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Review papers

Coppice forests, or the changeable aspect of things, a review§

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Abstract - Coppiced forests were the main source of firewood, brushwood, and charcoal for rural and urban settlements' basic needs such as cooking food and domestic heating for thousands of years and up to the mid-20th century in many European countries and, specifically, in Mediterranean countries. The global diffusion of fossil fuels reduced this leadership and the coppice system turned, to some extent, to a reminder of the past. Nowadays, the ongoing global changes and the related green-economy issues call for resilient systems and effective bio-energy producers. These issues have caused a second turning point and the coppice has returned fifty years later to play a role. A review of the silvicultural system has been carried out with a special focus on the changes which have occurred in between, taking Italy as a consistent case-study. The analysis is mainly framed upon the long-term research trials established by the CREA-Forestry Research Centre in the late sixties, to find out adaptive management strategies and overcome the system's crisis. The findings and further knowledge achieved so far on the dynamics and functioning of coppice forests in the outgrown phase, both as natural evolutive patterns and silviculture-driven processes, are highlighted in this paper. They provide useful tools to handle the management shift regarding forthcoming issues, i.e. the current role attributable to the coppice system within the changing environment and the renewable energy demand. The basic features of each management area and their complementarities within the current framework are outlined.

Keywords - silvicultural system, natural dynamics, pro-active silviculture, sustainability, past management, future forestry, Italy

Foreword

Coppices have imprinted the broad-leaved forest landscape across Europe since the establishment of early human settlements. Coppice is an anthropogenic system created and optimised for small-sized wood production over several million hectares. The main products; firewood and charcoal, have had a global use because they assisted people's common, daily needs such as cooking food and domestic heating, whilst manufacturing produced a further, huge demand for energy over the last centuries. The peak of coppice exploitation took place during the first industrial revolution whilst its role reduced following the diffusion of fossil fuels since the mid-1900's.

Coppice forests are a significant part of Europe's semi-natural forests (about 70%) (Forest Europe 2011), characterise the forest landscape of the five EU Mediterranean countries over about 8.5 million hectares (Morandini 1994), and cover more than 3.6 million hectares in Italy (Gasparini and Tabacchi 2011). Italian coppices account for almost 19% of the coppices in the EU28, which in turn represent 83% and 52% in the whole of Europe and at global level, respectively (UN/ECE-FAO 2000, Mairota et al. 2016a).

Coppice forests are therefore a significant element of forest landscapes throughout Europe. The landscape is an appropriate management unit because it considers the interrelatedness of component segments. The spatial heterogeneity made of a mosaic of structurally different forest patches, the presence of different age classes, and the implementation of contact or transition zones among contrasting ecosystems are all conditions that favour environmental variability and, therefore, biological diversity (Scarascia-Mugnozza et al. 2000).

Italy may be taken as a consistent case-study between the Mediterranean region and neighbouring continental countries because of its large coppice forest coverage, the diversity of growth environments, the number of tree species that exist, and the evidence of large changes which have occurred over the last two centuries. The fragmented forest ownership structure with many private (73%) small-sized forest holdings is also a common trait in Europe (Forest Europe 2011).

Cultivation techniques have been well-documented since the Middle Ages (Piussi 1980 and 1982, Szabo et al. 2015), but there is also evidence of the late conversion of wide, high forest areas into coppices between the 1800's and 1900's following the

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rising energy demand due to the sharp population increase and the concurrent rapid development of manufacturing activity (Agnoletti 2003).

Today, the analysis of silvicultural systems according to modern 'sustainability criteria' cannot ignore the basic question of the long-lasting, primary demand-driven, role of the coppice forest. In addition, it is nearly always impossible to separate this intensive cultivation system from the manifold overlapping uses and misuses of soil and tree vegetation. In fact, coppices have not only been used for short rotation wood production, but have also been over-exploited and used for deadwood and litter removal, the collection of leafy branches for fodder, occasional intercropping following shoots harvesting, and for unregulated pasture (Piussi 2006, 2015). This means uncodified, widely-practised 'multiple use'. The archives of Tuscany farms (central Italy) highlight that two thousand years of coppicing did not reduce stools vitality and site quality in the absence of overlapping, invasive uses (Piussi and Stiavelli 1986, Piussi and Zanzi Sulli 1997).

