



Pinus nigra J.F. Arnold subsp. *calabrica* (Poir.) of the Fallistro Biogenetic Natural Reserve: state of “Giant pines” stand after 40 years of observations

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Abstract

Aim of study: (1) to assess structural parameters of Giant pines; (2) to compare three several inventories and relative parameters; (3) to assess mechanical stability of Giant pines.

Area of study: Sila National Park, Calabria, Italy.

Material and methods: Mechanical stability assessment and full dendrometric analysis were used.

Main results: 40 years after the first measurements on the Giant pines, the most emblematic trees of the population confirmed the peculiar ecological characteristics of Calabrian pines: their posture, rapidity of growth, productivity and longevity. The pine forest containing 46 healthy monumental trees. The Ht/DBH ratio slightly decreased from first to last inventory. The decrease of the Ht/DBH ratio correspond to the increase of mechanical stability of trees.

Research highlights: the importance of preserving the Fallistro Biogenetic Natural Reserve as a source of biodiversity and to maintain the high ecological stability that characterize this important Italian forest area.

Keywords: Old-growth forest; Biodiversity conservation; Sustainable forestry; Calabrian pine; Forest ecology; deadwood.

Authors' contributions: : Conceived and designed the experiments: VB, SA, MP. Performed the experiments: VB, SA. Analyzed the data: VB, MP. Contributed materials/analysis tools: MP, VB. Wrote the paper: MP, VB.

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Supplementary material: Tables S1 and S2, and Figures S1 to S3 accompany the paper on FS's website.

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Introduction

Ancient trees are a heritage of inestimable historical and cultural value and natural monuments. Their presence in woodlands is the evidence of a long and strong relationship between human activities and land uses. The big and tall trees have not only scenic and aesthetic values, but they are also important from ecological and historical point of views (Cannizzaro & Corinto, 2014). Ancient trees differ from others of their species for their old age and unusual size and shape. Several features, such as height, stem diameter, crown shape and involvement of them in historical events, make these trees of public interest and therefore protected by law (Artese, 2015). According to Castagneri *et al.* (2012), a relationship between longevity and growth rate has been demonstrate. Old-growth trees

have a lower growth rate than younger trees growing at the same site and low growth rate during early life stages is probably associated with longevity (Black *et al.*, 2008; Matthes *et al.*, 2008; Bigler & Velben, 2009; Johnson & Abrams, 2009). These trees contain several information about past dynamics and climate. They can represent unique habitats for many rare species (Rolstad *et al.*, 2001; Nascimbene *et al.* 2009, Schweingruber & Wirth 2009; Castagneri *et al.*, 2012). Ancient trees are important parts of ecosystems and they are usually included in ecological studies of forest management.

The importance of old-growth forests has been recognized worldwide. They are ecosystems that have achieved maturity without disturbance during their life and growing cycles. They are complex ecosystems, which also contain high tree diversity.

The proper management of old-growth forests represent one of the main objectives of forest conservation. Old-growth trees are key features of these forests and they constitute important elements for biodiversity. Therefore, major knowledge on their growth and mortality pattern is required and necessary (Blasi *et al.*, 2010; Castagneri *et al.*, 2012). A large variety of animal species can live there because there are different types of trees. The persistence of many specialized insects depends on the presence of ancient trees scattered in the woods (Scalerio *et al.*, 2016), also in urban and peri-urban ecosystems or in open landscapes (Horák, 2017). In particular, old, dying and dead trees represent ideal lairs for animals and an important food source for them. Many animal species require intact old-growth forests to survive.

In these ecosystems the regeneration of significant plant species is favored. The necromass and deadwood improve the forest soil and enrich the availability of nutrients for living trees and microfauna. The loss of old-growth forests negatively affects animal and plant species and biodiversity.

