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Technical notes

Tree-oriented silviculture for valuable timber production in mixed Turkey oak (*Quercus cerris* L.) coppices in Italy

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Abstract - Coppice management in Italy has traditionally focused on a single or few dominating tree species. Tree-oriented silviculture can represent an alternative management system to get high value timber production in mixed coppice forests. This study illustrates an application of the tree-oriented silvicultural approach in Turkey oak (*Quercus cerris* L.) coppice forests. The rationale behind the proposed silvicultural approach is to combine traditional coppicing and localized, single-tree practices to favor sporadic trees with valuable timber production. At this purpose, a limited number of target trees are selected and favored by localized thinning. In this study, the effectiveness of the proposed tree-oriented approach was compared with the customary coppice management by a financial evaluation. Results showed that the tree-oriented approach is a reliable silvicultural alternative for supporting valuable timber production in mixed oak coppice forests.

Keywords - single-tree selection, localized thinning, valuable tree, mixed forests, sporadic tree species

Introduction

Coppice is a widespread silvicultural system in Mediterranean European countries where it covers about 23 million hectares (FOREST EUROPE, UNECE and FAO 2011). In Italy, coppice is the most frequently adopted silvicultural system in private forests, and it amounts to about 56% of the total forest area (http://www.inventarioforestale.org). The success of coppice system can be explained considering the advantages to forest owners, like simple management, easy and rapid natural regeneration, faster initial growth rate than the high forest system (Ciancio et al. 2006). Deciduous Turkey oak (*Quercus cerris* L.) occupies the intermediate vegetation belt between sclerophyllous and mountain broadleaved forest over one million hectares (Barbati et al. 2014). Turkey oak represents an economically relevant species with regards to coppice management. On the whole, tree species composition in the dominated Turkey oak forests usually reflects the natural vegetation, even though the diffusion of a few species (e.g. maples, ashes, service trees, wild service trees, hornbeams) has been frequently reduced by management in the past.

With the exception of chestnut woods, coppice management has been traditionally focused on the production of fuelwood and charcoal, which in the past have represented fundamental resources for people living in rural areas (Chianucci et al. 2016b). This approach has traditionally favored the wood production by dominant tree species, at the expenses of often neglected sporadic ones (Chianucci et al. 2016a). More recent changes in the management perspective aimed at integrating economic, social and environmental aspects have led to consider more sustainable silvicultural approaches for coppice woods (Corona 2014). In this line, sporadic tree species may have a potentially interesting role from the ecological and productive point of view (Spiecker 2006, Mori et al. 2007, Mori and Pelleri 2014, Manetti et al. 2016).

Sporadic tree species are less competitive than dominant tree species, and thus their conservation and valorization require specific, tree-oriented silvicultural approaches (Mori et al. 2007). The tree-oriented silvicultural concept has been developed in Central Europe for managing oaks, beech and spruce high forests (e.g. Abetz 1993, Sevrin 1994, Bastien and Wilhelm 2000, Abetz and Kladtke 2002, Wilhelm 2003, Oosterbaan et al. 2008, Spiecker et al. 2009) and specifically for protecting and valorizing of sporadic tree species (e.g. Spiecker 2003, Sansone et al. 2012, Pelleri et al. 2013, Mori and Pelleri 2014).

The objective of tree-oriented silviculture is obtaining high-quality timber assortments in a relatively short rotation period (Oosterbaan et al. 2008) simultaneously minimizing the operational costs. A

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limited number of target trees are selected, and their growth is supported by reducing surrounding competitors by frequent, repeated thinning from above (Kerr 1996, Perin and Claessens 2009, Lemaire 2010). Such interventions allow high crown enlargement, and therefore high and uniform diameter growth of released trees. Recent studies have demonstrated that this approach can be successfully applied to coppice woods (Mori and Pelleri 2014; Manetti et al. 2016).

In this technical note we illustrated the application of the tree-oriented silviculture approach in mixed (deciduous) Turkey oak coppice stands. Specific aims are:

i) to provide an overview of the proposed tree-oriented silviculture approach;
ii) to evaluate the financial feasibility of the investments required for the implementation of proposed approach at the forest district level;
iii) to illustrate a case-study of practical implementation of the silvicultural approach.

Description of the adopted silvicultural scheme

The silvicultural scheme here proposed is based on a two-fold system of intervention, designed to integrate the tree-oriented concept with customary coppicing. In Central Italy, customary coppice rotation for Turkey oak stands is 20 years, which approximately corresponds to the culmination of mean annual volume increment under average site conditions (Bianchi and La Marca 1984). Customary coppicing practices are combined with other interventions specifically focused on fostering tree growth of a few selected sporadic tree species (hereafter target trees). These tree-oriented interventions differ according to the development of target trees, as indicated by Sansone et al. (2012) and Mori and Pelleri (2014). Basically, there are three different stages of growth, here indicated as T1, T2 and T3 (Fig. 1), which may occur at different times within the rotation.

