the upper montane vegetation belt (1600–2000 m asl.) in the *Epipactido meridionalis-Fagetum* and those of the lower altitude located inside small narrow valleys in the *Rubo aetnici-Fagetum*

The Mount Etna beech stand structure is variable in relation to the dynamic stages and to past silvicultural practices and uses. Under the best ecological conditions, the beech tends to form pure, closed even-aged stands whereas in transitional ecological conditions, the beech tends to be substituted in the less mesophilous sites by Etna birch (*B. aetnensis*) and in the more xeric sites by the Calabrian laricio pine (*P. laricio*). Along the upper altitude edge, close to the timberline, the beech forms small pure isolated stands. On the basis of the general forest typology system identified in Sicily (Cullotta & Marchetti 2007), and according to climate, altitude, vegetation and main structural assessment, the Etna beech forests have been set in the stand types as reported in Table I.

Plot location and survey

A total of 30 circular sample plots with a 30 m diameter were established on all the volcano slopes (Figure 1(c)). The plots are regrouped in three plots using an L-shaped cluster method (Stahl et al. 2000, modified). The location of the plots was chosen in order to include all of the most important traditional structural-management beech types (i.e. silvicultural types), namely: high forest (HF), coppice (Co), high-mountain coppice (HMCo), coppice in conversion (CoC) to high forest and non-formal/not currently managed stand (nFS).

The diameter at breast height (Dbh) > 3 cm and the tree height (*H*) were measured for all living trees present in each plot. In Table II, all the measured variables are reported in the following category: stand structure (measured and calculated); site characteristics; litter and herb-layer characteristics. The presence and location of plant regeneration (gamic and agamic) were also registered (Table II).

The following structural characteristics have been then calculated: the stem density and stump density; mean tree Dbh and mean tree height; the basal area (G); the frequency distribution of trees in relation to Dbh (2.5-cm class) and tree height (5-m class). The volume of trees (dendrometric) was calculated according to the mathematical models proposed by the INFI 1985.

Data analysis

The spatial arrangement of trees in both their horizontal pattern and vertical profile was analysed. In particular, the *R* aggregation index (Clark & Evans 1954) has been calculated for each sample plot in order to describe the degrees of uniformity and the aggregation of trees in the horizontal level.

The Shannon index has been calculated using the function proposed by Pretzsch (1996) in order to include the concept of vertical distributions of plant crowns in different levels (three layers).

The analysis of variance (ANOVA) was carried out to determine whether there were significant differences in Dbh, tree height, top height, crown diameter, tree and stump density and the number of

Table I. Principal ecological factors and aspects affecting the main beech forest types of Mount Etna: (Fs1) macro/meso-therm beech stand of N and NW sides; (Fs2) oceanic macro-therm beech stand of E-sea side; (Fs3) high(alto)-mountain micro-therm beech stand.

			Main ecological factor				
Forest type	Altitude	Side	Thermic	Rainfall	Humidity (fog, cloud-cover)	Plant biodiversity (No. species)	Species composition (syntaxonomy)
Fs1	1400–1900	N, N–W	Macro–meso	1000–1500	Low–medium	Lower	• *E. meridionalis-Fagetum* *Aquifolio-Fagetum*
Fs2	800–1700	E	Macro	1400–2000	High	Higher	• *R. aetnici-Fagetum* *Aquifolio-Fagetum*
Fs3	1900–2280	N, N–W, W	Micro	1200–1500	Low–medium	Very low (monospecific)	• *E. meridionalis-Fagetum* *Rumici-Astragalion siculi*

Table II. Variables considered in this study (in bold: variables selected for the ANOVA and the PCA).

Code	Description	Unit
Stand structure		
Dbh	**Dbh ≥ 3 cm**	cm
H	**Height (of trees, shoots)**	m
Polar coordinate	Distance from the plot centre and angle from the North of each plant	m, degree (°)
Top tree height	**Mean of the height of the 20% largest trees in the plot**	m
Height crown insertion	Height of crown insertion	m
Crown radius	**Mean of the four cardinal directions**	m
Canopy cover		%
Stem density	**Number of trees and shoots per ha**	N/ha
Stump density	**Number of stumps per ha**	N/ha
Co shoots	**Number of shoots per stump**	N/stump
G	Basal area of trees and shoots	m^2
V	**Volume of tree and shoot (cormometric)**	m^3
Standing dead wood	Snag volume for Dbh > 3 cm	m^3/ha
Fallen dead wood	trunk with diameter > 6 cm and length > 1 m, volume calculated using the formula for a cylinder	m^3/ha
Gamic regeneration	**Saplings (*D* ≤ 3 cm at above ground level and *H* ≤ 1 m)**	N/ha
Agamic regeneration	**Shoots (*D* ≤ 3 cm at above ground level and *H* ≤ 1 m)**	N/ha
R	***R* aggregation index**	
A	**Shannon–Weiner index**	
Site characteristics		
Altitude	a.s.l.	m
Slope steepness		%
Rockiness		%
Litter and herb-layer characteristics		
Litter cover		%
Litter thickness		cm
Herb cover		%