In the past, necromass and deadwood were differently evaluated. In particular, the traditional forest management retains deadwood and necromass as a source of biotic and abiotic disturbances (Radu, 2006). Deadwood and necromass were wrongly considered by forest managers as indicators of bad-management and negligence of in the application of silvicultural practices (Pastorella *et al.*, 2016). Over time, the development of biodiversity-oriented forest management has modified the perception of forest managers regarding deadwood and necromass in forests. Nowadays the goal of forest management is to increase the amount of deadwood and reduce the difference in necromass volume between managed and unmanaged forests (Swanson & Franklin, 1992). The presence of necromass preserves the functionality of the forest ecosystem (De Meo *et al.*, 2018) by providing important habitats for arthropods, fungi and facilitating germination of conifers in mountain forests, playing an important ecological role for wildlife (Humphrey *et al.*, 2004, Vallauri *et al.*, 2003).

Necromass and deadwood are important carbon sinks due to their slow decomposition rate (Kalies *et al.*, 2016). They represent a key factor in nutrient cycle of C, N and Mg (Holub *et al.*, 2001; Krankina & Harmon, 1994), in natural regeneration (Vallauri *et al.*, 2003) and in the geomorphological and soil hydrological processes (Bragg & Kershner, 1999).

The health and the mechanical stability of trees is highly related to tree density (Marchi *et al.*, 2017). Height/Diameter at breast eight (Ht/DBH ratio) (Slenderness coefficient) has been demonstrated to be an easy and good indicator of mechanical stability of trees (Wang *et al.*, 1998) unlike many other indicators developed to assess biodiversity in forest ecosystems (Becagli *et al.*, 2013,

Chiavetta *et al.*, 2016, Latham *et al.*, 1998, Neumann & Starlinger, 2001, Pretzsch *et al.*, 2016). In particular, Ht/DBH ratio (Slenderness coefficient) is widely used as the main indicator of single-tree mechanical stability in conifers stands (Marchi *et al.*, 2018, Cantiani & Chiavetta, 2015). Recent studies showed that a high Ht/DBH can indicate that a tree has grown in a dense stand and can be more vulnerable to mechanical perturbations because their stems are not able cope with conditions of high mechanical perturbation, such as landslides and snow damage (Cremer *et al.*, 1982).

The Mediterranean forests have been altered by human activities for a very long time and practically no pristine forests appear to be present in the region (Bengtsson *et al.*, 2000). The generally high human population densities have led to intensive cultivation practices like coppice with short rotations. Along with overgrazing and frequent fires this resulted in severely degraded forests (Di Castri *et al.*, 1981): this situation makes the remaining pristine or close to pristine forests even more valuable (Stanners & Bourdeau, 1995).

In Italy, an important old-growth forest reserve is located in the Sila National Park. This is the Fallistro Biogenetic Natural Reserve, a precious forest stand made up of ancient trees of *Pinus nigra* J.F. Arnold subsp. *calabrica* (Poir.) (Calabrian pine) so-called locally as “Giganti della Sila”, *i.e.* Giants pines. They were planted in the middle of 17th century in order to create a topsoil protection from cold winds as well as a shelter for shepherds and animals.

This work represents the pursuance of a previous and already published study (Plutino *et al.*, 2018). In the present paper, the result of 40 years of forest mensuration carried out by the Research Centre for Forest and Wood in the Fallistro Biogenetic Natural Reserve are reported. 58 ancient Giant pines were measured in 1976, 1986 and 2016. The purposes of the paper are: (1) to assess structural parameters of Giant pines; (2) to compare three inventories and relative parameters; (3) to assess mechanical stability of Giant pines; (4) to highlight some important reasons for preserving the Fallistro Biogenetic Nature Reserve, *i.e.* the role of the Reserve as a source of biodiversity and to maintain high levels of ecological stability characterizing this important Italian forest area.

We focus on overall structure and consequently provide a characterization of the structural attributes and history of this forest, as a representative case study of other old-growth realities in the Mediterranean environment.

Materials and methods

Site description

The Biogenetic Natural Reserve of Fallistro has been studied since 1976. According to several authors (*e.g.*

Bonavita *et al.*, 2016, Avolio & Ciancio, 1985, Anzilotti 1950), it would be an artificial old-growth forest of Calabrian pine. The Authors report that the forest would be planted in the middle of 17th century by means of natural regeneration collected from surrounding forest areas in order to create topsoil protection from cold winds as well as a shelter for shepherds and animals. In 1987 the Reserve was established by law of the Italian Ministry of the Environment. It is located within the Neto River basin (Sila Grande), in Municipality of Spezzano della Sila (Province of Cosenza). It extends for about 5.4 hectares (Fig. 1). About 1500 uneven-aged trees are included, some of which are estimated to be over 390 years old (Avolio & Ciancio, 1985) (Fig. 2).

