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Research Article

Tree Community Ordering by Diversity Profiles: an Application to Chestnut Coppices

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Summary

The ecological and economical relevance of sweet chestnut (*Castanea sativa* Mill.) has long been related to its widespread geographical distribution and multipurpose product potential. In Italy, chestnut management represents a paradigmatic example of the potential conflict between landowner targets and tree species diversity conservation. Distinctively, the relationships between silvicultural treatment and tree species diversity of chestnut coppices are here investigated by means of diversity profiles to assess tree diversity of six stands in Central Italy. The stands were purposively selected in such a way to be characterized by the same site conditions but with different silvicultural features (age, number of thinning). Plot sampling was performed across the stands and their tree diversity was compared and ordered by means of intrinsic diversity profiles estimated from the sample data. The achieved results suggest alternative suitable options for managing chestnut coppice stands in order to enhance tree biodiversity while maintaining timber production.

Keywords: Forest management; Biodiversity; Plot sampling; Partial ordering; Rotation length

Introduction

Biodiversity monitoring is essential to support management decisions in maintaining multiple forest ecosystem functions at long term. The monitoring and assessment of forest biodiversity are strictly connected to sustainable management (see Criterion 4, [1]). Under the ecosystem approach endorsed by the United nations Convention on Biological Diversity [2], forest monitoring should not be restricted at the assessment of the traditionally measured features related to wood production; it should also assess composition, structure and function of forest ecosystems to provide a better understanding of the roles of the components of biological diversity for supporting the provision of multiple forest ecosystem services [3]. Distinctively, forest diversity is increasingly threatened with at least one tree species at risk in each country of the world [4]. Thus, increasing efforts to implement effective monitoring of forest tree diversity are required.

A paradigmatic example of the potential conflict between landowner targets and tree species diversity conservation is given by the sweet chestnut (*Castanea sativa* Mill.) stands. Its wide geographical distribution in Europe can be understood by considering the complexity of the ecological refugia during the last glaciation, the subsequent natural processes and changing environmental conditions (climate change, natural dispersal, interspecific competition) as well as human influence [5]. Humans have radically modified and controlled the distribution of chestnut over thousands of years and have long known how to manage it in profitable and diversified ways (e.g. by

coppices or orchards) to produce fruit, timber and other goods, mainly by simplifying natural forest stand composition [6].

This is of particular relevance in Italy, where chestnut forests cover an area of 0.8 million hectares [7], 70% are managed as coppices with standards and the remaining 30% as orchards for fruit production. In the early fifties of the last century, the relationship between the two types of cultivation system was reversed compared to now and it has been changing over time following the socio-economic changes which affected the rural areas and the spread of two destructive fungi causing, respectively, the chestnut blight (*Cryphonectria parasitica*) and the ink disease (*Phytophthora cambivora*) [8]. The domestic production of chestnut wood barely exceeds 0.9 Mm^3 per year, while the current annual increment of chestnut stands is 5 Mm^3 [7], meaning that the harvested volume might be significantly increased as claimed by the wood-chain stakeholders.

The wide spread ness of chestnut coppices is justified by landowner benefits: fast growth, short rotation, stumps vitality preserved by periodic clear cut, resilience to stress factors like forest fires and diseases. On the other hand, coppices have less recreational and touristic attractiveness than high stands, due to their higher density and smaller stem size, which make harder the public fruition. Coppice clear cuts, which are most often larger than 5 hectares, may involve visual and ecological impacts on the landscape, especially in the case of the widest cuts. On the other hand, coppicing may favor a wide range of wildlife, e.g. butterfly and bird species associated with early serial stages before the canopy closes [9]. Often brambles grow around the stools, encouraging insects or various small mammals that can use the brambles as protection from larger predators [10]. Whenever left in the stands, woodpiles may also favor dead-wood associated insects [11]. The size of cuts, their temporal distribution, and severity of disturbance are the key factors that account for changes in species composition and diversity.

The potential naturalness value of chestnut stands has been recognized by the European Community Natura 2000 network [12], which has declared both the chestnut-dominated forests and the long-established chestnut plantations with semi-natural undergrowth relevant habitats (9260: *Castanea sativa* woods) for biodiversity conservation [13]. On the other hand, in Italy concrete actions for preserving stand-scale biodiversity of chestnut coppices are often neglected by forest managers, at least at a certain extent, even when stands are located within landscapes of recognized naturalistic value and/or designated for conservation purposes.