Co shoots per stump among the main structural-silvicultural types. In addition, the maximum and minimum values (the largest- and smallest-sized tree in each study site) were compared. The ANOVA was also computed for the regeneration and for the applied spatial distribution indexes. The software used was SYSTAT 11. In all cases, all the replicates (sample plots) belong to the five structural-silvicultural types considered (see Table III). The Scheffe test was applied for the post hoc comparisons when ANOVA was significant ($p < 0.05$).

For the joint comparison of all results, a principal component analysis (PCA) was carried out using XLSTAT-Pro 7.5, considering 12 variables. Their correlation was also analysed using the Pearson coefficient.

Results

Main structural data

All the collected stand parameters are reported in Table III. After analysing the distribution of plant frequency in the different Dbh classes (Figure 2), the vertical and horizontal tree arrangement, the regeneration origin (gamic or agamic) and the stump presence, all plots were grouped into five main structural-silvicultural types: HF, Co, HMCo, CoC and nFS.

The size structure diagrams showed that HF and nFS are the stand structures with the widest plant distribution frequency in both Dbh and H classes (Figure 2(a),(e)). In HF, the largest trees have Dbh between 30 and 50 cm with some more than 60 cm (e.g. in plots: ANN1, ANN2, ANN3 and MAN4), dominant trees reach 20–30 m high (see Figure 2(a)). Similar observations have been made in regards to the structure of nFS (e.g. in ROC1, ROC3, PIT) (Figure 2(e)). In both HF and nFS, the high presence of small trees (smaller dimensional classes) can be explained via the regeneration process. Although both HF and nFS show a reverse J-shaped diameter distribution (uneven-aged stands), the presence of scattered stumps is the characteristic of nFSs (see Table III). A closer bell-shaped distribution curve can be observed in the other types studied (Figure 2(b)–(d)). The structure diagrams of HMCo differed significantly in terms of plant density and also in regards to their lower values of Dbh and H (Figure 2(c)).

Structural-silvicultural types and traditional management aspects

Coppice (Co). On Mount Etna, almost all beech forests have been subjected to simple Co treatments or selection Co. The frequency of past beech Co clear-cutting was approximately every 20 years,

Table III. Characteristics of study sites [mean (± S.E.) values] grouped according to the identified structural-silvicultural types.