No current silvicultural activities in this area are carried out and the Fallistro Biogenetic Natural Reserve has been left to natural evolution for a long time (Bonavita *et al.*, 2016).

The census of all tree species has been carried out. These data and historical information allowed to identify the forest typologies in the reserve.

The Calabrian pine is a botanically interesting species because of its localized natural distribution within the

Mediterranean basin. Largest populations are in Calabria, especially in Sila Plateau, where major stands are within protected areas (Farjon, 2013).

The area's altitude is from 1,398 to 1,448 m a.s.l. and it is characterized by exposure from NW to SE. The bedrock is siliceous and the soil is poorly developed. The Climate is Humid temperate (Mediterranean) (Le Pera & Sorriso-Valvo, 2000). Precipitation is typically spread throughout the autumn–winter season. The mean annual temperature is 9.0 °C and mean annual rainfall is 1,639 mm (San Camigliatello Silano meteorological station, data provided by ARPACAL 2016) (Fig. S1 [suppl.]). According to the Pavari's phytoclimatic classification (1916) the Fallistro site falls within the *Fagetum*, warm sub-zone.

Field measurements and data analysis

All trees and shrubs were counted. The species were identified for each individual.

In order to describe the conditions of Giant pines of the Fallistro Reserve, the main dendrometric parameters were evaluated: diameter at breast height (DBH), total

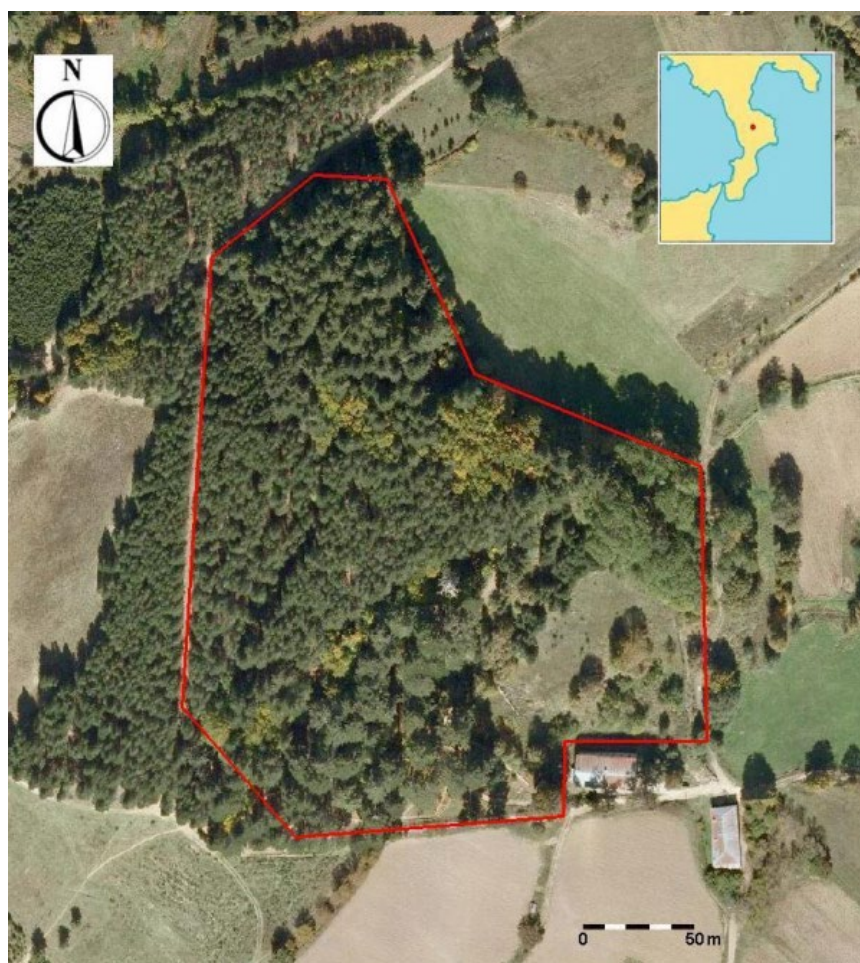


Figure 1. The delimitation of Fallistro Biogenetic Natural Reserve (Ortophotos by Regione Calabria Geo-portal) (Font: Plutino *et. al.*, 2018).