Recently, [14] have examined the relationships between forest management and biodiversity. The authors point out that the main concerns of a wise management should be about structures, stand

functionality and dynamism. Nevertheless, in spite of the importance ascribed to the maintenance of forest biodiversity, experimental investigations examining the influence of silvicultural treatments on biodiversity and the relationship between tree diversity and other forest attributes are still limited (e.g. [15-20]).

The requirement of improving both diversity and yield and wood quality from chestnut coppices leads to the search for innovative management models. That requires efficient tools for assessing the potential of chestnut coppice stands with respect to biodiversity purposes. Accordingly, a relevant issue concerns the easy and reliable assessment of biodiversity, at least in term of tree species diversity. Intrinsic diversity profiles are useful tools to this end [21], as they are capable to overcome the shortcomings of scalar diversity indexes, such as Shannon and Simpson indexes (e.g. [22].)

The relationships between silvicultural treatment and tree species diversity of chestnut coppices are here investigated by means of diversity profiles to assess tree diversity of six stands in Central Italy, as a case study. The stands were purposively selected in such a way to be characterized by the same site conditions but with different silvicultural features (age and number of thinning). Plot sampling was performed across the stands and their tree diversity was compared and ordered by means of intrinsic diversity profiles estimated from sample data.

The main objectives of the paper are: a) to assess tree diversity in the investigated chestnut coppices using diversity profiles; b) to conceive alternative silviculture models in order to couple tree diversity targets with wood production.

Study area

The study was carried out on chestnut coppice stands located on the Sabatini Mountains (Latium Region, Central Italy), within the municipalities of Bracciano (RM), Oriolo Romano (VT) and Sutri (VT). The investigated stands belong to private landowners (Figure 1). The study area is settled within a landscape of high conservation value, included both within the Regional Natural Park of Bracciano-Martignano and the European Commission Natura 2000 site network.
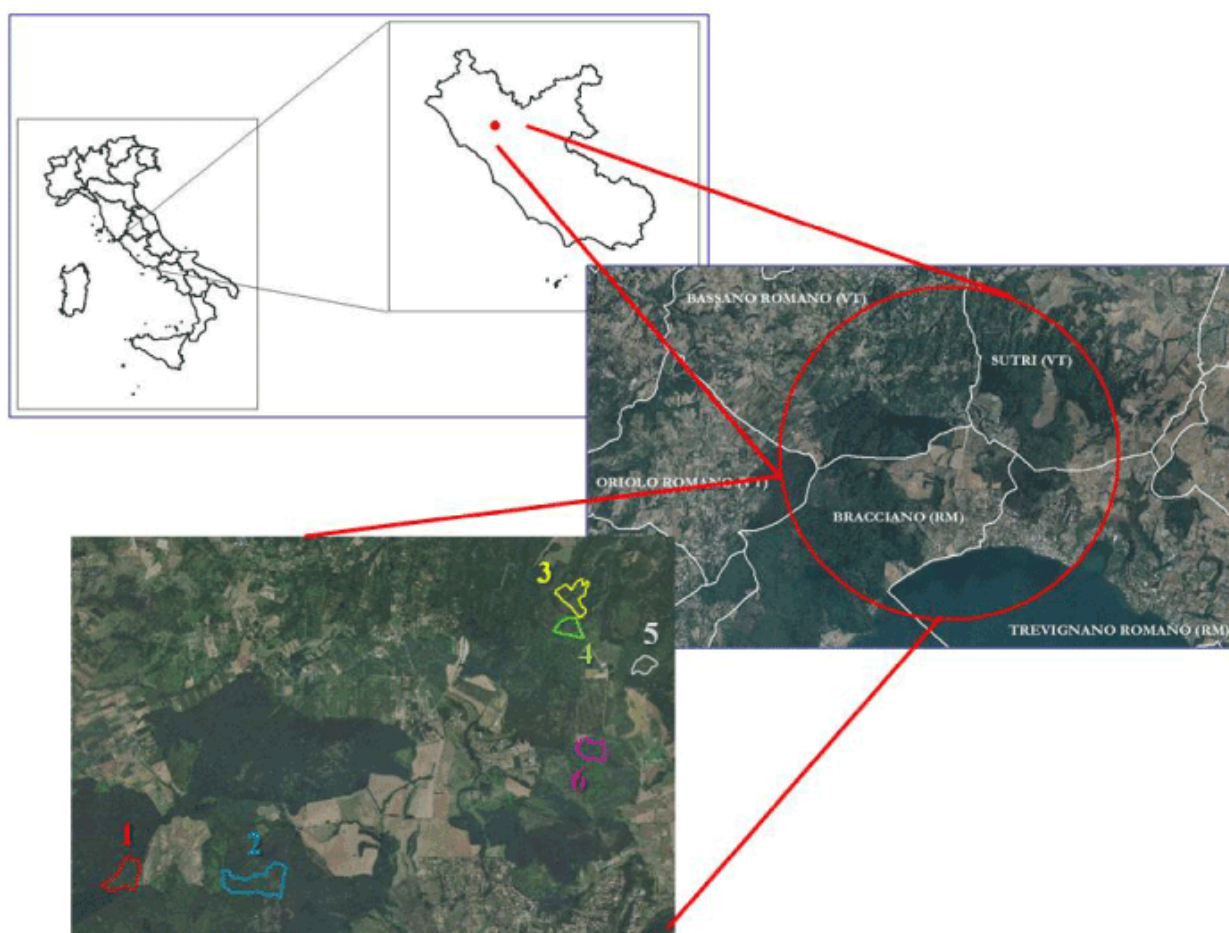

