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Long-term effects of experimental cutting to convert an abandoned oak coppice into transitional high forest in a protected area of the Italian Mediterranean region

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ABSTRACT

This paper reports the results 20 years after undertaking experimental cutting to convert an abandoned Turkey oak (*Quercus cerris*) coppice into transitional high forest. The basic idea was to convert the coppice into high forest in a single intervention, by way of which an agametic high forest is shaped into an almost permanent compositional and structural arrangement. Two very low release densities, which were unusual both due to legal provisions and to that already tested in Italy, were applied and compared to natural evolution. The experimental thinnings were sustainable from a social and economic perspective, having given rise to positive revenue and not having limited the economic activities of the region. From an ecological perspective, the treated areas experienced an increase in volume between 77% and 80% – recovering from 91% to 100% of the harvested volume – and maintained a persistently low mortality rate for the entire period of observation. In the same period, the areas with natural evolution experienced an increase in volume of less than 14% and a high mortality rate, which, in addition to the Turkey oak individuals, also drastically reduced the presence of other tree species. The experimental thinnings modified the dimensional structure of the treated areas, making it almost uniform and physiognomically similar to that of a one-layer high forest. In the untreated areas, natural evolution produced a dimensional structure that is not very different from that of the treated areas, but over longer times and with selective processes occurring by chance. Twenty years later, the initial hypothesis of undertaking a conversion in a single intervention is corroborated by the results obtained.

1. Introduction

In the inland areas of southern Italy, for decades now, many coppice woods have been in a state of *abandonment*, which consists in the cessation of uses upon completing the usual rotation. The causes of the phenomenon are multiple: depopulation of mountain areas, disadvantageous prices of stumpage due to high labour costs and lack of mechanisation, but also emerging needs for the protection of natural habitats and biodiversity conservation, among others.

Coppices are man-made forests that have been heavily modified in their composition and structure, the existence of which requires periodic coppicing. Once active management ends, the compositional and structural balance, brought about and maintained by centuries of forestry practices, is no longer sustainable by the ecosystem. Therefore, the abandoned coppices over time will tend towards new compositional and structural balances, in accordance with environmental and stand factors. From a physiognomic perspective, they will probably evolve towards high forests, but the course and timeframes of the succession process are mostly unpredictable.

The technical aspects of the conversion of Turkey oak (*Quercus cerris*) coppices into high forest are documented by various Italian studies carried out for this purpose (Amorini et al., 1979; Susmel, 1981; Bernetti, 1983; Ciancio, 1983, 1990; La Marca, 1987). When the decision is made to proceed with conversion into high forest, the options to achieve the objective are essentially:

- *Undetermined ageing:* exploiting the ability of the stand to evolve towards a high forest naturally;
- *Indirect conversion:* after a period of ageing, aimed at restricting the sprouting capacity of the stumps, one proceeds by thinnings with high release densities, creating a transitional high forest of agametic origin.

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- *Direct conversion:* by progressively leaving standards, releasing upon each coppicing a growing number of individuals from which the high forest from seed will originate (preferable in mixed coppices or in the presence of numerous standards).

For indirect conversion, several studies suggest undertaking light repeated thinnings (Guidi, 1975; Amorini and Fabbio, 1988, 1989; La Marca, 1987; La Marca et al., 2009; Fabbio and Amorini, 2006; Amorini et al., 2006, 2010). This option is sustainable in the event of satisfactory demand for firewood, an adequate road network, stands located in morphological conditions suitable for mechanisation and low labour costs.

The Turkey oak coppices in Gargano, the utilization of which has been abandoned, with the exception of those damaged by fire, by excessive grazing or in degraded sites, are good candidates for conversion into high forest because they react well to cutting in a short timeframe. In addition, those examined fall within the boundary of the Gargano National Park (a headland located in south-eastern Italy, in the northern part of Apulia), in the area in which the protection regulations require management based on natural criteria. The ownership of the woodlands in the area of study is mostly Municipal and is encumbered by public use rights for resident populations (grazing in the woods). These aspects make conversion into high forest a feasible and cost-effective management option.

This paper reports the results 20 years after experimental thinning for indirect conversion into high forest compared with natural ageing and is divided into three parts: (1) progress over time of population parameters; (2) effects of intervention on the structure and evolution over time; (3) conclusions with recommendations for the management of abandoned Turkey oak coppices in protected areas in the Mediterranean environment.

2. Materials

2.1. Area of study

The Turkey oak (*Quercus cerris*) woods in Gargano cover an area of about 17,500 ha, of which about 8000 ha (46%) are pure forests and the remaining 9500 ha (54%) are mixed forests of Turkey oak and other broadleaved tree species (*Fagus sylvatica*, *Carpinus betulus*, *Ostrya carpinifolia*, *Acer opalus*, *Acer campestre*, *Quercus pubescens*, *Quercus ilex*) (La Marca and Vidulich, 1989). Turkey oak woods form an irregularly evolving body, are located mainly in hills and low mountains and constitute a typical element of the Gargano forest landscape (La Marca et al., 2002).

The experimentation was carried out in the district of "Bosco di Manfredonia," approximately 300 ha in size, property of the Municipality of Manfredonia, but falling within the administrative boundary of the Municipality of Monte Sant'Angelo. The area is located about 700 m above sea level with gradients of 20–25%, facing north-northeast. The soils belong to the brown forest earths formed on limestone of organic origin (Lippi-Boncambi, 1959; Lopez, 2003). The climate is typically Mediterranean with rainfall concentrated in the autumn–winter period and a dry summer period; average annual rainfall amounts to 726 mm; the average annual temperature is around 12 °C.