(T1) The first tree-oriented interventions occur at mid coppice rotation (at 10, 30, 50, 70, 90, 110 years, …). In this stage the young target trees are selected, and their growth is favored by localized thinning from above of the main competitors to support uniform crown enlargement (Table 1). Pruning of target trees may also be carried out in this stage to accelerate the qualification of a branch-free bole and reach more than 2.5 meters length.

(T2) The second stage of growth of target trees occurs at the end of coppice rotation (at 20, 40, 60, 80, 100, 120 years, …). During this stage, a protective ring is being created around the target trees to favor individual crown enlargement with localized thinning every 6-10 years (Fig. 1). The minimum diameter of protective ring corresponds to the mean height of coppice standards. If the target trees are close to each other, a single protective ring is created around them. Pruning of target trees may also be carried out in this phase to complete the qualification of the branch-free bole.

(T3) The third stage of growth occurs when the target trees reached a size adequate to compete with the dominant trees. During this stage, the protective ring is removed and the target trees are left to grow further until they reach the awaited harvesting size. The felling of the target tree coincides with the coppicing period (at the ages of 40, 60, 80, 100, 120 years).

The proposed approach is similar to the one proposed t by Mori et al. (2007) and Mori and Pelleri

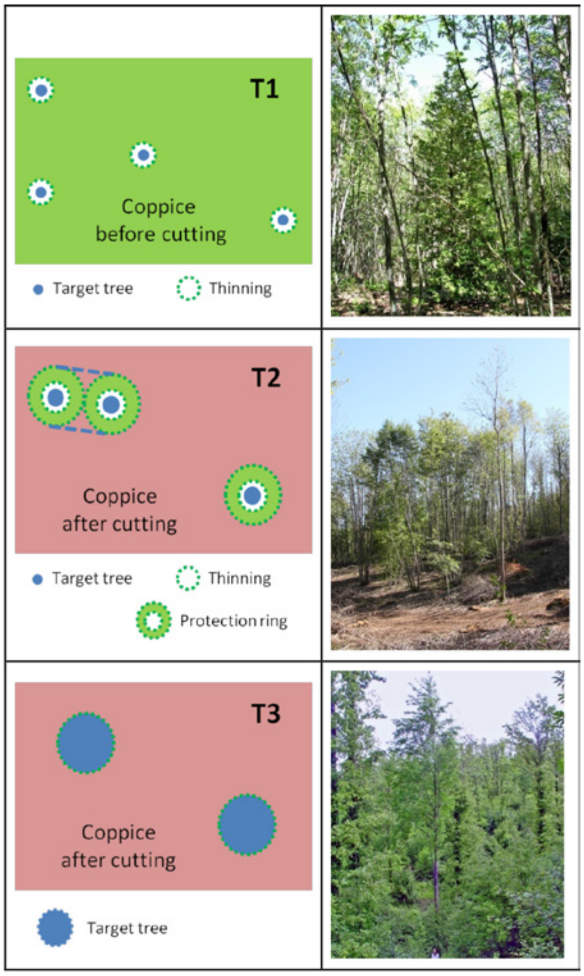

Figure 1 – Growth stage T1: localized thinning undertaken to promote target valuable sporadic tree species in a young coppice. Growth stage T2: coppice stand cut at the rotation end where a number of trees is being left as a protective ring around the target trees. Growth stage T3: coppice stand cut at the rotation end where protective trees are being removed to allow free growth of target trees.

(2014) for Turkey oak coppices, but differs as for the transition period herein of 80 years (previous studies indicated 72 years). In the following stage, the number of target individuals (selected, thinned and felled) of sporadic tree species is expected to remain constant over time and homogenously distributed in the three stages of growth. A synthetic description of the model is reported in Table 1 considering an observation time of 120 years. The main features of the proposed scheme are:

- about 6 target trees per hectare selected at the each mid coppice rotation for timber production (at 10, 30, 50, 70, 90, 110 years);
- coppicing every 20 years (coppice rotation);
- harvesting of about 6 mature target trees per hectare at the end of the transition period (80 years and every 20 years after 80 years);

The above features need to be considered as general guidelines, and they need to be calibrated and adapted to the actual site and stand bio-ecological conditions.