		Structural-silvicultural types				
		HFs	Cos	HMCos	CoCs	nFS
Plot (code)		ANN1, ANN2, ANN3, MAN4, MAN5, MAN6	CUB, ORS, SPA1, SPA2, SPA3, TRI1	GEL1, GEL2, SCA	MAR1, MAR2, MAR3, MAN1, MAN2, MAN3, TIM1, TIM2, TIM3	MAR4, TRI2, ROC1, ROC2, ROC3, PIT
Stand structure	Stem density (N/ha)	694 ± 86.9	4249 ± 873.9	8521 ± 568	4210 ± 701.5	1267 ± 260.3
	Stump density (N/ha)	2 ± 2.3	1066 ± 210.3	1104 ± 170.9	901 ± 113.2	241 ± 68.5
	Co shoots (N/stump)	0.5 ± 0.50	4.4 ± 0.65	7.9 ± 0.77	3.4 ± 0.54	3.3 ± 0.34
	Dbh (cm)	26.2 ± 1.13	11.7 ± 0.16	6.3 ± 0.09	10.7 ± 0.11	19.3 ± 0.5
	Tree height (m)	18.3 ± 0.54	13.3 ± 0.11	6.3 ± 0.07	10.6 ± 0.07	16.3 ± 0.35
	Top tree height (m)	24.1 ± 0.4	19.5 ± 1.8	10.0 ± 1.29	15.7 ± 0.74	22.7 ± 1.65
	Crown radius (m)	3.2 ± 0.16	2.7 ± 0.03	2.0 ± 0.04	2.5 ± 0.04	3.1 ± 0.10
	Canopy cover (%)	96.5 ± 0.67	91.3 ± 1.73	86.1 ± 1.15	90.3 ± 1.37	93.5 ± 1.52
	Basal area (m^2/ha)	34.7 ± 3.41	37.8 ± 3.72	26.9 ± 4.28	32.2 ± 3.02	33.2 ± 4.43
	Volume (m^3/ha)	353.3 ± 36.61	302.5 ± 27.55	120.3 ± 21.39	218.5 ± 16.64	321.9 ± 47.17
	Standing dead wood (N/ha)	5 ± 3.2	1522 ± 304	745 ± 95	57 ± 9.3	45 ± 29
	Standing dead wood (m^3/ha)	0.15 ± 0.07	8.5 ± 1.95	2.5 ± 0.38	0.9 ± 0.21	26.6 ± 13.79
	Fallen dead wood (m^3/ha)	n.a.	0.5 ± 0.12	0.1 ± 0.02	0.05 ± 0.01	3.1 ± 1.38
	Gamic regeneration (saplings) (N/ha)	299.5 ± 110.41	4.7 ± 4.66	9.3 ± 4.66	40.9 ± 27.94	115.5 ± 77.59
	Agamic regeneration (shoots) (N/ha)	0	273.5 ± 171.82	4506.0 ± 1000.88	562.9 ± 337.99	233.7 ± 147.46
	R aggregation index (*R*)	0.99 ± 0.06	1.12 ± 0.04	0.67 ± 0.12	1.07 ± 0.04	0.61 ± 0.05
	Shannon-Wiener index (*A*)	0.80 ± 0.09	0.92 ± 0.06	0.76 ± 0.02	0.86 ± 0.05	1.09 ± 0.07
Site characteristics	Altitude (m)	1507 ± 11.7*	1593 ± 171.2*	1908 ± 75.3*	1714 ± 89.4*	1463 ± 86.2*
	Slope steepness (%)	13.2 ± 7.7*	12.7 ± 4.9*	28.0 ± 10.6*	25.8 ± 15.1*	31.8 ± 24.4*
	Rockiness (%)	5.7 ± 4.9*	10.0 ± 9.0*	8.3 ± 4.2*	9.7 ± 7.4*	10.8 ± 12.4*
Litter and herb-layer characteristics	Litter cover (%)	97.5 ± 4.2*	86.5 ± 7.3*	87.5 ± 4.6*	86.3 ± 14.6*	58.6 ± 25.5*
	Litter thickness (cm)	6.3 ± 2.2*	7.0 ± 4.1*	3.3 ± 0.6 *	5.9 ± 3.3*	7.7 ± 4.4*
	Herb cover (%)	30.0 ± 6.3*	2.8 ± 0.9*	23.3 ± 15.3*	5.7 ± 5.9*	± 9.2*