The forest vegetation in the area of study may be ascribed to the *Physospermum verticillata-Quercus cerris* combination (Biondi et al., 2008). Among the grass and shrub species, there are the *Cyclamen neapolitanum*, *Rosa canina*, *Prunus spinosa*, *Crataegus oxyacantha*, *Pteridium aquilinum*, *Brachipodium pinnatum* and *B. sylvaticus*, *Fragaria vesca*, *Cornus mas*.

In 1996 the coppice under experimentation was 35 years old and almost ten years had passed since the usual rotation. The coppice had a well-defined two-layer vertical structure: (i) a dominant layer made up of old Turkey oak standards (of various ages) and shoots, in a reduced number per stump; (ii) a very dense dominated layer (60–65% of the total of individuals), consisting of *Ostrya carpinifolia, Acer opalus* and *Acer campestre* with a high number of individuals per stump.

3. Methods

3.1. Experimental thinning

Two release densities were tested for transitional high forest: 600 individuals per hectare (A) and 800 individuals per hectare (B). These are very low release densities both with respect to the provisions of local laws (Apulia Region, 2010) and with respect to the literature (La Marca et al., 2002).

The purpose of the low release densities is to create a transitional, low-competition high forest that evolves rapidly and remains fairly stable from a demographic perspective until the adult stage is reached. Therefore, action is taken drastically and selectively with the starting cut without further intervention or, if necessary, by carrying out only one considerably deferred cut, which acts as a preparation cut for the renewal cuts.

Taking into account the extent of ageing, the density of the shoots, the number and level of crown coverage of the standards, the ecological state of the populations, the specific biodiversity, the adequate fertility of the soil and the presence of livestock raised in the wild, to obtain the target densities the following actions were taken: (i) release of one to two individuals of Turkey oak per stump, chosen from among the best ones based on appearance and vigour; (ii) elimination of all individuals with a diameter at breast height less than 7 cm; (iii) release of some old standards as habitat trees and for landscaping reasons; (iv) release of individuals belonging to other tree species, even if their appearance was not good, but they were in a good vegetational state at the time of selection.

3.2. Intensity and grade of experimental thinning

Many methods have been proposed for objectively determining the intensity and type of thinning (Vezina, 1963), but thinning still remains an event that is difficult to model because of the subjective nature of the decisions that make the process of selecting the individuals to be removed intrinsically fuzzy (Kahn, 1994). Intensity is the simplest parameter to quantify. In the case study, it is expressed by the relative weight of the removed basal area (r_G) by way of the ratio: removed basal area/total basal area (Djomo, 2014). On the other hand, the type of thinning is expressed by the ratio between the number of individuals removed (r_N = removed trees/total trees) and r_G (Murray and Gadow, 1991). The ratio r_N/r_G quantitatively expresses selection preferences in terms of the size of individuals (Zhang et al., 2014). Thinning from below by removing proportionately more individuals than the basal area will have a ratio of $r_N/r_G > 1$. Conversely, thinning from above, by removing more basal area than individuals, will have a ratio of $r_N/r_G < 1$. The more r_N/r_G differs from 1, the more the type of thinning is defined (Pommerening et al., 2015).

3.3. Stand structural complexity

Biodiversity is a broad concept and is therefore difficult to measure overall (Sahotra and Margules, 2002). In addition, it takes on a range of different values depending on the context and the purpose for which it is assessed (Williams, 2004). Since we are interested in framing biodiversity according to the extent of forest stand and for management purposes (Ferretti et al., 2006), it is appropriate to use proxies that summarise the relationship between the various components of biodiversity and the variety and/or complexity of structural components (Sahotra and Margules, 2002). Considering that there is no predefined set of descriptors (McElhinny et al., 2005) in terms of forest stand, it is possible to use the dimensional diversity of individuals as a proxy for structural complexity (Lähde et al., 1999; LeMay and Staudhammer, 2005; Liang et al., 2007). Dimensional variation among individuals is an expression of inter- and intra-specific competition. As such, it is always present even in even-aged and mono-specific stands and, moreover, varies with the development of population (Weigelt and Jolliffe, 2003). Dimensional diversity can be quantified by way of tree attributes – such as diameter, height, volume or biomass (LeMay and Staudhammer, 2005) – easily measurable when not already available based on common forest management practice. Among the measurements commonly used to quantify structural complexity, there are standard deviation, the coefficient of variation, the Theil index and the Lorenz curve (Weiner and Thomas, 1986). These metrics, even if indirectly and approximately, provide a quantitative measure of structural complexity. In addition, due to their quantitative nature, they are useful for comparing the structures of different populations, quantifying the influence of different forestry treatments and assessing changes over time (Lexerød and Eid, 2006; Staudhammer and LeMay, 2001).