Figure 2. An exemplar of “giant pine” of considerable size in the Fallistro biogenetic reserve.

tree height (Ht), early dry branches height, early alive branches height, stand density, cormometric volume.

All data were published in Plutino *et al.* (2018) and archived in an open access dataset at <https://zenodo.org/record/1100340> and metadata at <https://zenodo.org/record/1100340> (Pollastrini *et al.*, 2017). Dataset is attached as supplementary (Table S1 [suppl.]).

Cormometric volume has been calculated applying a form factor derived from measurements carried out on Giant pines fallen on the ground and already highlighted in Plutino *et al.* (2018).

In 1986 a structural transect has been permanently traced in order to evaluate the stand vertical and horizontal profile evolution. In 2016, the same transect (40m x 140m) was replaced and the horizontal profile was re-constructed. Trees' coordinates (X, Y), diameter at breast height, tree total height, living branch height, crown length and crown projection area were measured again. Tree total height was measured using the ipsometer Vertex III. The measurement of the crown diameter was measured as vertical lineament of the crown projec-

tion recorded in four directions and calculated as a mean of four measurement values.

Statistical analysis

For each variable the average values and standard error (SE) values were calculated to identify the level of variability of data collection in 3 inventories (Table 1). A summary of Ht/DBH statistical values of three inventories are shown in Table 2.

A Fisher's analysis of variance (ANOVA) was performed to test the effect of time and size on each of analyzed variables. The ANOVA allows to compare two or more groups of data by comparing the variability “within groups” with the variability “between groups”. Total height (Ht) was subjected to one-way ANOVA.

The diameters, basal area (ba) and volume (v) were subjected to ANOVA of repeated measurements to define the degree of variability between and within the groups of 3 inventories considering DBH range of 40 cm

A Tukey's HSD test was done when these effects were identified as significant (Table 4).

Also Ht/DBH ratio (slenderness coefficient) was subjected to one-way ANOVA to define the degree of

Table 1. Statistical values of dendrometric parameters. Up: DBH (Diameter at Breast Height); Ht (total height); down: ba (basal area), v (volume). SE (standard error value)

	1976	1986	2016
Number of trees	58	53	46
Mean DBH (cm)	124.0	127.2	128.7
DBH SE	3.6	3.8	4.1
DBH range (cm)	70.0-185.0	71.0-187.0	73.0-189.0
Mean Ht (m)	35.0	35.8	36.0
Ht SE	0.7	0.7	0.8
Height range (m)	20.0-44.0	22.0-44.0	15.0-4.04
Mean ba (m ²)	1.3	1.3	1.4
ba SE	0.1	0.1	0.1
ba range (m ²)	0.4-2.6	0.4-2.7	0.4-2.8
Mean v (m ³)	24.0	25.7	26.7
v SE	1.5	1.7	2.0
v range (m ³)	4.9-60.4	5.3-62.2	5.2-63.8

Table 2. Ht/DBH ratio (slenderness coefficient) statistical values of three inventories

Year	Average	Std Dev	SE
1976	29,13	5,91	0,79
1986	29,18	5,82	0,82
2016	28,84	6,11	0,89

Table 4. Tukey's HSD test post hoc of v values: it is used to find means significantly different from each other. HSD test shows that the means of ba for each block are significant different

Blocks	DBH	Ba	v	Ht/DBH
1	a	A	a	a
2	b	B	b	b
3	c	C	c	c

variability of trees' stability between and within the groups of 3 inventories.

Necromass estimation

Necromass has been evaluate as following: (a) for standing necromass: number of dead stems standing, the percentage of dead trees standing on the total, the volume with Huber's formula; (b) for ground necromass: the volume of each linear segment and the total volume per hectare using the formulas by La Fauci *et al.*, (2006).