*Indicates ± SD

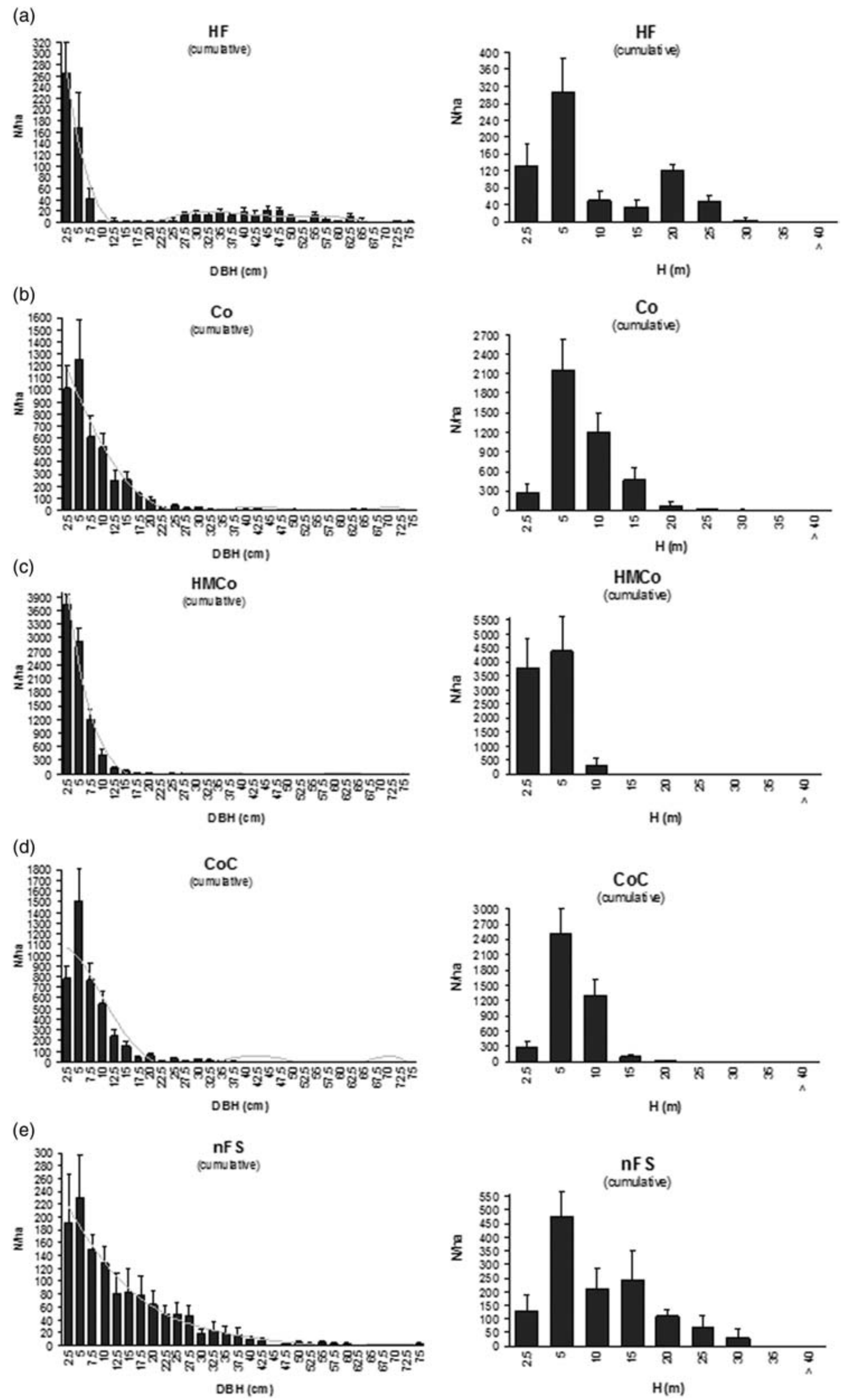

Figure 2. Size structure diagrams of Dbh (cm) and height (*H*) (m) of trees in the studied structural-silvicultural types (mean values and standard error for the different replicates of each type). For acronyms of structural-silvicultural types see the text.

leaving 100 standards per hectare (Hofmann 1960). It is only since the 1950s that traditional silvicultural practices on the beech stands have ended; this and regular non-traditional silvicultural practices have already led to the conversion of old Cos to HFs (Figure 3(b)) with many beech Cos which are