Since diversity implies two aspects, evenness and richness, we refer evenness to the relative apportionment of abundances among individuals, where abundance is ranked from high to low (Valbuena et al., 2013). In the case study, the evenness was evaluated using the concave variant of Lorenz curve (1905) and the derived Gini coefficient (Gini, 1912) applied to the distribution of the basal area (Brand and Magnussen, 1988; Weiner and Solbrig, 1984; Ozdemir and Donoghue, 2013; Bourdier et al., 2016). Among tree attributes, we selected basal area because is derived from diameter at breast height which is the simplest and most precise tree attribute, even easily available in forestry practice. Confidence intervals for the population Gini coefficient can be obtained by a bootstrapping procedure. Two samples have similar Gini coefficents if the confidence interval around the difference of means intersects zero (Dixon et al., 1987). The Lorenz curve is attributable to intrinsic diversity ordering methods (Patil and Taillie, 1979; Lambshead et al., 1981), that are proven to be reliable procedure for ensuring that two stands are comparable (Liu et al., 2007). The Lorenz curve is a monotonic increasing function thus if two (or more) stands have distinct intrinsic diversity ordering, the resulting Lorenz curves will not overlap. Conversely, if Lorenz curves intersect there would be no intrinsic diversity ordering among them (Valbuena et al., 2012). In the same way, when comparing observed Lorenz curves with known theoretical distribution curves (e.g. uniform), it is possible to establish whether the distributions are intrinsically different (Valbuena, 2015). Since the analytic assessment of differences in intrinsic ordering is not easy, because it implies the comparison of the entire profile, a visual assessment by means of quantile–quantile plot was adopted (Swindle et al., 1987).

3.4. Experimental design

The adopted experimental design is randomised blocks, with three groups replicated twice. Each plot has an area of 2500 m^2 and is surrounded by a 10-m-wide buffer zone. To avoid the edge effect, the buffer zones are treated as inside the experimental area.

In 1996 before the thinning, all the individuals were callipered at 1.3 m and a series of tree heigths per plot were measured. Immediately after the thinning, in each plot all the individuals were numbered, identified by species, and again callipered at 1.3 m. The callipering was repeated in 2006 and 2016. The trees felled with thinning together with a further supplementary sample were used for the construction of the height and volume models (La Marca et al., 2002). These models were used for volume estimation.

The assessment of any differences in the population parameters was undertaken by ANOVA based on non-homogeneous variances between the comparison groups (Welch, 1951), and post-hoc non-parametric analysis (Games and Howell, 1976) to take the unbalanced sample size into account. Data management and statistical analyses were performed using the software “R” (R Core Team, 2017) together with the “ineq” package (Zeileis, 2014).

Table 1
Stand parameters at 1996 before thinning.

Year	Thesis	N	G	V	QMD	H	Hdom
1996	A (average plot 1–4)	3940	34.52	270.7	10.6	11.3	18.7
	B (average plot 2–5)	3940	35.75	277.5	10.7	11.4	18.7
	C (average plot 3–6)	3834	34.53	264.3	10.6	12.6	18.8

N: number of trees (ha^{-1}); G: basal area (m^2 ha^{-1}); V: standing volume (m^3 ha^{-1}); QMD: quadratic mean diameter (cm); H: total height (m); Hdom: height of dominant trees (m).

Table 2
Thinning: removal (a), intensity and type (b).

(a) Thesis	N	G	V	QMD
A	3336	17.60	126.3	8.2
B	3130	14.61	104.6	7.7

(b) Thesis	rN	rG	rN/rG
A	85%	50%	1.7
B	80%	41%	1.9

N: number of trees (ha^{-1}); G: basal area (m^2 ha^{-1}); V: standing volume (m^3 ha^{-1}); QMD: quadratic mean diameter (cm).

4. Results

4.1. Thinning

Population parameters per group in 1996 before thinning are shown in Table 1. The absence of significant differences among the groups allowed the experimentation to continue (La Marca et al., 2002). Extent, intensity and type of thinning are shown in Table 2. Finally, Table 3 shows the population parameters per group after the thinning in 1996, 2006 and 2016. The harvested timber was sold as firewood, producing positive revenues for both thinned-out groups. More details on the quantities of firewood, the methods of logging, time working and revenues earned are available in La Marca et al. (2002).

The thinning intensity was strong because, in terms of the basal area, the removal intensity varied from 41% of group B to 50% of group A (Table 2b). The ratio r_N/r_G was equal to 1.7 for group A and 1.9 for group B (Table 2b). As such, under both groups, the thinning type was from below: removal involved a large number of individuals of not very different sizes that were small, on average.

4.2. Number of trees

The number of individuals from 1996 (after thinning) to 2016 for the three groups under comparison is shown in Table 3. Fig. 1a shows that from 1996 to 2016, the number of individuals varied little in the thinned-out groups (A and B), while in the non-thinned-out group (C) it drastically decreased. In 20 years, group A lost 4.3% of the individuals, group B lost 9.6%, and group C lost 73.4% (Table 4b). Among the thinned-out groups, the mortality rate on a ten-year basis increased more in B, going from 1.2% in 1996–2006 to 8.5% in 2006–2016, while in group A, it increased by only one percentage point (Table 4a). The ten-year mortality rate in group C went from 42.3% in 1996–2006 to 54% in 2006–2016, with an increase of more than 11 percentage points. On a twenty-year basis in all the groups, the mortality of the other tree species is ever higher than that of the Turkey oak, but with different proportions: in 20 years, groupA has lost only 8.1% of the other tree species, while group B has lost 18.6% and group C 89.6% (Table 4b).

Table 3
Stand parameters at 1996 (soon after thinning), 2006 and 2016.