The common judgment of non-sustainable system, in the long run has been built, therefore, on the full integration of the manifold uses on the same ground rather than on the coppice system itself (Fabbio 2010). Other external pressures (e.g. wildfires and uncontrolled grazing) or sensitive environments (e.g. steep mountain sides, shallow soils, and harsh climate conditions) have contributed to, and many times have caused, the decay of site fertility and the complete erosion of forest texture (MEDCOP 1998, Fabbio et al. 2003). This is the why there is evidence today of a vast array of conditions, from the relict cover of scattered trees to dense, well-growing coppiced forests where their management has followed the basic rules and supplementary uses have been less intensive or lasting, or site quality has supported them. Driving forces, limiting factors, and feedbacks were the determinants of the co-evolutive pattern between land use and growth medium (Fabbio 2010).

The background between the 1800's and 1900's

In the 1800's and early 1900's, coppiced forests clearly depicted the pressure exerted by the increasing population density on the available natural resources. Total forest cover at country level underwent a significant reduction in the 40 years between 1868 and 1911 when first-time coppice system prevailed over high forest. The reasons for this were the doubling of the population during this period and the industry's energy requirements which were 85% (1861) of fuelwood and charcoal

Large, vital stool in an outgrown beech forest aged 70 yrs (Tuscany).

(Agnoletti 2002). The rising price of charcoal caused social problems in the early 1900's and Italy began to import it between 1906 and 1913. At this time nine-tenths of charcoal were used for cooking food. The city of Rome alone burnt up to 90 million kg per year in the course of World War II (Hippoliti 2001). The ratio between forest resources and the population only changed in the mid-1900's when firewood and charcoal supplied 11% of the country's energy requirements compared to 85% during the previous century. At this time, the coppice system took part in the major socio-economic shift of the modern era since the first industrial revolution (Fabbio 2004).

Many factors contributed to coppice downgrading: first, the much decreased economic significance of firewood production and the related lower profitability of its harvesting; then, the less intensive practice of forestry because of the emerging societal demands other than wood production; and finally, the critical association of coppicing with an out-of-date, ecologically-incorrect forest management system. Thus, the coppice system progressively reduced its leading role and turned, to some extent, to a 'reminder of the past' (Amorini and Fabbio 1994).

The new frame of reference can be outlined as the change of the original ground hosting the common matrix of coppiced young stands into a variable texture of stand ages and structures, stand dynamics, and growing stocks. In Italy, the current

Table 1 - Coppice cover in Italy by main tree species and stand age (source: Gasparini and Tabacchi 2011, INFC *mod.*).

tree species	cover		stand age					
	ha	%	<20 years	%	20<years<40	%	>40 years	%
Fagus sylvatica	477225	13.0	7728	1.6	128513	26.9	340984	71.5
Castanea sativa	593242	16.2	91908	15.5	277709	46.8	223625	37.7
Carpinus b. e *Ostrya c.*	636662	17.4	85250	13.4	325034	51.1	226379	35.6
Q robur, Q. petraea, Q.pubescens	534325	14.6	54256	10.2	241590	45.2	238479	44.6
Q. cerris	675532	18.4	124999	18.5	314835	46.6	235699	34.9
Q. ilex, Q. suber	372020	10.2	27241	7.3	146679	39.4	198099	53.2
other spp.	374137	10.2	81390	21.8	151169	40.4	141578	37.8
Total	*3663143*	*100*	*472772*	*100*	*1585529*	*100*	*1604843*	*100*

distribution of coppice forests with respect to stand age (Tab.1) (Gasparini and Tabacchi 2011 *mod.*) highlights that young stands represent less than 1/3 of mature coppices, which is quite similar to that of ‘ageing’ stands. This composite panorama includes the stands which are still managed, the outgrown stands, and the minority proportion of stands being converted into high forests, which are mainly under public ownership and located in the upper mountain belt (Amorini and Fabbio 1992, Fabbio et al. 1998a) .