Figure 1: Study area and location of the surveyed chestnut coppice stands.

Chestnut coppices are the main forest type present, prevalently located around the volcanic lake of Bracciano between 400 m and 950 m a.s.l.. The coppice area is rather homogeneous in terms of vegetation (*Doronico-Fagion* phytosociological alliance, with ingression of acidophile elements of the *Quercetalia robori-petraeae* phytosociological order), soils (pyroclastic soils, ando soils and

volcanic ashes) and bioclimate (mesomediterranean sub-humid). No major natural disturbances such as forest fires, hurricanes and floods were recorded since many years. On the other hand, due to surrounding settlements, all the forest stands support low human disturbances, like mushroom picking, fodder and litter collection and very moderate grazing.

Even if located within landscapes of recognized conservation value, the current forest management of the chestnut stands is based on short rotation (common rotation is 14-18 years with a unique thinning, usually at ages of 12-13 years, not always carried out) in monospecific even-aged stands clear cutted on large areas (around 10 hectares per cut, on average), with the purpose to profitably yield valuable wood assortments (poles and beams).

Materials and methods

Coppice stands were selected within the study area at various ages (ranging from 6 to 22 years) and characterized by a different number of thinnings carried out (from 0 to 2) (Table 1). The boundaries of the stands were drawn from the vectorial information provided by the local forest management plans.

Stand ID	Area [ha]	Altitude [m a.s.l.]	Slope [%]	Exposure	Age [years]	Thinnings	No. plots
1	13.3	430	15	NE	12	1	5
2	12.5	435	0	SW	20	0	7
3	10.6	420	5	S	22	1	7
4	9.1	425	10	E	22	2	7
5	8.1	425	5	SE	16	1	7
6	11.2	455	10	SE	5	0	7

Table 1: Characteristics of the surveyed chestnut coppice stands and number of sampling plots.
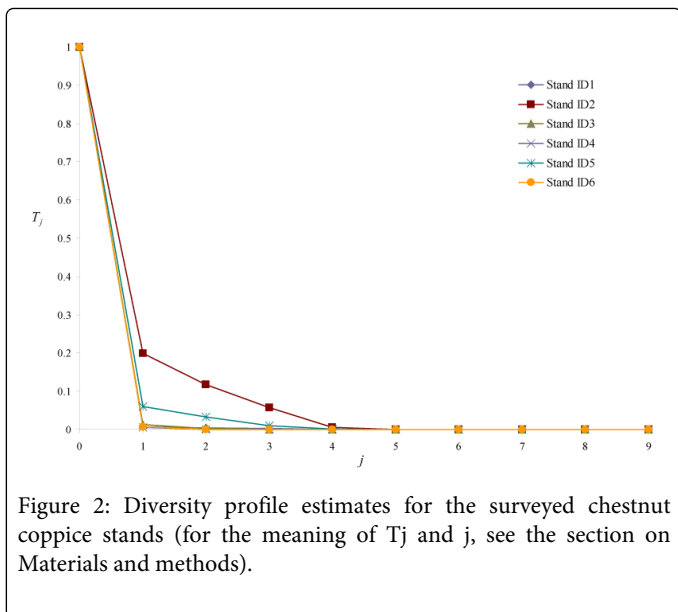
Seven circular sampling plots of 10 m radius were established in each stand, with the exception of the stand ID 1 where the number of plots was reduced to five because of its less variability concerning dendrometric features. The total number of sampling plots was 40. Plots were randomly located in each stand and reached in the field by means of GPS with submetric accuracy.