Year	Thesis	Ce%	As%	N	G	V	QMD
1996	A	87.7	12.3	604 (0)	17.45 (1.05)	144.4 (10.5)	18.8 (1.3)
	B	85.4	14.6	810 (20)	21.14 (0.44)	172.9 (4.0)	18.7 (2.1)
	C	37	63	3834 (246)	34.53 (1.41)	264.3 (18.2)	10.6 (0.7)
2006	A	88.2	11.8	594 (3)	23.45 (1.07)	202.5 (10.3)	22.3 (0.6)
	B	86.3	13.8	800 (6)	27.38 (0.33)	231.9 (2.7)	21.5 (2.8)
	C	51.2	48.8	2212 (91)	35.74 (1.02)	289.3 (10.0)	17.8 (0.5)
2016	A	88.2	11.8	578 (8)	29.18 (1.27)	260.0 (13.0)	25.3 (0.4)
	B	87.1	12.9	732 (11)	33.19 (0.02)	307.5 (0.3)	24.8 (0.9)
	C	75.2	24.8	1018 (110)	35.08 (0.27)	300.9 (0.7)	21.0 (1.1)

Ce: Turkey oak; As: other tree specie; N: number of trees (ha^{-1}); G: basal area (m^2 ha^{-1}); V: standing volume (m^3 ha^{-1}); QMD: quadratic mean diameter (cm). Standard deviation in brackets.

4.3. Basal area (G) and quadratic mean diameter (QMD)

The values of G and QMD from 1996 (after thinning) to 2016 for the three groups compared are shown in Table 3. In the 20 years after thinning, the G and QMD performance in the thinned-out groups A and B have always been on the rise (Fig. 1b–c). The difference in G between the two thinned-out groups in terms of individual mean basal area is not significant, whereas the individual mean basal area in groups A and B is significantly greater than that of group C for the entire period observed (Table 5; Table 6). In twenty years, G in group A increased by 67.3% and in group B by 57% (Table 4b). The variation in the basal area (Δ_G) of group A is higher than that of group B also in the two decades, with a larger deviation in the 1996–2006 period compared to the 2006–2016 period (Table 4a). From 1996 to 2006 to 2006–2016, Δ_G was decreasing in group A, while it was slightly on the rise in group B (Table 4a). The situation in the non-thinned-out group C is very different: from 1996 to 2016, the basal area increased by only 1.6% (Table 4b); on a ten-year basis, it increased by 3.5% between 1996 and 2006 and decreased by 1.8% between 2006 and 2016 (Table 4a).

The variation in QMD (Δ_{QMD}) on a twenty-year basis in group A was slightly higher than group B (Table 4b). On a ten-year basis in the 1996–2006 period, Δ_{QMD} increased more in group A (18.8%) than in group B (14.6%), while in the 2006–2016 period, Δ_{QMD} increased more in group B (15.6%) than in group A (13.7%) (Table 4a). In group C, there was the greatest variation in Δ_{QMD}. On a twenty-year basis, it was equal to 98.6% (Table 4b), but most of the increase occurred in the 1996–2006 period, when Δ_{QMD} of group C increased by 68.8% (Table 4a). The broad difference between Δ_{QMD} of group C and groups A and B is due to the effect of the high mortality that occurred in group C,

Table 4
Periodic variation of stand parameters.

(a)

Period	Thesis	$\Delta\%_{Ce}$	$\Delta\%_{As}$	$\Delta\%_{N}$	$\Delta\%_{G}$	$\Delta\%_{QMD}$	$\Delta\%_{H}$	$\Delta\%_{V}$
1996–2006	A	−1.1	−5.4	−1.7	34.4	18.8	6.7	40.2
	B	−0.3	−6.8	−1.2	29.5	14.6	4.5	34.1
	C	−20.2	−55.3	−42.3	3.5	68.8	27.8	9.5
2006–2016	A	−2.7	−2.7	−2.7	24.4	13.7	2.8	28.4
	B	−6.4	−12.7	−8.5	21.2	15.6	3.3	32.6
	C	−32.4	−76.6	−54.0	−1.8	17.7	5.0	4.0

(b)

Period	Thesis	$\Delta\%_{Ce}$	$\Delta\%_{As}$	$\Delta\%_{N}$	$\Delta\%_{G}$	$\Delta\%_{QMD}$	$\Delta\%_{H}$	$\Delta\%_{V}$
1996–2016	A	−3.8	−8.1	−4.3	67.3	34.7	9.7	80.1
	B	−6.6	−18.6	−9.6	57.0	32.5	8.0	77.8
	C	−46.0	−89.6	−73.4	1.6	98.6	34.2	13.8

Δ%: percentage variation; Ce: Turkey oak; As: other tree specie; N: number of trees; G: basal area; QMD: quadratic mean diameter; H: total height; V: standing volume.