Historical statistics on firewood harvesting (Hippoliti 2001, Pettenella 2002, Ciccarese et al. 2006, Pra and Pettenella 2016) (Fig.1) show a minimum exploitation in the mid-seventies, whilst the last official statistics available on domestic fellings (ISTAT 2011) are similar to 2004. According to Forest Europe (2015), the current felling rate as a percentage of Net Annual Increment in Italy is one of the lowest in Europe: 39.2% compared to 47.3% in France, 80.3% in Germany, and 55.5% in Spain (Pra and Pettenella 2016). Even if the internal consumption of firewood from forests is only a part of the total consumption of the wood biomass for energy in Italy, which is estimated to be equal to 21.20 Mt (range between 16.37 and 22.17 Mt according to Pra and Pettenella 2016) or 19 Mt (Ciccarese et al. 2012), the official statistics are heavily underestimated (Corona et al. 2007). The reasons for this are generally related to the cross-sectorial character and fragmentation of the market. The multiplicity of sources on the supply side and the presence of different sub-markets and final users on the demand side make the wood energy market complex to clearly define and quantify

Visual impact of customary, slope-oriented coppice harvesting on a mountainside (central Apennines).

Final harvesting in a coppice with standards (Turkey oak forest, Latium).

(Steierer 2007, SFC 2008 in Pra and Pettenella 2016).

The increased rotation length has been induced by several reasons: the suspension of charcoal production, the improvement in chopping tools and hauling/processing machinery (Schweier et al. 2015) and, especially, by the opportunity to harvest higher stocks per unit area. Over the last decades, the much-increased differential between manpower

Thickness of a holm oak coppice forest close to the age of rotation. Growing space occupancy is quite full (Corsica).

The high mortality rate is a typical trait of the early outgrown phase (holm oak forest, Sardinia).

Turkey oak coppice under conversion into high forest (Tuscany).

costs (x80) and firewood costs (x16), even with higher (x4) manpower productivity for processing and logging, led to doubling rotations and reaching the optimal shoot size of 10-15 cm. This trend, as highlighted by Hippoliti in 2001, is today the consolidated operational principle ruling the practice of coppice forestry.

Concurrent reasons are gaining ground today for the following reasons: the awareness of the residual stock of fossil fuels, the evidence of the climate shift in progress, the need for pro-active mitigation, i.e. that resilient and efficient forest systems have to be managed effectively, the fulfillment of emerging green economy issues (Marchetti et al. 2014). All of these call for streamlined production processes in a time of environmental change and increased bioenergy demand. This is why the coppice system has returned to play a potential, prominent role within the forestry domain.

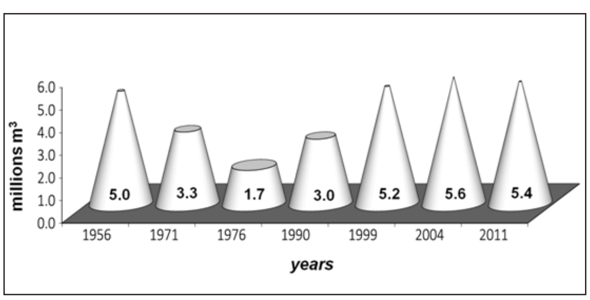

Figure 1 - Firewood harvesting over the last sixty years in Italy (2011, last official data available). (Sources: Hippoliti 2001, Pettenella 2002, Ciccarese et al. 2006 and 2012, Pra and Pettenella 2016).

This newly-established perspective leads, on the one hand, to the reconsideration of the legacy of the past, i.e. the fully tried techniques used for coppice systems; and on the other hand, calls for working hypotheses which are free of any subjective opinion other than ground-based evidence and the body of knowledge achieved so far.

The aim of this paper is to review the research questions which arose fifty years ago, the research pathway, and the main findings from the long-term research trials which have been established on this topic since the late sixties in Italy by the CREA - Forestry Research Centre. The main traits of the current scenario between the area managed under longer rotations, the outgrown area, the area undergoing conversion into high forest, and the role of each are outlined.

The need to handle the shift towards the suspension of harvesting/abandonment within a significant share of coppice area and to also suggest hypotheses for alternative, pro-active management has originated a series of applied research trials. These have compared the new options of coppice maintenance under the updated rules and/or conversion into high forest with the natural evolutive pattern or 'outgrown phase' in progress. These trials have contributed a better understanding of coppice system functioning above and below ground in terms of growth and re-growth ability, of dynamics and structure of the standing crop, as well as of the main drivers acting within each management choice.