Results

Forest stand conditions are the result of several variables as age, site, area occupancy and intensity of competition, associated with number, dimensions, and distribution of trees in a given stand. The main results are shown below.

Forest typologies

Since 1985 to last inventory, the age of trees was identified by counting tree rings in: a) several cross sections taken along the trunk from fallen trees (Fig. S2 [suppl.]) (Avolio & Ciancio, 1985); b) stumps and wood samples for several age classes. The count of the rings on the stumps and trunk of fallen trees over the years would seem to testify to a coetaneity of monitored population.

Moreover, the hypothesis is based by old testimonies of the local population; the testimonies describe that small old smoothed surfaces are present in the forest and could serve as a shelter for animals. The old owners would be planted and used the pines to beautify and protect the soil (Allegri, 1954, Anzilotti, 1950). In 2012, core drilling and counting were repeated on medium diameter trees up to class 150-200 (Bonavita, 2012).

According to Avolio & Ciancio, (1985), the forest typologies of the area would be classified as follows: 390 years old pine high forest (11% on total surface); 150-200 year pine high forest (33%); 80-120 year pine high forest (12%); 40-60 year pine forest (9%); 15-30 year

pine young growth forest (4%); beech (*Fagus sylvatica* L.) outgrown coppice (7%); 80-100 year poplar (*Populus tremula* L.) stand (5%). At the edge of the area ancient and large stumps of mountain maple (*Acer pseudoplatanus* L.) and chestnut (*Castanea sativa* Miller) are present. Renewal of alder (*Alnus cordata* Desf), beech and mountain maple has been affirmed at the edge of the pine and beech stands, hawhilst poplar and Calabrian pine renewal has been affirmed on forest clearings.

In several forest typologies understory is poor. In growing coppices are exclusively present *Asperula odorata* L., *Oxalis acetosella* L., *Anemone nemorosa* L., *Saxifraga rotundifolia* L.. In other stands, understory is characterized by *Pteridium aquilinum* L., *Crataegus oxyacantha* L., *Rosa canina* L., *Sambucus racemosa* L., *Sorbus aucuparia* L., *Malus silvestris* Borkh., *Prunus cocomilia* Ten., *Salix capraea* L., *Lithospermum calabrum* Ten., *Rubus fruticosus* L.

Comparison of inventories

The data reported in Table S1 [suppl.] (Plutino *et al.* 2018) compare: average diameter, basal area, total height and cormometric volume of the individual alive plants measured in 1976, 1986 and 2016.

Table 1 shows all means values. The one-way ANOVA of Ht doesn't show significant differences among three inventories ($F=0,456$; $p=0,634435$). DBH, ba and v showed significant differences within DBH size (Table 3).

The survival was 86.2% over 1976-1986, 90.0% over 1986-2016, 77.6% over 1976-2016.

The alive trees' average DBH has increased from 124.0 to 128.7 cm. The dead trees' average DBH in 1986 and 2016 is 132.2 and 136.3 cm.

Total basal area values have decreased from 73.2 to 60.4 m². From 1986 to 2016, dead trees' total basal area has decreased from 11.0 to 7.3 m². The decrease is probably due to mortality. Total height values of alive pines vary between 35.0 (1976) and 36.0 m (2016). Total height values of dead pines in the years 1986 and 2016 measure 34.2 and 36.0 m.

The alive trees total volume in 1976, 1986 and 2016 are respectively 1,394.4, 1,285.0 and 1,203.5 m³. For dead trees, total volume values are 197.2 and 139.1 m³ in 1986 and 2016. Average volume measures 24.6 and 27.8 m³ respectively.

Diameter distribution for all inventories are reported in Fig. 3.

Necromass

Data collected in the field were elaborated to assess necromass volume.