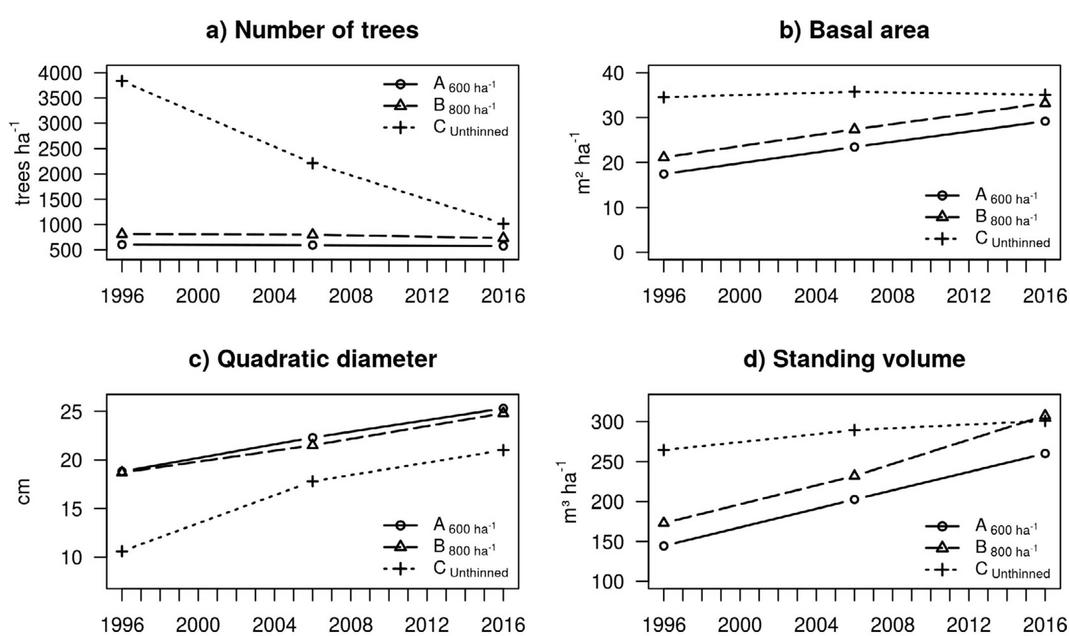

Fig. 1. Stand parameters at year 1996 (after thinning), 2006 and 2016.

Table 5
Individual basal area and volume: averages and variances by thesis.

Year	Thesis	n	*Basal area*[a]		*Volume*[b]	
			Mean	Variance	Mean	Variance
1996	A	300	278.9	4.7	232.08	42.67
	B	400	276.9	3.9	228.72	35.65
	C	1917	104.6	2.4	69.24	17.11
2006	A	295	390.5	7.1	336.87	71.81
	B	397	364.9	5.5	310.94	53.22
	C	669	250.0	4.3	205.39	39.04
2016	A	289	504.8	10.7	449.82	113.67
	B	366	483.4	8.1	426.24	84.28
	C	509	344.7	6.8	294.35	66.04

[a] cm^2.
[b] dm^3.

which struck small individuals in the dominated layer above all.

4.4. Standing volume (V)

The performance of V from 1996 to 2016 for the three groups under comparison is shown in Table 3. The volume gap in 1996 between the thinned-out groups (A and B) and the control group (C) is due to thinning (Fig. 1d). In fact, immediately after the thinning, V of A and B is respectively equal to 54.6% and 65.4% of the volume of C (Table 3). As with G, the difference in V between the two thinned-out groups is also not significant in terms of average individual volume for the observed years, while the average individual volume of groups A and B is significantly greater than that of group C for the entire period observed (Table 5; ANOVA results not shown).

In twenty years, the variation of V (Δ_V) was equal to 80% in group A and 77.8% in group B, while in group C it was 13.8% (Table 4b). On a ten-year basis (Table 4a), in the 1996–2006 period, group A achieved a volume increase equal to 40.2%, while in group B, Δ_V was 34.1% and was 9.5% in group C. In the 2006–2016 decade, Δ_V in group A was equal to 28.4%, in group B it was equal to 32.6%, and in group C, it was equal to 4%. In all the groups, Δ_V on a ten-year basis was decreasing between the two periods, but with different proportions: in group A, it fell by 11.8 percentage points, in group B by 1.5 points and in group C by 5.5 points.

4.5. Structural complexity

From a structural perspective, thinning significantly changed the distribution of the basal area in groups A and B: in 1996 immediately after the thinning, the Lorenz curves of groups A and B were closer to the diagonal than to group C (Fig. 2a). The Gini coefficients of groups A and B were about half of that in group C and pairwise comparisons yield significant differences (Table 7a-b). The Lorenz curve for group C in 1996 is far from the diagonal and does not intersect the profile of the generic uniform curve while the Lorenz curves of A and B do (Fig. 2a). In even aged stands, a disproportion like that of group C can occur when there is a two-layer structure, of which one is clearly dominated. In fact, in 1996, group C featured a crowded dominated layer composed of individuals of other tree species mostly small-sized. The quantile–-quantile comparison of Lorenz curves (Fig. 3) shows profiles of groups A and B intersecting the diagonal, meaning that there is no evidence of different intrinsic ordering when compared to the profile of a generic uniform. Conversely, the Lorenz curve of group C (Fig. 3) does not intersect the diagonal so there is evidence of different intrinsic ordering when compared to the profile of a generic uniform.

Considering the proportion of basal area above QMD (Gove, 2004), after thinning the individuals above QMD in groups A and B accumulate 67% and 62% of basal area, respectively (Table 8). In group C the individuals above QMD accumulate 92% of basal area (Table 8).

In 2006, the Lorenz curves of groups A and B are almost indistinguishable and the Lorenz curve of group C is much closer to both

Table 6
Analysis of variance and post hoc comparisons.