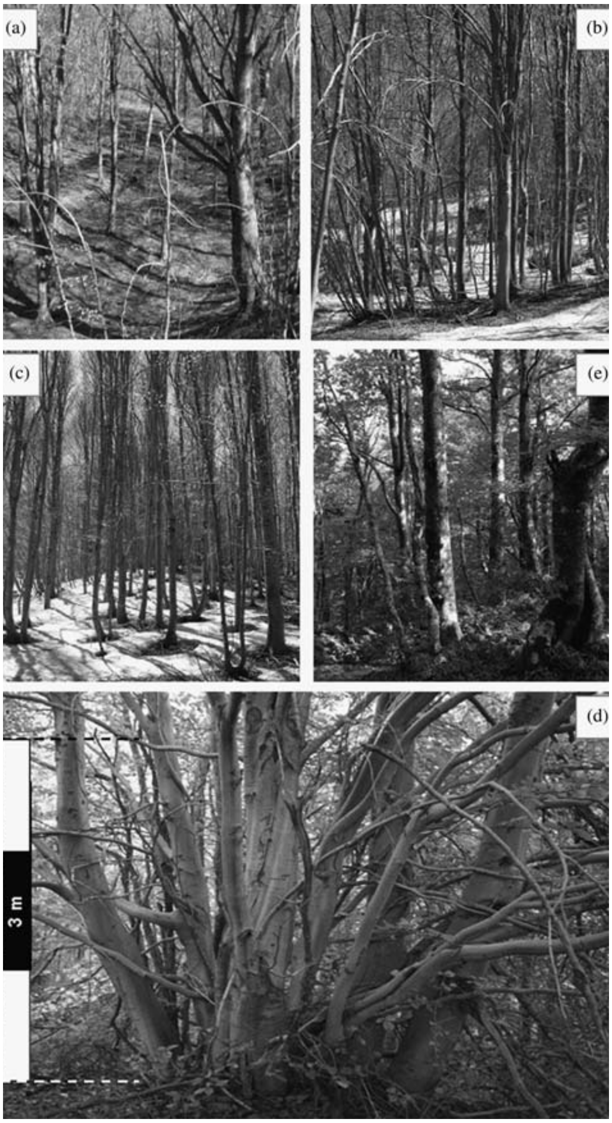

Figure 3. Photos of the main physiognomy-structural beech stand types, namely silvicultural forms, of Mount Etna: (a) HF, (b) Co, (c) CoC, (d) HMCo and (e) nFS.

currently 50–70 years old (Hofmann 1960; Mercurio & Spampinato 2008).

High forest (HF). As reported by Hofmann (1960), the plots located in the Annunziata forest (ANN1, ANN2 and ANN3) (Table III) represent one of the rare cases of HF stands on Mount Etna. The vertical profiles of these stands are usually bilayered (Hofmann 1960) (Figure 3(a)), with dominant trees of 160–190 years old in average.

High-mountain coppice (HMCo). The HMCo stands represent the beech communities at the higher altitude (1800–2280 m asl.), reaching the timberline at around 2000 m asl. They occur in small and isolated pure stands or mixed with other trees typical of the mountain vegetation belt on Mount Etna. However, past occasional treatments (e.g. felling) have also played a role in creating this structural type characterized by larger Co shoots of 50–70 (rarely 90) years old (Figure 3(d)).

Coppice in conversion to high forest (CoC). The transformation from a Co stand at the rotation age into a HF can take up to 150 years (Figure 3(c)). The conversion process can be applied to 'aged-Co', namely Co not regularly cut where the abandonment of management practices has exceeded the ordinary rotation age (very common on Mount Etna). Thus, beech aged-Cos are currently 50–70(80) years old, which were subjected to the gradual thinning of sprouts in recent decades (mainly 15–25 years ago).

non-Formal stand (nFS) – i.e. other non-currently managed stand in natural evolution. This group includes all the stands difficult to judge as belonging to one of the above stated canonical silvicultural form types due to their heterogeneous, dendrometric and structural characteristics (Figure 3(e)). These stand structures are the result of the abandonment of processes associated with previous silvicultural treatments and of sporadic tree felling. In almost all cases, the values detected show the highest heterogeneity.

Stand-structural characteristics

The five structural types differ in the mean and maximum stand-structural values (Figure 4). The highest mean Dbh (>26 cm) was recorded in the HF management type (Figure 4(a)) ($p < 0.05$) compared to CoC and HMCo. The same pattern was observed when comparing the mean of the measured maximum Dbh of the largest trees among structural types. Similar patterns showed the mean and maximum tree height (top height) (Figure 4(b)). No differences were highlighted matching the mean crown radius among the studied structural types (Figure 4(c)).

Stem density showed significant statistical differences when comparing HF, HMCo and other forms of Co and CoC. The highest densities were observed in HMCo, with a mean of 8521 stem/ha, whereas HF showed the lowest value with <700 stem/ha. When comparing the stump density, statistically significant results were only found when comparing HF and nFS with all the Cos. The mean number of shoots per stump differed significantly; HMCo often reached values of eight shoots per stump.

Regarding the regeneration aspects, statistically significant differences were found only between the HFs, 300 saplings/ha, and the HMCo, 4506 shoots/ha. No significant differences were observed among