The focus here is on the main tree species, i.e. the deciduous and evergreen oaks (Turkey oak, *Quercus cerris* L.; holm oak, *Quercus ilex* L.) and beech (*Fagus sylvatica* L.). Chestnut (*Castanea sativa* Mill.) was also considered in the trials but will be addressed in a next paper (Manetti, *forthcoming*) because of its peculiar traits with its set of available management options and the array of available wood assortments.

The research questions

At the time the early papers on the subject-matter were issued (Gambi 1968, Guidi 1976, Amorini and Gambi 1977) and CREA's first experimental trial was established (1969), a few basic questions were asked: (i) how could the share of coppice forests no longer being harvested be managed? (ii) what are coppiced forests' growth patterns beyond the customary rotation? (iii) what is the decay rate of stools' resprouting ability with stand ageing? (iv) what is the most suitable stand age to undertake coppice conversion into high forest and which practices should be implemented? (v) how can economic sustainability be achieved in order to tackle any pro-active silviculture, given that profitable firewood harvesting no longer exists? (vi) how can 'standards', i.e. the trees (usually from seed) released from one up to a few coppice rotations be managed?

The consolidated management cycles, which have been improved and finely tuned throughout centuries of cultivation, could not provide any answer to the above questions due to the ruling principles at that time. Rotations in use, well-grounded on the specific growth rate, were optimal for the: (i) size of harvested assortments (brushwood, charcoal, and fuelwood); (ii) cutting tools and the hauling techniques in use; (iii) avoidance of any yield loss due to the heavy competition among shoots and stools causing natural ('regular' according to Oliver and Larson 1996) mortality beyond customary rotations. Yield tables specific to coppice forests identified the rotations in use as close to the age of mean volume increment culmination, i.e. to the age of maximum wood production (Castellani 1982, see also Bernetti 1980).

Agrimed (1979-82) 'Multiple use and prevention of forest fires'. Combined thinning method: opening of parallel clear-cut strips and selective thinning of standing crop (Turkey oak coppice forest, Tuscany).

The research pathway

The first CREA trials, established in the late 1960's when the suspension of harvesting was already in progress, basically compared the fairly unknown evolutive pattern of outgrown coppices and the alternative option of pro-active silviculture for coppice conversion into high forest. All of this may be seen as the establishment, ahead of its time, of an adaptive management approach. The following tools were used: the periodical survey of mensurational parameters, stem and root branches analyses, the analyses of tree layering set up and dynamics, and the shoots' mortality rate and progress survey. The collection of sample trees at the same sites allowed the measurement of dendrotypes within the consistent size-age span and the calculation of species-specific (beech, Turkey oak, holm oak) allometric functions (Amorini et al. 1995, Brandini and Tabacchi 1996, Amorini et al. 2000, Fabbio et al. 2002, Nocetti et al. 2007). Stem and root branches analyses made it possible to plot growth patterns from the coppice rotation up to the outgrown phase. These analyses were, therefore, a contribution to understanding the functions and processes already acting within the coppice cycle.

Further trials were implemented by the CREA within; the EU-Agrimed 'Multiple use of Mediterranean forests and prevention of forest fires' (1979-82) with an Italian-French partnership (Morandini 1979, Amorini et al. 1979), the EU-AIR2 'Improvement of Mediterranean coppices' MEDCOP (1994-98) involving the five EU Med. countries (Morandini 1994, Fabbio et al. 1998a), and the regional/national projects 'LIFE-Summacop' (Grohmann et al. 2002), 'TraSFoRM' (Amorini et al. 2002), 'RiSelvItalia'(2002-2004) (Fabbio 2004), ARSIA-Cedui (2004-06).

Each project contributed to the establishment of further trials and analyses (Amorini et al. 1996, 1997, 1998ab, Fabbio 1994, Fabbio et al. 1996).

A basic entry within the newly-established research design was the 'adjusted coppice system' which was revised for average rotation length, harvesting, and thinning practices, the definition of 'standards' release (number, positioning, and aggregation on the ground), and the choice of the suited phenotype (Amorini et al. 1998c, Grohmann et al. 2002, Becagli et al. 2006, Cantiani et al. 2006, Savini 2010, Savini et al. 2015).