Basal area							
1996	*Oneway Anova for y = basal area and x = thesis (groups: A, B, C)*						
		SS	Df	MS	F	p-value	
	Between groups (error + effect)	0.15	2	0.07	247.74	< .001	
	Within groups (error only)	0.68	2302	0			
	Post hoc test: Games-Howell						
		diff	ci.lo	ci.hi	t	df	p-value
	B-A	0	0	0	0.13	612.37	0.991
	C-A	−0.02	−0.02	−0.01	13.37	358.58	< .001
	C-B	−0.02	−0.02	−0.01	16.23	526.84	< .001
2006	*Oneway Anova for y = basal area and x = thesis (groups: A, B, C)*						
		SS	Df	MS	F	p-value	
	Between groups (error + effect)	0.05	2	0.03	52.49	< .001	
	Within groups (error only)	0.71	1358	0			
	Post hoc test: Games-Howell						
		diff	ci.lo	ci.hi	t	df	p-value
	B-A	0	−0.01	0	1.32	583.8	0.386
	C-A	−0.01	−0.02	−0.01	8.04	454.82	< .001
	C-B	−0.01	−0.01	−0.01	8.09	750.47	< .001
2016	*Oneway Anova for y = basal area and x = thesis (groups: A, B, C)*						
		SS	Df	MS	F	p-value	
	Between groups (error + effect)	0.06	2	0.03	38.89	< .001	
	Within groups (error only)	0.95	1161	0			
	Post hoc test: Games-Howell						
		diff	ci.lo	ci.hi	t	df	p-value
	B-A	0	−0.01	0	0.88	574.37	0.654
	C-A	−0.02	−0.02	−0.01	7.14	497.17	< .001
	C-B	−0.01	−0.02	−0.01	7.36	743.32	< .001

SS: sum of squares; Df and df: degrees of freedom; MS: mean of squares; F: test statistic; diff: difference of means; ci.lo and ci.hi: lower and upper 90% confidence intervals, respectively; t: test statistic.

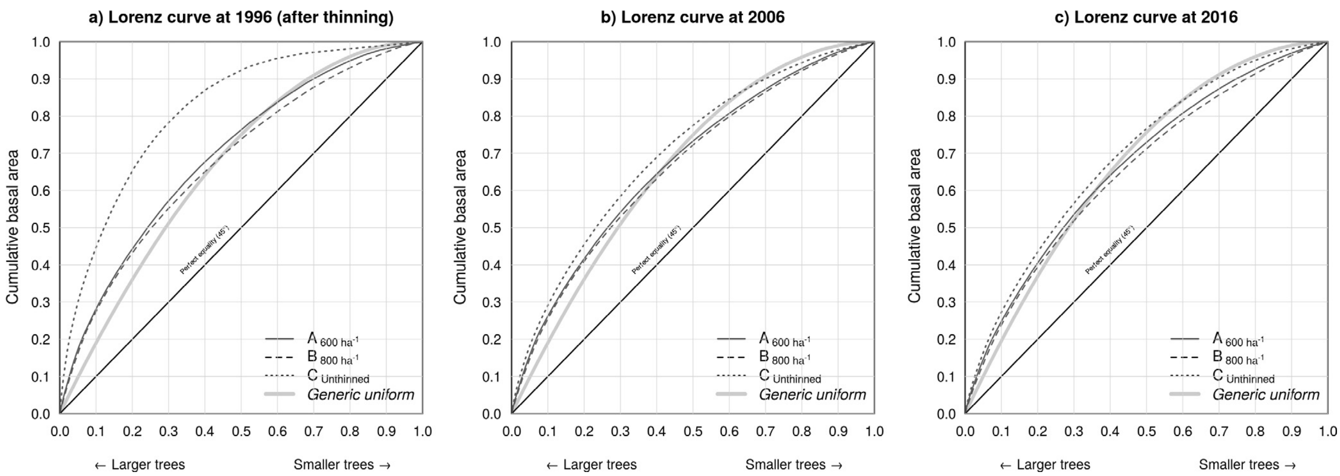

Fig. 2. Lorenz curve of distribution of basal area. On the x-axis the relative cumulative distribution of individuals ranked from larger to smaller; on the y-axis the relative cumulative distribution of basal area.

Table 7
Gini coefficient: means and pairwise comparisons.

(a) Year	Thesis	Gini	ci.low	ci.high
1996	A	0.39	0.37	0.40
	B	0.35	0.34	0.37
	C	0.63	0.62	0.65
2006	A	0.34	0.33	0.36
	B	0.33	0.31	0.34
	C	0.40	0.39	0.41
2016	A	0.33	0.32	0.35
	B	0.31	0.29	0.32
	C	0.38	0.37	0.40

(b) *Post hoc test: Games-Howell*		t	df	p-value
1996	B-A	92.14	1874	< .0001
	C-A	358.75	1696	< .0001
	C-B	542.55	1932	< .0001
2006	B-A	51.37	1870	< .0001
	C-A	183.78	1859	< .0001
	C-B	274.36	1998	< .0001
2016	B-A	88.98	1878	< .0001
	C-A	167.59	1986	< .0001
	C-B	282.75	1937	< .0001

ci.lo and ci.hi: lower and upper 90% confidence intervals, respectively; t: test statistic.; df: degrees of freddom.