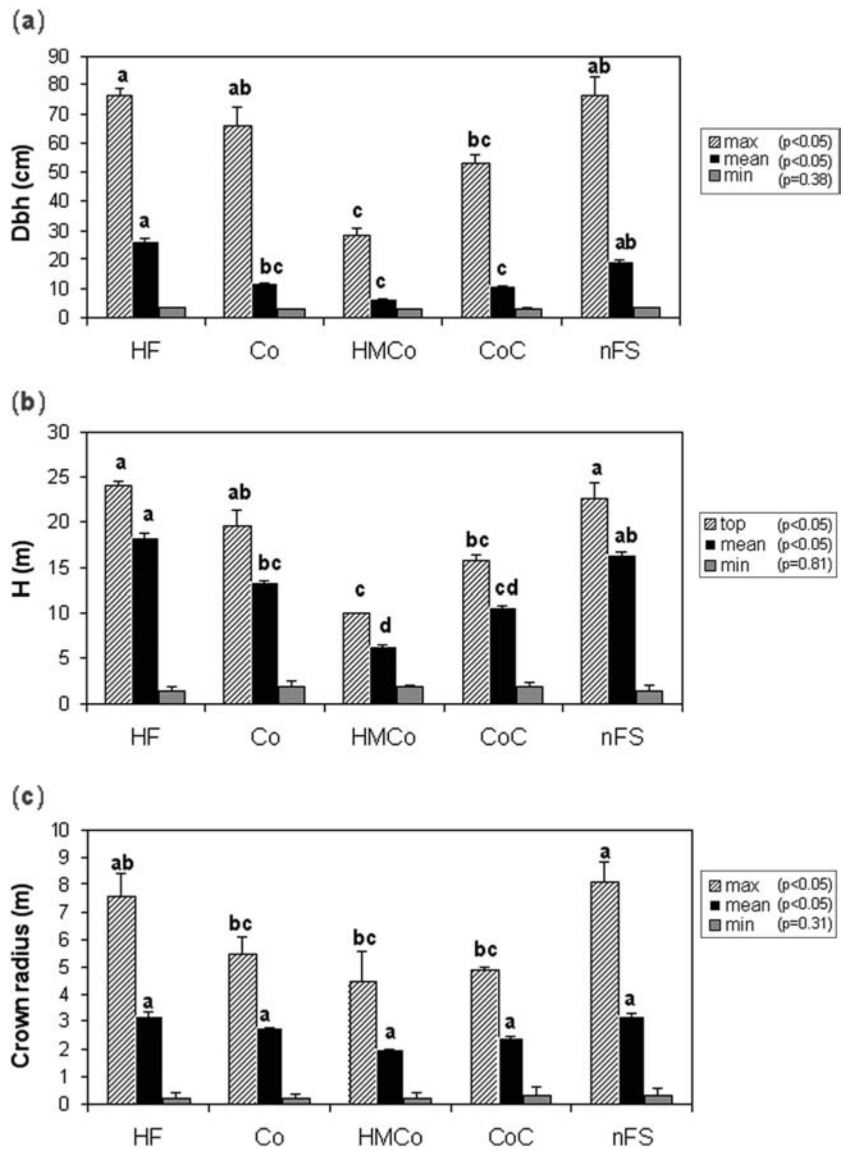

Figure 4. Mean and standard error of maximum, mean and minimum values of (a) Dbh, (b) height (*H*) and (c) crown diameter of trees and shoots in the studied areas. Results of ANOVA are also included (when $p < 0.05$; different letters indicate significant differences by Scheffé's test). For acronyms of structural-silvicultural types see the text.

the other groups, for both gamic and agamic regeneration.

Standing dead wood, measured as plant frequency, shows the highest values in Co and HMCo. Standing dead wood was recorded as 8.5 m^3/ha in Co and 2.5 m^3/ha in HMCo (Table III). HF plots had only 0.15 m^3/ha in contrast to the highest mean value of 26.6 m^3/ha of standing dead wood displayed in nFS (high heterogeneity among these plots). A similar trend with low values in regards to detected fallen dead wood (see Table III) was detected among the structural groups.

According to the *R* index, the HMCo and the nFS form a clustering pattern, with statistically significant differences when compared with the other groups. The *A* index pointed out differences between the nFS stands, which have a multilayered profile, and the HMCo stands, which have a monolayered profile (Table III).

The herbaceous layer shows a mean cover of $<$30% in all different structural groups, albeit with some differences (Table III). No particular indications came out from the analysis of the litter characteristics.