In each sampling plot the following attributes were measured: diameter at the breast height (dbh) of the live and dead sprouts and of the standards (minimum dbh threshold 5 cm); number of stumps; age of sprouts assessed by a tree corer on those with mean dbh. The following stand attributes were calculated from raw data: number of sprouts (live and dead) per hectare; number of standards per hectare; number of stumps per hectare; basal area of sprouts and standards.

Number of stems ranges from 1942 to 11445 n ha^{-1}, mainly composed by live sprouts (values from 1482 to 11014 n ha^{-1}, with a mean dbh ranging from 4 to 16 cm). The number of sprouts with dbh larger than 5 cm ranges from 1373 to 2765 n ha^{-1}. Total basal area has a minimum value of 17.54 m^2 ha^{-1} and a maximum value of 41.86 m^2 ha^{-1}. The standards range from 36 to 91 n ha^{-1}, with a mean dbh between 24 and 46 cm.

The assessment of tree diversity was performed on the basis of intrinsic diversity profiles. The populations of stems within the six stands were denoted by P1,…,P6. In accordance with [23], the concept of intrinsic diversity was used to compare these communities. A community was considered intrinsically more diverse than (in symbols,) if was obtained from by a finite sequence of the following operations: (i) transferring abundance from more to less abundant species without reversing the rank-order of the species; (ii) transferring abundances to a new species; (iii) relabeling species. Indeed, operations (i) and (ii) increased diversity, while diversity remained unchanged by operation (iii). In [23] it was proven that any intrinsic diversity ordering, if present, can be determined by means of intrinsic diversity profiles. The diversity profile of the l-th population was the plot of the pair , , where was the relative abundance of the K-j less abundant species and K was the number of species in the study area. Obviously, and . If the diversity profile of stand l was everywhere above that of stand h, than . On the other hand, if the two profiles intersected one or more times, no intrinsic ordering of the two stands was possible.

Because the intrinsic diversity profiles were unknown, they were estimated from sampling plots. To this purpose, the estimate of the abundance N_{kl} of the tree species k in the stand l was necessary for each species and each stand. The abundance estimate of a species in the stand was achieved adopting the Horvitz-Thompson criterion, which in the case of plot sampling reduced to $\hat{N}_{kl} = (A_l X_{kl})/(n_l a_l)$, where A_l was the size of the stand l, a_l was the size of each sampling plot and X_{kl} was the total number of stems of species k observed within the n_l plots [24]. From the abundance estimates of the K tree species, the abundance of the whole stand l was given $\hat{N}_l = \hat{N}_{1l} + \ldots + \hat{N}_{Kl}$, from which the relative abundance estimate of each species was $\hat{p}_{kl} = \hat{N}_{kl}/\hat{N}_l$. Following [21], estimates of the intrinsic diversity profiles of stands were obtained by means of $\hat{T}_{kl} = \hat{p}_{(k+1)l} + \ldots + \hat{p}_{(K)l}$ $(k = 1, \ldots, K-1)$, where $\hat{p}_{(1)l} \geq \ldots \geq \hat{p}_{(K)l}$ were the ranked relative abundance estimates. Figure 2 shows the estimates of intrinsic diversity profiles for the six observed stands. In order to rank the stands according to their diversity, hypotheses regarding equivalence, dominance or crossing of the profiles were assessed on the basis of the profile estimates [21]. All the $\binom{6}{2} = 15$ possible paired comparisons between couples of profiles were performed at a significance level $\alpha = 0.05$. Equivalence of two profiles was rejected and dominance was accepted if there was at least one significant positive (negative) difference between two profile components and no significant negative (positive) differences. Equivalence of two profiles was rejected and crossing was accepted if there is at least one significant positive difference and one significant negative difference (see [21] for more details).