Table 3. ANOVA of DBH (cm) , ba (basal area, m²) and v (volume, m³) values. Year represents the inventories' years. Blocks represents a DBH range (1: 70-110 cm; 2: 111-150 cm); 3: (151-190 cm). SS is deviance, d.f. is degree of freedom, MS is variance, F is Fisher test, *p*-value (calculated probability) defines the significance level (the lower it is, the greater the difference)

	Source for Variation	SS	d.f.	MS	F	<i>p</i> -value
DBH	Year	84	2	42	0.33	0.718738
	Blocks	94631	2	47315	374.98	<u><0.001</u>
	Error	18422	146	126		
ab	Year	0.0661	2	0.0331	0.602	0.549129
	Blocks	38.4444	2	19.2222	349.839	<u><0.001</u>
	Error	8.0771	147	0.0549		
v	Year	6.66	2	3.33	0.099	0.905872
	Blocks	18079.91	2	9039.96	268.611	<u><0.001</u>
	Error	4947.21	147	33.65		

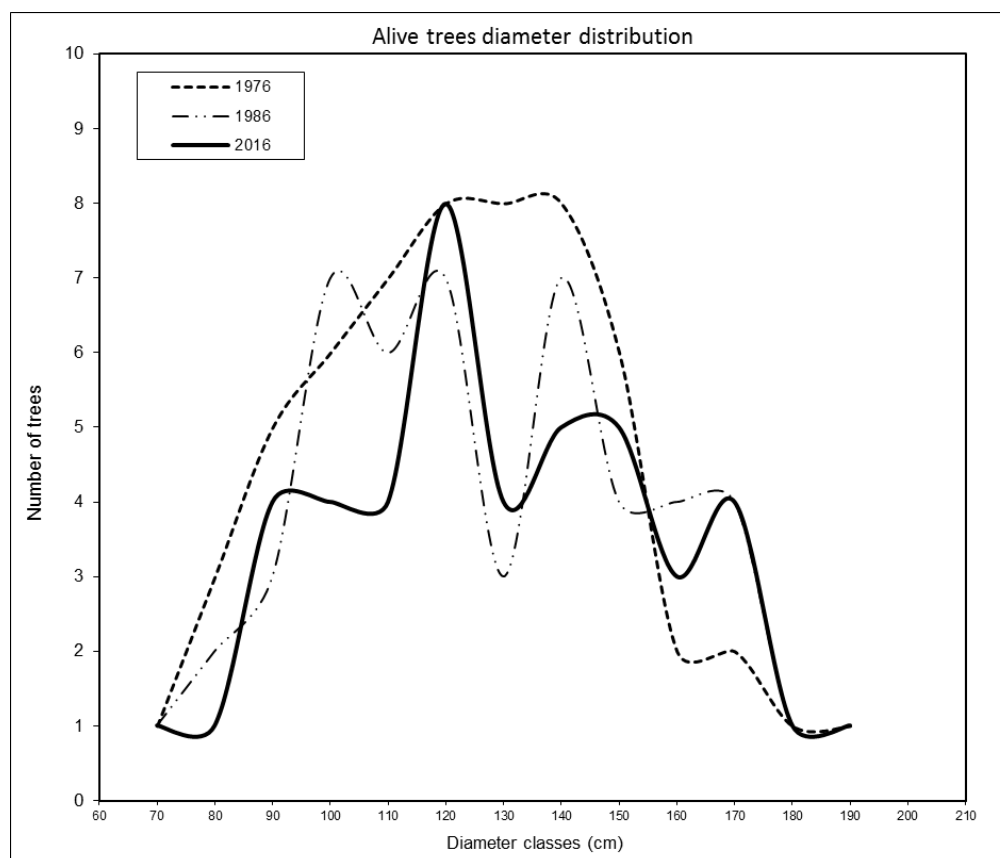


Figure 3. Diameter distribution in 1976, 1986 and 2016.

Necromass is a fundamental substrate for numerous species and a key factor in carbon and nutrient cycles. In 2016 the Calabrian pine forest was characterized by a high quantity of necromass (51.7 m³ ha⁻¹) in which 69% was lying necromass, 31% standing dead trees, showing an increase if compared to the values recorded in 1986 (30.3 m³ ha⁻¹) where the necromass was composed by 65% of lying necromass and 35% of standing dead trees.

Mechanical Stability of Forest System differences in Ht/DBH

The principal statistical parameters of Ht/DBH ratio are reported in Table 2. The 1-way ANOVA don't show statistically differences among three inventories ($F=0.045$ $p=0.956383$). The Ht/DBH ratio slightly decreased from 1976 to 2016. The decrease of the Ht/DBH ratio correspond to increase of mechanical stability of trees.