(Fig. 2b). The Lorenz curves of all groups intersect the generic uniform curve and therefore are not distinguishable from the latter. The Gini coefficients of all groups decreasead and the greatest reduction occurred in group C. However pairwise comparisons yield significant differences (Table 7a-b). The quantile–quantile comparison of Lorenz curves (Fig. 3) shows profiles of groups A, B, and C intersecting the diagonal, meaning that there is no evidence of different intrinsic ordering when compared to the profile of a generic uniform. The mortality of group C in the 1996–2006 period mostly eliminated the small individuals of the dominated layer, making the proportions of basal area more balanced. In the groups A, B, and C, the individuals above QMD accumulate 60%, 63% and 62% of basal area, respectively (Table 8).

In 2016, the Lorenz curves of all the groups are still intrinsically indistinguishable from the generic uniform distribution curve (Fig. 2c). The quantile–quantile comparison of Lorenz curves (Fig. 3) shows profiles of all group intersecting the diagonal, meaning that there is no evidence of different intrinsic ordering when compared to the profile of a generic uniform. The Gini coefficients of all groups slightly decreasead from 2006 but pairwise comparisons yield still significant differences (Table 7a-b). In the groups A, B, and C, the individuals above QMD accumaulate 61%, 60%, and 69% of basal area, respectively.

5. Discussion

The adopted thinning intensities and the selection criteria for individuals ensured the demographic stability of the populations, in which the mortality rate remained low for the entire observation period. Even tree species other than Turkey oak survived well, albeit with some differences between groups with different release densities. On the contrary, in the group in which no intervention were carried out, in the period observed, there was a significant self-thinning process that constantly kept the mortality rate high, in particular for tree species other than Turkey oaks. Therefore, from a forestry perspective, the

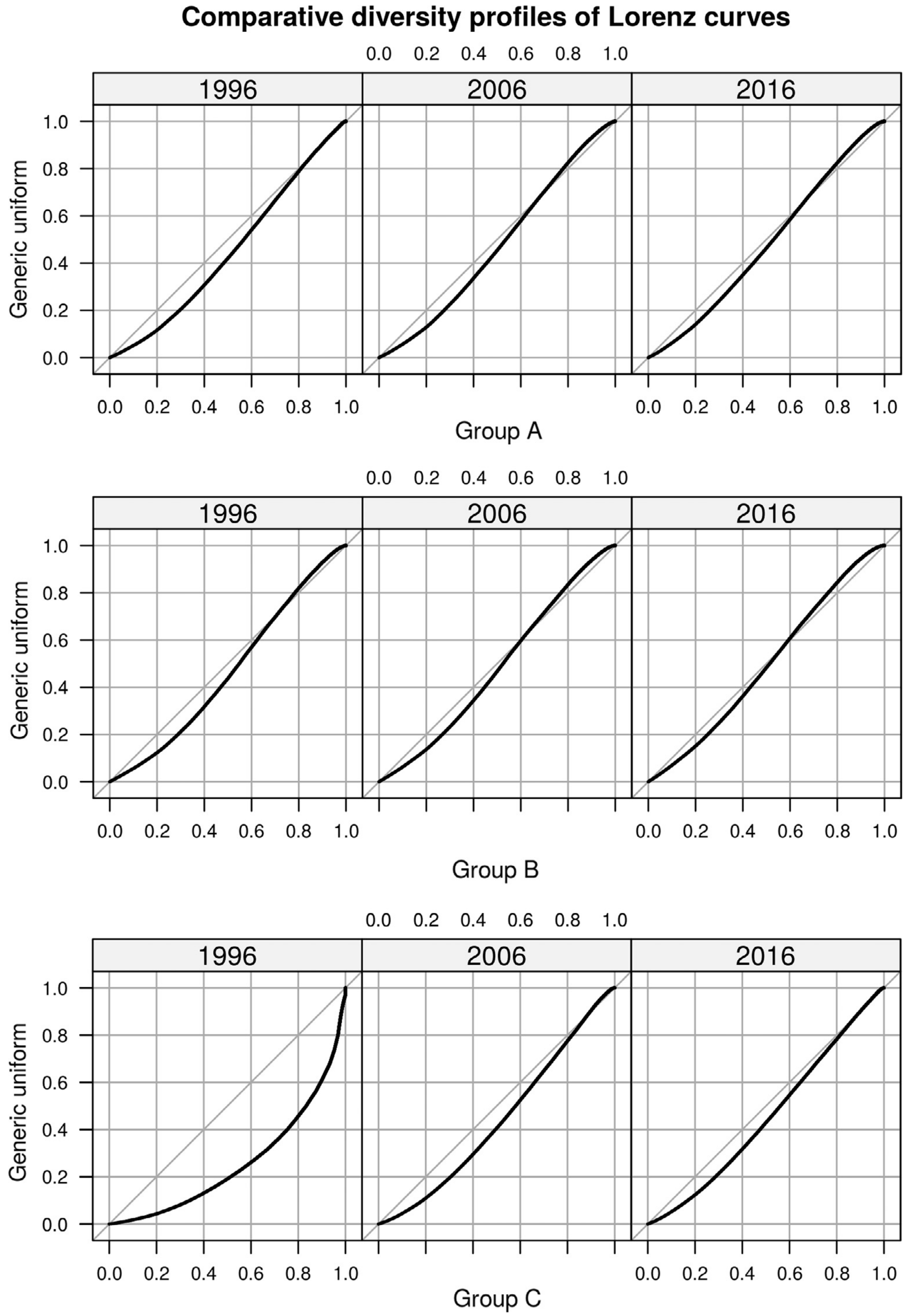

Fig. 3. Quantile-quantile plot of empirical Lorenz curves and generic uniform.

experimental cutting brought forward and rationalised what natural selection did in 20 years and in a completely random way.