Further analyses addressed the parameters of productivity (litterfall, leaf area index), the canopy properties and the radiative climate (Cutini 1994ab, Cutini 1997, 2006, Cutini and Hajny 2006), the eco-physiological traits (Cutini and Mascia 1998, Cutini and Benvenuti 1998), the inner microclimate (Fabbio et al. 1998b), the dynamics of tree biomass and deadwood density (Bertini et al. 2010, 2012), and the stand structure and compositional diversity (Manetti and Gugliotta 2006, Manetti et al. 2013).

The theory and practice of silviculture according to the options in progress (Fabbio and Amorini 2006, Amorini et al. 2006), genetics and stand structure (Ducci et al. 2006), harvesting operations and hauling systems (Piegai and Fabiano 2006), technological improvement of wood assortments (Berti et al. 1998), biodiversity conservation (Baragatti et al. 2006), landscape analysis (Mairota et al. 2006), and the economic sustainability of the management systems (Fagarazzi et al. 2006) were the main subjects investigated within the mentioned projects.

The final points take into account the forthcoming issue of concern, i.e. analysing the resprouting ability of outgrown coppice stools. The issue is highly important if a share of the currently abandoned coppice area will be used for coppicing again.

The revision of practices ruling the customary technique of conversion to high forest has been tackled within the LIFE-ManForCBD (2010-2015). Innovative adaptive practices consisted of lowering symmetrical competition by reducing stand evenness to better address tree canopies for future regeneration by selective thinning. A case study was carried out in a beech stand under conversion to high forest (Fabbio et al. 2014). The advance seed cutting in the same forest type is addressed by Cutini et al. (2015), whilst long-term data on litter production, leaf area index, canopy transmittance, and growth efficiency estimates are again reported from a beech trial by Chianucci et al. (2016) .

Further contributions to the subject matter within the period of review are available in 'The improvement of Italian coppice forests' (Accademia Nazionale di Agricoltura 1979), 'Improvement of coppice forests in the Mediterranean region' (Morandini 1994), 'The coppice forest in Italy' (Ciancio and Nocentini eds. 2002), and 'The coppice forest. Silviculture, Regulation, Management' (Ciancio and Nocentini 2004).

The 'coppice issue' is also well-addressed by: the ongoing Cost Action FP1301 (EuroCoppice 2013 https://www.eurocoppice.uni-freiburg.de/) which aimed to develop the innovative management and multifunctional utilisation of traditional coppice forests and is an answer to future ecological, economic and social challenges in the European forestry sector; the international Conference held in Brno (Coppice 2015 http://coppice.eu/conference_en.html) where the past, present, and future of coppice forests were analysed alongside the new challenges in a changing environment; the LIFE FutureForCoppiceS (2015 http://www.futureforcoppices.eu/en/) which aimed to demonstrate the outcomes of different approaches by datasets collected from long-term experimental plots networks and improve the knowledge of Sustainable Forest Management indicators in view of the forecasted changes in key drivers and pressures.

The common goals addressed by these ongoing activities acknowledge the role of coppice system and the challenge for forestry within the newly-established economical and environmental conditions.

Main findings

Stand dynamics of outgrown coppice forests

The above ground process

In Italy, the available yield models for coppice forests date back to the 1940's up to the early 1980's (Tab.2). Predictive models set the age of 'maximum yield' or the 'age of mean annual volume increment culmination'. Scheduled rotations are quite short and vary as a function of the specific growth capacity and the site-index. The age of maximum yield often reported both for growing stock as a whole and for the firewood/brushwood component, underlines the attention paid to each harvestable assortment.

The evidence of incremental values higher than those recorded at the ages of previous rotations was provided by the repeated measurement of the standing crop volume and biomass undertaken since the establishment of the first permanent monitoring CREA sites in the late sixties (UNIF 1987). All of

Table 2 - Yield models for coppice forests in Italy (source: Castellani 1982).

main tree species	yield tables (years)	site class	stand age corresponding to the maximum yield (years)		
			growing stock	firewood	brushwood
Turkey oak	1948-49 to 1965-66	-	14-16		
	1950	I	9	12	
		II	9	12	
		III	12	12-15	
	1950	I		12	9
		II		12	9
	1966 to 1982	-		14	
holm oak	1963 to 1972	I	26-28		
		II	28	32	
		III	28		
beech	1947	I	17-18		
		II	16-22		
		III	18-23		