Figure 2: Diversity profile estimates for the surveyed chestnut coppice stands (for the meaning of Tj and j, see the section on Materials and methods).

Results

The tree diversity comparisons are summarized in Figure 3. Stands in the upper boxes are more diverse than those in the lower boxes. Stand ID 2 (20 years old, no thinning) is the most diverse. Older stands (ID 2, ID 3 and ID 4) follow an order coinciding with the number of thinnings carried out (respectively, 0, 1 and 2).

Stands thinned only once (ID 5, ID 3, ID 1) are more diverse than the stand ID 4, the only one in which two thinnings were performed. The order among these stands is not related to the age, but to the temporal distance from thinning (four years, three years and one year for the stands ID 5, ID 3 and ID 1, respectively). Moreover, the order from upper boxes to lower ones follows the temporal distance from any silvicultural actions carried out (final cut or thinning): stand ID 2 was clearcutted twenty years ago; stands ID 1 and ID 4 only one year ago, but the two thinnings carried out in stand ID 4 cause cumulative impact on the stand.

The only exception is stand ID 6, which is the youngest among those analyzed (5 years old). That is not surprising because a final cut (coupled with the relatively very low number of standards usually released, i.e. 30-50 per hectare) causes a more intense disturbance than thinning. Light conditions obviously depend only on the number of standard trees retained after coppice harvesting [25] and on the previous density and vitality of the coppice layer [26]. Stand ID 6 (the youngest) and stand ID 4 (two thinnings) are the least diverse.

Figure 3: Partial diversity ordering of the surveyed chestnut coppice stands.
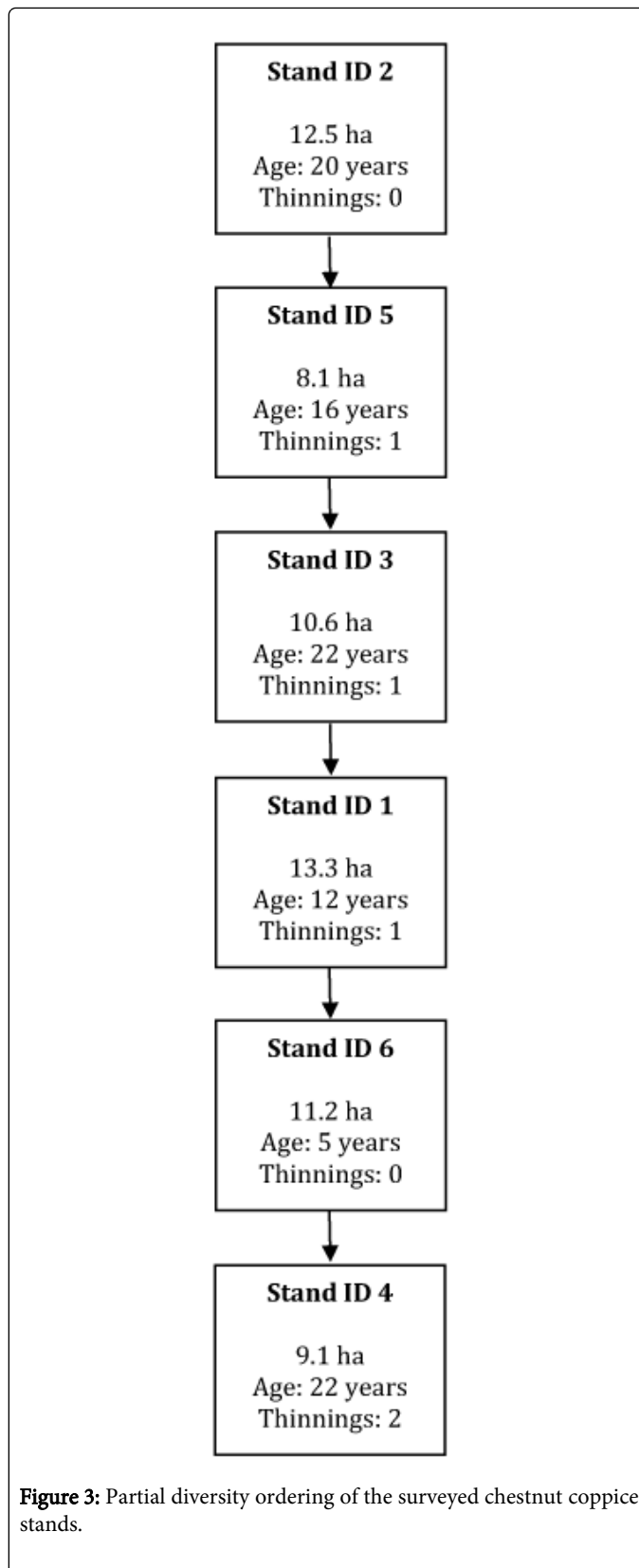
Discussion and conclusion