Considering all the measured and calculated stand-structural variables via a PCA, the first two factors extracted a total of 63.35% of the variance (Figure 5). Along *F*1 (axis I), more important loading factors were Dbh, H and volume (at the positive end), stem density, stump density and the no. of shoots per stump (at the negative end); on *F*2 (axis 2), main loading factors were the *R* index,

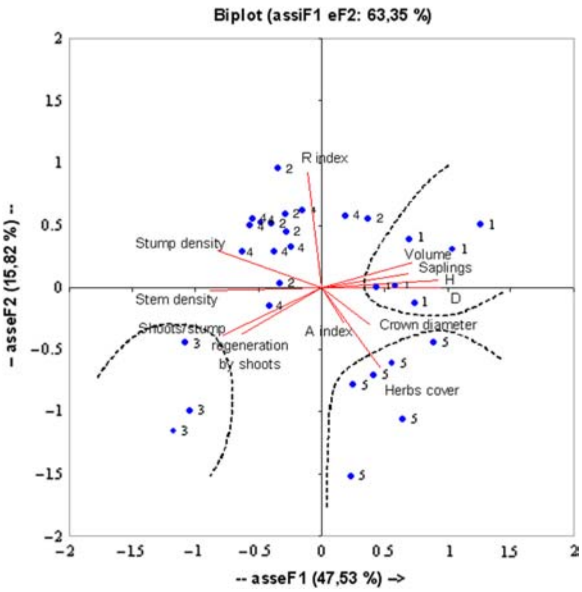

Figure 5. Location of the study plots in the biplot defined by the first two axes in the PCA (1, HFs; 2, Cos; 3, HMCos; 4, CoC; 5, nFS).

positively correlated, and the herb cover, negatively correlated. Thus, the first axis ordered the study plots according to the size of the beech trees (with the larger dimension associated with higher regeneration by saplings and both lower density and regeneration by shoots); the second axis in relation to a structural gradient (mainly expressed by the *R* aggregation index and by the herb cover). The PCA representation showed that HMCos, HFs and nFSs are well defined in their location (Figure 5).

The Pearson correlation analysis between the used variables in the PCA highlights the high correlations found among the dendrometric variables. Regeneration aspects were also correlated with the previous variables.

Discussion and conclusions

Data from the analysed plots showed a great variability in the European beech stand structures of Mount Etna, especially in the dimensional character of trees, their spatial patterns and their regeneration aspects. The altitude gradient, as a site characteristic, can summarize this concept. For example, it shows a degree of anthropogenic impact in relation to the main stand types. The altitude is clearly negatively correlated with the size of trees (Dbh, H, Volume) with HF and nFS mainly located around 1400–1500 m asl., Co and CoC mainly at around 1600–1700 m and HMCo around the timberline at 1900–2000 m. This trend is also the expression of a gradient of suitable environmental conditions. Historically, management (especially concerning Co treatments) has occurred more intensively on the more accessible and productive beech stands which are located at medium and lower altitudes. This general trend related to the altitude is also expressed by the positive correlations of main structural-silvicultural forms and the density aspects (of stems, stumps and shoots/stump) of analysed stands.

Vegetative regeneration (sprouting) strongly predominates in HMCos, as shown by the great density of re-sprouts in the understorey (multi-stemmed plants). This is a common beech strategy for surviving in these sites that are located at the highest altitudes with less suitable environmental conditions for seedling survival (e.g. Peñuelas et al. 2007).

The unplanned felling of trees (Cullotta & Maetzke 2009) and the spatially irregular pattern of the tree felling result in forest stands that are difficult to structurally classify as one of the canonical silvicultural forms (e.g. CoC and nFS). Moreover, the historical actions of silviculture practices on stands, and especially those related to Co choices (simple Co, Co with standards and selection Co), have increased the variability of the structures observed in the CoC and nFS groups today. In addition, the current effects of the abandonment process on forest stand dynamics in different micro-ecological conditions must be considered. Bibliographic data on historical silviculture practices report that the Co with standards was the most widespread treatment on the beech stands of Mount Etna until the half of the last century (Hofmann 1960; Mercurio & Spampinato 2008).

When comparing the structural values of the analysed Cos with the available bibliographic data on beech Cos located in the central and southern Apennines in Italy (e.g. Ciancio et al. 2006, 2008), similar or lower Dbh, H and Volume values for the Mount Etna stands emerge; similar results were also found with regards to the HFs (e.g. Piovesan et al. 2010). Differences for mean stand-structure values increase if we compare the lower structural values of Etna beech stands with other bibliographic data of beech stands located at northern latitudes and under more favourable macroclimatic conditions (e.g. Peters 1997; various authors cited in Christensen et al. 2005).