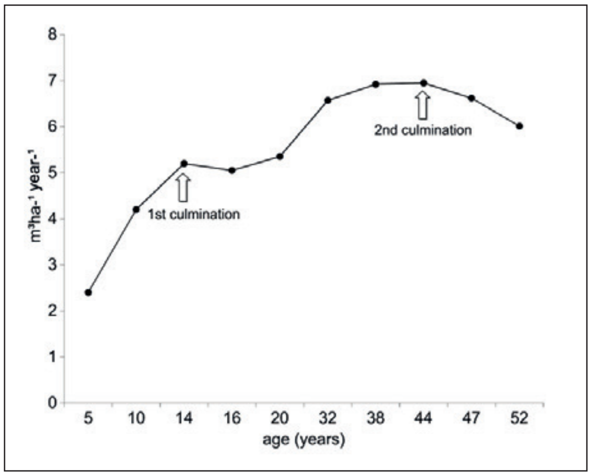

Figure 2 - Stand dynamics of an outgrown Turkey oak coppice forest: trend of mean annual volume increment.

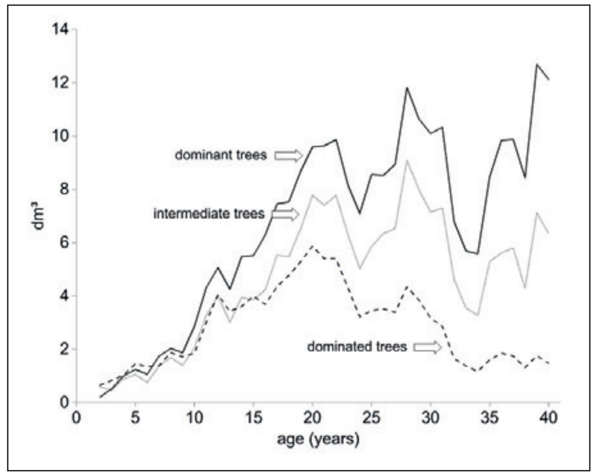

Figure 3 - Shoots dynamics of an outgrown Turkey oak coppice forest: averaged trend of current annual volume increment by the stem analysis per social ranks (same trial as in Fig. 2).

this occurred in spite of the heavier natural mortality rate recorded in between in the fully stocked outgrown coppices.

A second, higher culmination of mean annual volume increment was assessed for the first time in a 44-year-old Turkey oak coppice (Fig.2), much later than the first one (at the age of 14) as ruled by the yield models for the species (Amorini and Fabbio 1988). The same pattern was found to be common in the other stands investigated, i.e. beech and evergreen oak coppice forests (Amorini and Fabbio 1990).

This evidence clashed with previous literature and suggested further analyses. Stem analysis provided the ultimate answer to the matter. The analysis was carried out at the early-established trials on beech and Turkey oak in the Tuscan Apennines (Amorini and Fabbio 1986, 1989). The stratified tree sampling per growth layer (dominated, intermediate, and dominant) showed patterns made by synchronous current volume increment cycles in progress since the differentiation of ranks within the customary coppice rotation (Fig.3). The higher growth rate of the dominant shoots and the lower competitive ability of the not-dominant shoots over time were highlighted.

The current availability of a series of long-term monitoring trials allows the assessment of the growth dynamics in the outgrown (stored) coppice type between 44 and 75 years of age (Tab.3). The values show that growth culmination has already occurred at most sites, whilst the reduced difference of current to mean volume increment suggests that the peak is not far away at the other sites. Shade-tolerant species (holm oak, beech) show that growth culmination has not been reached yet between 60 and 75 years of age, with auto-ecology being the main driver.

What is, therefore, the meaning of the early culmination widely acknowledged by former yield models? It actually detects a first peak of growth shaped by the subsequent temporary steadiness due to the triggering of heavy competition among shoots and stools. It identifies the technical rotation suitable for small-sized wood harvesting, anticipates the occurrence of natural mortality, i.e. of any firewood production loss. It testifies the physiognomic evidence of the relative peak of growing space occupancy that takes place within the early rising stretch of the growth curve, but it is not the true culmination of stand growth from the current and mean volume increment patterns.