Forest ecosystems have the potential to harbor great levels of biological diversity, more than any other terrestrial ecosystem [27]. During the last years, the continuous loss of biodiversity has lead to focus onto ecosystem management aimed to nature conservation through the safeguarding of habitat and species. The maintaining and, if possible, the improving of biodiversity are now key-factors for a sustainable forest management [3]: this is mostly important in the framework of stand-level forest type approach [28-30].

Tree species diversity is one of the most important issues to assess the diversity of a forest community and allows to easily detect relationships with stand age and other characteristics of forest structure [31]. If significant, these relationships highlight increase or decrease of the number of the ecological niches available for the different species. Tree species show a particular inertia in the occupation and in the abandon of the niche, because they are more related to stand structure, which is controlled by management practices.

In the perspective of biodiversity conservation and sustainable land management, the forest mosaic should be analyzed, described and indexed both in qualitative and quantitative ways (e.g. [16]. A reasonable management goal is to maintain tree diversity in a managed stand comparable to the diversity in a natural or unmanaged stand of similar age and in comparable environmental conditions [32, 33]. Unfortunately, single diversity indexes (such as Simpson or Shannon indexes) are not suitable for comparing forest stands in that different indexes may lead to different rankings [22]. In order to avoid inconsistent rankings, stands have been compared adopting the concept of intrinsic diversity ordering and using diversity profiles.

Coppice age causes changes in the forest structure over the years as a result of forest growth. On the whole, habitat conditions such as spatial structure, structural density, shade and humidity and deadwood profiles change as the coppice ages from young to mature. These changes subsequently impact on forest biodiversity. Younger coppice have an high number of small stems and low amounts of dead wood, particularly of large-diameter logs or snags. Along the time, self-thinning process decreases the number of living sprouts per stump and generates small snags. However, the diversity profiles here exploited show that thinning effects are more relevant than age effects, and that thinnings decrease the presence of the other tree species.

The ordering gives a positive indication about stand evolution when stands are left undisturbed. The conditions for hosting high-quality species increase, a mesophilous micro-climate is created together with a soil with a longer water retention. The stands left undisturbed during the rotation cycle (i.e. without thinning) maintain higher diversity profiles.

Taking into account the sole richness of trees allows to evaluate diversity variations from a quantitative point of view (an higher richness maybe related to disturbance) but it could incorrectly characterized the real dynamic. In absence of management, chestnut stands tend to be replaced by homeostatic tree communities associated with various *Quercus* or *Fagus* species. When addressing diversity, it is important to take into account an integrated approach which also makes use of qualitative considerations.

Finally, it should be stressed that optimal rotation age is a topical issue for forest managers because there is a potential trade-off between the benefits of harvesting and biodiversity preservation, as already observed by [10]. The results were achieved from intrinsic diversity profiles allow to propose alternative management models for the sweet chestnut coppice stands in order to improve biodiversity as well as wood production. A 20-22 [25] years rotation without thinning can be considered a valid silvicultural model for coppices within areas designated for nature conservation because it allows a better quality evolution, at least in location with good fertility. This kind of management is not exceptional within the study area: it is applied in small landownerships where the limited stand area to be managed (usually less than 3 ha per landowner) may make the thinning unprofitable. However, the effectiveness of the management approach here devised is worth to deserve further investigation under various structural and silvicultural conditions.

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