1. Financial assessment

Methodological considerations

The feasibility of the investments required for the implementation of the proposed silvicultural scheme was carried out according to the financial evaluation methods proposed by Andrighetto and Pettenella (2013) and Marone et al. (2014). The financial evaluation is aimed at verifying the profitability of the approach compared with customary coppicing, with regards to the following indicators:

- Net present value (NPV);
- Internal rate of return (IRR), i.e. the discount rate corresponding to a zero NPV;
- Payback period;
- Cash flows;
- Revenues to costs ratio (R/C).

The analysis has considered an evaluation period of 120 years. This was motivated because the profitability of the single-tree approach needs to be evaluated after the end of the transition period, when the single-tree approach is meant to provide a constant production through time (6 target trees every 20 years after 80 years).

Thinning cost was estimated based on real data collected in demonstrative areas of the LIFE project PProSpoT (Marone and Fratini 2013, see also http://www.pprospot.it). Thinning cost of sporadic tree species was included within coppicing costs. To avoid the influence of fluctuations in market prices

Table 1 - The proposed silvicultural (tree-oriented) scheme for Turkey oak coppice stands in Central Italy.

Phase		**T1**	**T2**	**T1**	**T2-T3**	**T1**	**T2-T3**	**T1**	**T2-T3**	**T1**	**T2-T3**	**T1**	**T2-T3**
		Transition period								*Ordinary regime*			
		Years											
Operations	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Selection and marking of the target trees T1 for timber production (n/ha^{-1})		6		6		6		6		6		6	
Selection target trees T1 for biodiversity (n/ha^{-1})		2											
Marking main competitors (n/ha^{-1})		8	8	14	6	12	6	12	6	12	6	12	6
Pruning target trees T1 (n)		6		6		6		6		6		6	
Localized thinning/girdling of the competitors of target trees T1 (n/ha^{-1}))		8		6		6		6		6		6	
Individuation of protection rings (n/ha^{-1})			8		6		6		6		6		6
Pruning target trees T2 (n)			6		6		6		6		6		6
Localized thinning inside protection rings T2 (n/ha^{-1})			8	8	6	6	6	6	6	6	6	6	6
Logging woods resulting from thinning (n)			8	14	6	12	6	12	6	12	6	12	6
Release of target trees T3 (n/ha^{-1})					8		8		8		8		8
Felling and logging of mature target trees (n)									6		6		6
Coppice harvesting (ha)	The whole surface		Net surface without the protection rings		Net surface without the protection rings		Net surface without the protection rings		Net surface without the protection rings		Net surface without the protection rings		Net surface without the protection rings
Total number of target trees (n/ha^{-1})	0	8	8	14	14	20	20	26	20	26	20	26	20

Table 2 - Market prices (€ m^{-3}) of roundwood from sporadic tree species (from Marone et al. 2014 *modified*).

Tree species	First timber quality class	Second timber quality class	Third timber quality class
Cherry	340	226	113
Service tree	665	443	221
Wild apple	300	200	100
Field maple	300	200	100
Wild pear	665	443	221
Field elm	340	226	113

on stumpage, we considered a null stumpage value by assuming the coppicing costs and the stumpage price as 5,000 € ha^{-1} and 50 € ton^{-1}, respectively, and a coppice yield of 100 tons ha^{-1} at the end of coppice rotation. Indirect costs have been identified in the reduction of coppice yield due to the release of target trees, which was assumed reducing the exploitable coppice area by 180 m^2 per target tree.

Timber market prices considered were selected from comparable local stand and site conditions (Table 2). To perform the calculation of the financial indicators, we adopted a discount rate decreasing over time (3.5% after the first 30 years; 3.0% between 31 and 75 years; 2.5% between 76 and 120 years), consistently with the approach proposed by HM Treasury (2011) for a proper evaluation of public resources in investments lasting several decades.

The revenue of single-tree silviculture heavily depends on the target tree species. Table 3 lists result from a field survey in Viterbo (Central Italy) of the main production and composition from the most diffuse sporadic tree species in a coppice stand representative of mean conditions in Turkey oak coppices in Central Italy; these values were considered in the financial evaluation. The post-intervention increments were verified through appropriate monitoring activities carried out in Tuscany, three years after the interventions in various forest stands within the LIFE project PProSpoT. The wood material obtained by coppice thinning to favor T1 and T2 trees and the wood obtained from pruning was considered negligible and thus not considered in the revenue.

Financial simulations

Financial simulations were carried out by analyzing the influence of the following aspects: coppice productivity under canopy cover of target trees and their protective rings; transition period and target timber size; age of selection of target trees and type of selected individuals.