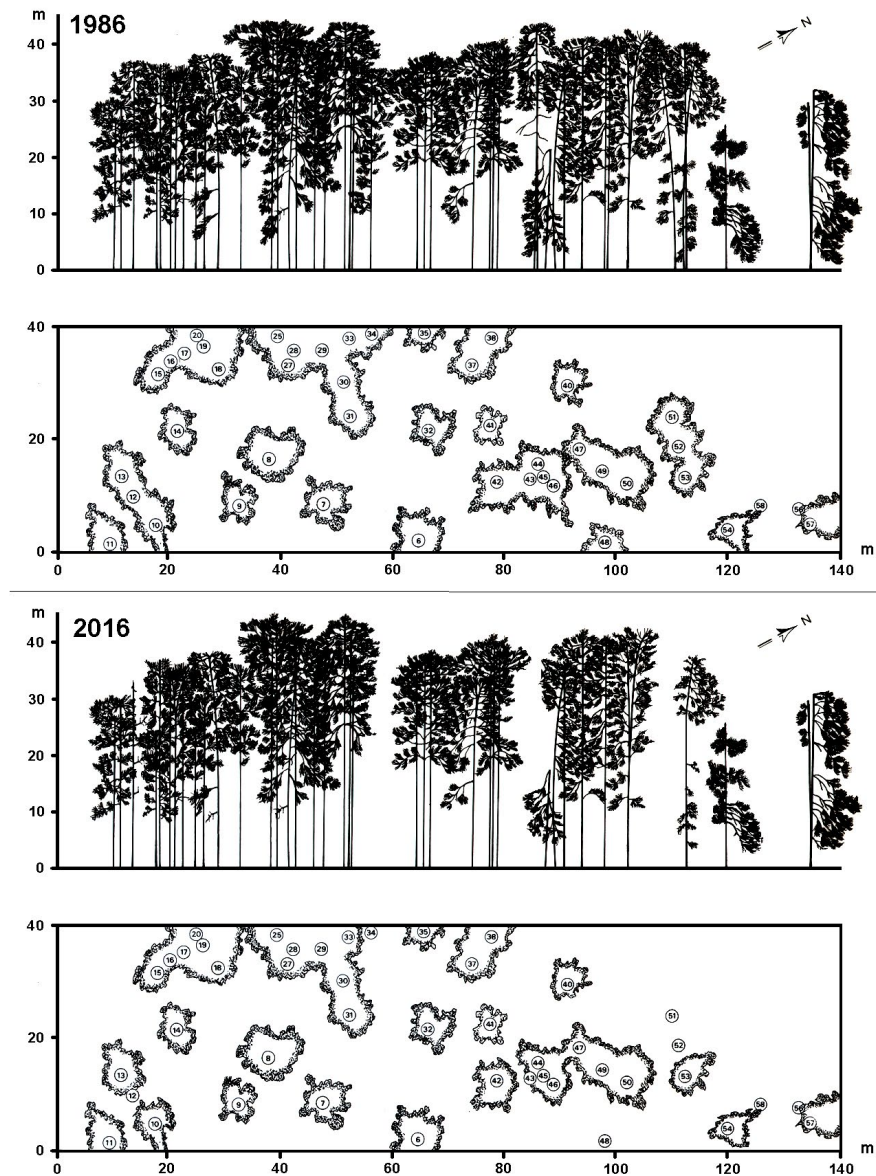


Figure 4. Transects profile and cover projections in 1986 and 2016. In order to represent all trees, all coordinates (X, Y), DBH, total and crown height and crown projections (at North, East, West and South) were measured.

Other characteristics of stem and foliage

Some trees were subjected to slotting, a procedure for harvesting the pine's resin. Local shepherds and lumberjacks used this practice in order to obtain splinters to be used as torches or for lighting fires.

In 2016, 10 slotted trees were present. The most slotted plant is the n. 40, showing a cavity of m 3.77x1.52x1.33 m.

Twenty-tree pines (23) present columnar stems, without dried branches and stumps until the insertion of the first alive branches. This is the consequence of self-pruning started many years ago and which continues progressively upwards. Along the stem of other 22 trees, instead, remains of stumps or dry branches of various sizes are present.