In terms of growth, the experimental cuttings yielded good results: in both of the thinned-out groups, the growth of the basal area was sustained for the entire observed period, without significant differences between the two release densities. In relative terms, group A grew more than B in the first ten years and less in the following decade, in which group B grew more. Group B reacted less energetically in the first decade and declined slightly in the second decade, but over the twenty years, it retained fairly constant growth. After twenty years, in group B there is the same standing volume as in group C, while group A has a volume equal to nine-tenths of group C. In twenty years, group B recovered the entire volume removed through cutting, while group A recovered 91.5%. Moreover in the thinned-out groups, the standing volume is distributed among a smaller number of individuals that are of a larger size on average and have phenotypic characteristics and vigour, which are better on average due to having been selected by the silviculturist.

A diversity index should be considered as a brief summary of an aspect of biodiversity and different indices summarise slightly different aspects. Lorenz curve tells where distributional inequality of individuals weighted on abundance of basal area occour, and the derived

Table 8
Proportions of number of trees and basal area above quadratic mean diameter.

Year	Group	QMD	N > QMD	G > QMD
1996	A	18.8	39%	67%
	B	18.7	37%	62%
	C	10.6	53%	92%
2006	A	22.3	36%	60%
	B	21.5	40%	63%
	C	17.8	38%	67%
2016	A	25.3	37%	61%
	B	24.8	38%	60%
	C	21	39%	69%

QMD: quadratic mean diameter; N: number of trees; G: basal area.

Gini coefficient summarize the magnitude of this inequality. The assessment of structural complexity in terms of size diversity does not take into account the spatial component of the forest structure (Zenner and Hibb, 2000); however, a complete assessment of the spatial component would require the collection of specific data, almost never available in forest management practice (Pretzsch, 1997). The Lorenz curve coupled with comparison of differences in intrinsic ordering are suitable tools for the visual representation and comparison of the horizontal structures of forest populations (Bachofen and Zingg, 2001) because they show where the distributions are different (Weiner and Solbrig, 1984; Lexerød and Eid, 2006; Valbuena et al., 2012). Moreover, when a theoretical curve of reference (e.g., uniform) is superimposed on the empirical curves, it is possible to assess whether the profiles have different intrinsic ordering or not (Swindle et al.. 1987; Valbuena, 2015).

Thinning significantly modified the dimensional structure in groups A and B, making it not distinguishable from a theoretical uniform distribution in terms of basal area evenness (Figs. 2a and 3a; Fig. 3). Conversely, in 1996 the group C had a high degree of inequality either in terms of basal area evenness (Figs. 2a and 3a; Fig. 3). Twenty years after thinning (2016), the Lorenz curves and diversity profiles of all the groups are indistinguishable from the theoretical uniform distribution. The experimental thinnings modified the dimensional structure, making it more uniform and physiognomically similar to that of a one-layer high forest. In the non-thinned-out group, natural evolution operated in much the same way, but over longer times and with selective processes occurring by chance.

6. Conclusions

Conversion into transitional high forest through preparatory thinning is a practicable and beneficial option in abandoned coppices of Turkey oak, such as those under experimentation. The existence of a protected area, the responsiveness of the Turkey oak, the adequate condition of the site and the morphology of the places are elements that contribute positively to conversion.

The experimentation, conducted in abandoned coppices with a prevalence of Turkey oak in the area of “Bosco di Manfredonia”, highlights how populations treated with low release densities generally have a natural mortality that is still low 20 years later. Even species other than Turkey oaks, numerically very small in areas of natural evolution, survived to a large extent and have a good chance of continuing to do so. The hypothesis of reducing density so as to convert in a single intervention, by way of which an agametic transitional high forest is shaped into an almost permanent compositional and structural arrangement, is still valid.

The experimental cuttings as made are anomalous with respect to the requirements of local laws, which require higher release densities and removal not exceeding 25% of the total basal area. Despite this, they met the requirements of ecological improvement, protection of biodiversity and social and economic sustainability. Also from the perspective of mitigating the effects of greenhouse gases, experimental cuttings as made are sustainable because they allow a saving of fossil fuels and, in a relatively short time, allow the re-storage of the Carbon removed by cutting. In the Mediterranean environment, where the risk of fire is high, the removal strategy is preferable to the accumulation strategy, given the high risk of loss of biomass. Moreover, it is true that the areas left to natural evolution maintain a high biomass per hectare over time, but in doing so they have a low Carbon storage capacity, acting more often as a *source* of Carbon, due to the high and constant mortality, rather than as a *sink*.

Understanding the implications of applied forestry practices requires a long-term perspective and tools for objective assessment on a quantitative basis. For the assessment of the structural evolution of populations under conversion from coppice into transitional high forest or left to natural evolution, the Lorenz curve and related Gini coefficent together with profile comparisons are effective tools. Using information normally available in forestry practice, such as the diameter of individuals and the basal area (or volume), it is possible to quantify the immediate and long-term effects of different management systems.

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