Coppice productivity under canopy cover of target trees and their protective rings

A target tree must grow isolated for the period required to reach a commercially profitable stem diameter. This may trigger shading phenomena in the surrounding coppice shoots depending by the crown size of the target tree, its crown porosity, and the light requirements of coppice shoots (Chianucci 2016). In financial terms, the occurrence of shading phenomena represents an opportunity cost, consisting in the loss of part of coppice productivity. This production loss depends on the number of target trees per surface unit, and it then stabilizes after the transition period (i.e. after 80 years Table 4). Even in case that no productivity loss occurs due to shading effects, there is still a surface loss due to the coverage of the protective rings. Therefore, a reduction in coppice productivity during the transition period (80 years) was considered as part of the financial evaluation (Table 5). A 50% productivity reduction in

Table 3 - Stem diameter at breast height and volume (m^3 $tree^{-1}$) foreseen by the application of the proposed tree-oriented silvicultural approach during two transition periods (minimum: 60 years; optimal: 80 years) in average site conditions and for different sporadic tree species (expected assortment = 6 m). For cherry (*Prunus avium* L.) it is assumed a growing cycle of 60 years, considering the relatively high growth rate and to prevent plant diseases often occurring at older ages in this species.

Tree species	Transition period 60 years Diameter (cm)	60 years Volume (m^3)	80 years Diameter (cm)	80 years Volume (m^3)
Prunus avium L.	72	2.2	-	-
Sorbus domestica L.	36	0.4	48	1.0
Malus sylvestris Mill.	36	0.4	48	1.0
Acer campestre L.	42	0.5	56	1.3
Pyrus pyraster Burgsd.	36	0.4	48	1.0
Ulmus minor Mill.	36	0.4	48	1.0

Table 4 - Coppice income loss (expressed in percent) in relation to the reduction of coppice wood production in protective rings due to shading effects by the target trees in Turkey oak coppices in Central Italy.

Transition period (years)	Wood production in the protective rings compared to customary coppicing 0%	25%	50%	75%	100%
20	14	14	14	14	14
40	25	22	18	14	11
60	36	30	23	17	11
80	47	38	29	20	11
100	47	38	29	20	11
120	47	38	29	20	11

Table 5 - Financial indicators of the proposed tree-oriented silvicultural approach as a function of wood productivity reduction in protective rings of the coppice stand due to the shading effect by the target trees.

Wood production in the protective rings compared with customary coppicing	R/C	IRR (%)	NPV (euro ha^{-1})	NPV (euro ha^{-1} $year^{-1}$)	Year when cash flow becomes positive	Payback period (years)
0%	1.01	2.46	100.16	0.83	80	100
25%	1.01	2.63	145.60	1.21	80	100
50%	1.02	3.00	249.20	2.08	80	100
75%	1.02	3.02	259.57	2.16	80	100
100%	1.03	3.35	354.08	2.95	80	80

the protective rings around the target trees is used for all the financial assessments below reported.

Transition period and target timber size

Based on previous studies (Table 3), we considered 60 years as a minimum transition period to reach profitable timber from sporadic species in the proposed silvicultural scheme, while the optimum transition period was foreseen after 80 years, because it offers higher financial performances, leading to permanent property improvement and an increase in income capability. A sixty year transition period may be recommended on fertile sites and in situations where target trees are characterized by relatively fast growth species (e.g. *Prunus avium* L.) (Table 6).

Target trees selection period and type of selected individuals

Financial convenience is compared with respect to 80 year transition period with target trees selected at different times (Table 1). Three situations were compared:

- Early selection: target trees consist of coppice shoots selected at mid coppice rotation (T1);
- Medium-late selection: target trees consist of coppice shoots selected at the end of each coppice rotation (T2):
- Late selection: target trees consist of coppice shoots and standards selected at the end of coppice rotation (i.e. a few target trees from T2 and a few from T3).

Late target trees selection is theoretically more convenient (Table 7), since the starting time of production guarantees both a positive cash flow and a shorter payback period. However, late selection can only be carried out when there are enough target trees able to produce a sufficient amount of valuable timber assortments. This condition is not often met under most Turkey oak coppices in Central Italy.