The average height of insertion of the first alive branch is at 13.8 m with the minimum at 3.2 m (tree 53) and the maximum at 30.8 m (tree 19). The average crown amplitude is 21.8 m varying from m 3.0 (tree 19) to m 34.0 (tree 21) (Data just illustrated are attached as supplementary (Table S2 [suppl.])).

In Fig. 4 is represented the two transects profile and cover projections obtained following mensuration in 1986 and 2016.

Discussion

Fallistro Reserve is the last remnant of ancient forest in Sila preserved until the beginning of the 17th century.

It has remained undisturbed until the Unity of Italy (1861), when started an intensive exploitation of forest resources (Anzilotti, 1950). Since 2016, the Reserve is managed by the Fondo Ambiente Italiano (FAI).

40 years after first measurements on the Giant pines, the most emblematic and ancient trees of the population confirmed the peculiar ecological characteristics of Calabrian pines: their posture, rapidity of growth, productivity and longevity.

The pine forest would be 390 years old and it is represented by 45 green monuments in good vegetative and health status. Certainty does not exist on the origin of pine forest, but the studies conducted since 1950 would lead to the hypothesis that it is coetaneous and artificial (Allegri, 1954, Anzilotti, 1950). The affirmation is based on considerations that mainly derive from testimonies of the local population collected by authors: the old owners would be used the pines to beautify and protect the soil (Avolio & Ciancio, 1985, Anzilotti, 1950).

Total survival is 77.6%; 86.2% after the first 10 years and 90.0% at the end of the study. The greatest trees are characterized by maximum size in diameter (189 cm) and height (44 m), by high structural heterogeneity and by stratification of the tree cover. The pine forest maintains the prerogative of acting as a true center of propagation of the species.

Nowadays there are no evidences of the decline of the species, although undoubtedly stands have been logged and replaced by other land use or woodland types in the past and threatened by environmental disturbances, especially fires.

The low anthropogenic disturbance experienced in this area for longtime has determined particular features of longevity, and uniqueness of pine posture in this centuries-old pine forest. These conditions have determined a progressive natural aging and the affirmation of a precious woodlot representing the natural populations of the past of Calabrian pine to be preserved for future generations.

Calabrian pine stand is far from having started degenerative processes which inexorably and slowly accompanies forest stands close to their biological decline due to age limits, hence depauperating also the high natural, scenic, ecological and genetic value of the giant pines' nucleus. It is a forest stand that fully responds to the definition proposed by FAO of old-growth forest in 2001 Montreal conference: "*Old growth forest stands are stands in primary or secondary forests that have developed the structures and species normally associated with old primary forest of that type have sufficiently accumulated to act as a forest ecosystem distinct from any younger age class*" (UNEP/CBD/SBSTTA, 2001).

The pine stand is a centuries-old pine forest characterized by a natural dynamic that had determined for decades the presence of all the regenerations phases of the Calabrian pine including the senescent one.

Fallistro forest is constituted by "green patriarchs" and presents large quantities of necromass.

The natural aging of the pine forest proceeds slowly if compared to other old forests. Why this phenomenon occur is still little known, but probably it is correlate with the good management practice of the pine stand and with the institution of the Biogenetic Natural Reserve "Sila's Giants" (D.M. n. 426 of 1987 July 21, Ministry of Environment) that reduced the negative effects connected to the anthropic disturbance.

Other crucial events for conservation and valorization of this area were: Calabria National Park's institution in 1968; Sila National Park's institution and collocation of Biogenetic Natural Reserve as integral reserve and integral protection; a free-loan agreement between the Calabria Region to the Sila National Park Authority for 29 years, and successively entrusted to FAI (Fondo Ambiente Italiano) on a loan-for-used basis by the Sila National Park.

The main objective of the management of the great patriarchs must be the conservation of senescent ecosystem for the collection of Calabrian pine seeds and for production of direct descents, on which to start genetic studies.

In conclusion, Giants pines of Fallistro have particular meaning and suggestiveness not so much for size and age reached by the trees, but for representing the last tangible testimony of the ancient "*Silva brutia*" (Avolio & Ciancio, 1985).

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