The anthropogenic actions on Mount Etna beech stands are also confirmed by the dead wood values. In fact, in all structural groups, standing and fallen dead wood values showed that historical anthropic actions (prevalently wood felling and harvesting) irregularly influenced the Etna beech stands (e.g. Barreca et al. 2005; Mercurio & Spampinato 2008). In addition, the frequent deposition of volcanic ash and lapillus on the ground covers fallen dead wood. Thus, the detected value of dead wood in Mount

Etna beech stands are lower than the bibliographic data at national and continental level (e.g. see Bretz Guby & Dobbertin 1996; Christensen et al. 2005; Lombardi et al. 2008).

With reference to the spatial arrangement of trees, the *R* aggregation index highlighted that the HMCo and the nFS tend to form a clustered pattern compared with other stands; this is probably due to the dominant effects of marginal environmental limits for the HMCo and to the silvicultural effects (felling) for the nFS (multilayered profile), as above stated. In marginal condition, the HMCo for the monolayered thin profile was strongly influenced by very limited height growth (low multi-stemmed plants) (Figure 3(d)). Usually, in the analysed plots of the nFS group, dominant, co-dominant and dominated layers were found. The high re-sprouting capacity observed in HMCos may have led to stump enlargements or new stumps by the capacity of sprouts to rooting. From the bottom half of the stem, the branches spread horizontally, with the lower branches in contact with the soil rooting. The proliferation of natural shoots is frequent at the timberline, as is agamic reproduction (layering) from the lower branches (Mercurio & Spampinato 2008).

In general, our data collection indicates a high variability of beech stand structures in relation to the heterogeneity of the site characteristics, as well as to the effects of disturbance factors (both natural and anthropogenic). The occurrence of particular stand structures along the altitude gradient in Mount Etna, as demonstrated by the analysed multi-stemmed HMCos, can be primarily explained by the changing and limited ecological factors (high altitude, steep slope, shallow soil, volcanic-ash deposition and frequent strong wind). However, it should still be noted that past anthropic actions (felling) have also played a role in determining stand structures at higher altitudes; as observable at the wider Mediterranean level (e.g. Kalajnxhiu et al. 2012).

Similar complete structural data of mountain-Mediterranean contexts was not forthcoming in the scientific literature to compare to the Mount Etna HMCos. However, multi-stemmed or very limited height growth of *Fagus*, as well as *Notofagus*, stands can be found all around the world under natural stress, due to the latitude and/or altitude limits (Peters 1997; Barrera et al. 2000; Cuevas 2002). Both dry Mediterranean and cool montane climates seem to be favourable for sprouting in European beech (Mormiche 1981; Papalexandris & Milios 2010). Only bibliographic information on the location of beech on mountain-Mediterranean locations (at upper limit – timberline) at altitudes lower than on Mount Etna could be found; e.g.:

- around 1900 m asl. in southern Italy and 1800 m in central Italy (Piovesan et al. 2005; Marchetti et al. 2010);
- around 1900 m in central Greece (Tsiripidis et al. 2007);
- around 1700 m in central and north-eastern beech stands of Spain (Peñuelas & Boada 2003).

In summary, it is on Mount Etna that *F. sylvatica* reaches its southernmost limit and its highest altitude point of its entire distribution area at European continental level. Here, the forests are relict stands surviving in several extreme living conditions: the volcanic substrata and frequent ashes/lapillus deposition on soils, the severe macro-climate dryness during summer season that typically occurs in central-southern Mediterranean areas and the long-term management uses.

The results obtained in this study confirm the variability of ecological and management effects which affect the beech stands on Mount Etna, in a relatively small territorial area. This is demonstrated in the complex and diverse structural-silvicultural types detected. From the point of view of silviculture management, the policy adopted during the last few decades, at both national and continental level, to favour the conversion of Cos to HFs and the monitoring of natural stand-dynamics (especially for large areas of abandoned Cos) is particularly appropriate for achieving sustainable forest management and for ensuring the conservation of these marginal beech forests, in relation to suitable micro-ecological conditions.

The expression of the most peculiar site conditions of Mount Etna beech stands was found in the analysed HMCos. These displayed stand-structural patterns that highlight their ecological marginality in terms of latitude and altitude inside the Mediterranean Basin. These southern environmental conditions with the presence of a typical middle-European species, such as the European beech, call for more detailed studies on the suitability of the management-silvicultural treatments currently applied to these forest stands. This last aspect is of primary importance especially at their southernmost range edge of this species, as they may hasten biome change.

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