Financial assessment of implementing the tree-oriented silvicultural scheme at a case-study level

Financial feasibility of the investment required for the implementation of the adopted silvicultural scheme was verified over an area of 12.5 hectares in a Turkey oak coppice in Grotte S. Stefano (Viterbo, Central Italy). Target trees selection was carried out at the end of the first coppice rotation (late selection). Early selection is then applied during subsequent coppice rotations, every 10 years. A transition period of 80 years was considered and wood production within the protective ring was estimated equal to 50% of customary coppice regime. The harvestable roundwood as a function of the transition time (years) is reported in Table 8. The first selection of target tree species has not taken advantage of the early silvicultural operations during the selection phase to get valuable timber assortments. Nevertheless, convenience indicators gave positive outcomes: R/C =1.01; IRR = 2.54%; NPV = 126 € ha^{-1}. Payback time is 100 years and the cash flow turns positive after 60 years (Table 8).

Table 6 - Financial indicators of the proposed tree-oriented silvicultural approach as a function of transition period length.

Duration of transition period (years)	R/C	IRR (%)	NPV (€ ha^{-1})	NPV (€ ha^{-1} year^{-1})	Year when cash flow becomes positive	Payback period (years)
60	1.00	2.65	26.24	0.22	60	100
80	1.02	3.00	249.20	2.08	80	100

Table 7 - Financial indicators of the proposed tree-oriented silvicultural approach as a function of time of target tree selection.

Time of selection	R/C	IRR (%)	NPV (€ ha^{-1})	NPV (€ ha^{-1} year^{-1})	Year when cash flow becomes positive	Payback period (years)
Early (T1 trees)	1.02	3.00	249.20	2.08	80	100
Medium Late (T2 trees)	1.07	4.30	730.68	6.09	60	60
Late (T2+T3 trees)	1.12	6.52	1.298.50	10.82	40	40

Discussion

This study showed that enhancing sporadic tree species able to produce valuable timber, coupled

Table 8 - Harvestable roundwood (expressed in m^{3}ha^{-1}) from the proposed tree-oriented silvicultural approach as a function of years from the first intervention (transition period) in the case-study (I = first timber quality class; II = second timber quality class; III = third timber quality class).

Tree species	Transition period (years)									
	40			60			80			100
	I	II	III	I	II	III	I	II	III	I
Service tree	0.02	0.06	0.02	0.31	0.21	0.42	3.50	1.70	0.67	2.98
Wild service tree					0.03	0.09		0.09	0.08	0.37
Wild apple		0.02					0.06			0.06
Field maple						0.14	0.22		0.08	0.22
Wild pear		0.02					0.15			0.10
Field helm				0.56	0.39	0.22	2.67	1.18	0.22	2.20

with coppice management, is more convenient than customary coppice management. Main advantages of the proposed tree-oriented silvicultural approach rely on the improvement of the property, on its profitability and low introduction costs, mainly due to a reduction of coppice revenues rather than of actual cash outflow.

The highest financial performances are guaranteed by silvicultural practices which largely maximize the revenue to cost balance, especially in the late selection of target trees (Fig. 2), rarely occurring anyway in the practice. On the other hand, the early selection of target trees represents the easiest silvicultural choice, and has the highest potential to yield valuable timber production at the end of the transition period, especially on fertile sites. In the early selection of target trees, however, the revenue to cost ratios are relatively low, which may limit the attractiveness of the investment in this silvicultural approach. Other critical issues linked to the introduction of the proposed tree-oriented approach in Turkey oak coppice silviculture are mainly referred to the: (i) operational costs for localized (target trees) silvicultural practices during coppice rotation; (ii) relatively long investment return time; (iii) market uncertainty, with possible substantial changes of the stumpage and market price of sporadic tree species timber. For these reasons, the financial support by European Union Common Agricultural Policy, and namely Rural Development Plans, is deemed desirable for allowing the implementation of tree- oriented silvicultural approach: particularly, the incentives could enable the intensification of silvicultural tending, mandatory to increase the technological quality of wood material.

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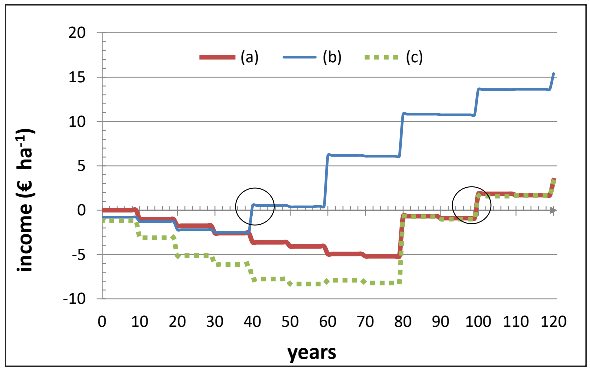

Figure 2 - Cash flow and payback period (circles) according to the proposed tree-oriented silvicultural approach with respect to the cases described Table 7 (a = early selection of the target trees; b = late selection of target trees) and at Table 8 (c).

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