The unavailability of outgrown coppice forests up to the 1960's, the unfeasible checking of the temporariness of observed shoots' mortality and of the following growth recovery at the stand level, and

Table 3 - Assessment of growth pattern with reference to the age of maximum yield at the permanent sites monitored by CREA (*m.a.i.* = mean annual volume increment; *c.a.i.* = current annual volume increment).

main tree species	site	stand age (years)	c.a.i. $m^3ha^{-1}y^{-1}$	m.a.i. $m^3ha^{-1}y^{-1}$	m.a.i. = > c.a.i.
Turkey oak	Emi1*	60	2.8	4.0	*Yes*
	Laz1*	50	4.3	4.2	*close to*
	Mar1*	50	5.6	5.9	*Yes*
	Sic1*	65	3.0	3.5	*Yes*
	Vas	47	1.8	6.6	*Yes*
	Cas	55	3.6	7.5	*Yes*
	Pop	44	1.4	3.6	*Yes*
holm oak	Tos1*	65	3.8	4.0	*Yes*
	Tos2*	70	4.8	3.6	*No*
	Laz2*	65	5.5	3.5	*No*
	Sar1*	65	4.0	4.3	*Yes*
	Isc	55	0.9	4.1	*Yes*
beech	Emi2*	60	6.3	5.4	*No*
	Lom3*	60	9.0	5.7	*No*
	Pie1*	75	6.8	4.6	*No*
	Cat	67	6.5	7.5	*Yes*

* ICP- Forests Level II plots.

the already achieved firewood size are the likely, concurrent explanatory reasons for the general acceptance of traditional yield models (Amorini and Fabbio 2009). The evidence of further positive growth patterns supports well the current shifting of coppice rotations towards higher stand ages and large-sized firewood production.

Basal area growth rates from 1.4 - 1.9% up to 2.5 - 3.1% are being recorded in the deciduous/ evergreen oaks and beech outgrown coppice plots of the ICP intensive monitoring network in Italy (Fabbio et al. 2006a). Net primary production varies from 10.2 (Turkey oak) to 11.6 Mgha^{-1}y^{-1} (beech), whilst growth efficiency varies from 2.0 to 2.6, respectively.

A further index descriptive of growth patterns is the relative space occupancy calculated as the percentage ratio of shoots' standing biomass (standards excluded) to the volume defined by mean stand height per unit area (the proxy of the age-related growing space). The two case-studies (beech and Turkey oak) reported in Fig.4 describe species-specific patterns. The shade-tolerant species shows an early drop following the age of customary harvesting (24 years), and then the tendency is for a smooth increase until the end of the observed lifespan (67 years). The pattern of light-demanding oak maintains lower values throughout and has a nearly steady increase which reaches its culmination at the age of 44.

The pro-active practice of coppice conversion into high forest (Amorini and Gambi 1977, Fabbio and Amorini 2006, Amorini et al. 2006, 2010) allowed the comparison of this option to the outgrown phase within the same trials. The early, sharp drop in density at the first thinning and the much more reduced decreases following the intermediate harvestings

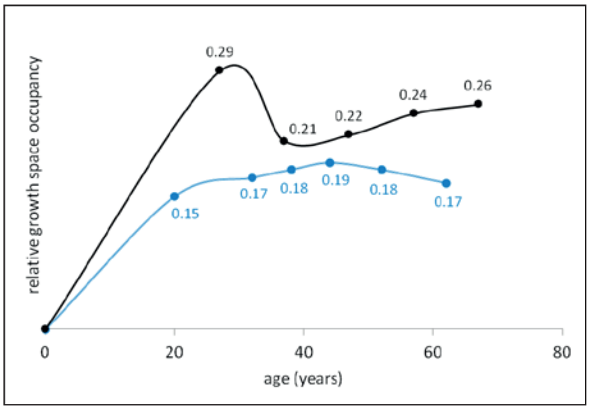

Figure 4 - Pattern of growing space occupancy by standing crop as a function of stand age in outgrown beech (black line) and Turkey oak (blue line) stands. Growing space occupancy is calculated as the relative ratio between standing crop volume and the theoretical available volume upper-bounded by the age-related mean stand height. Resprouting mass (shoots) is considered only. The small number of trees released since former cycles (the standards) at both stands makes them comparable.

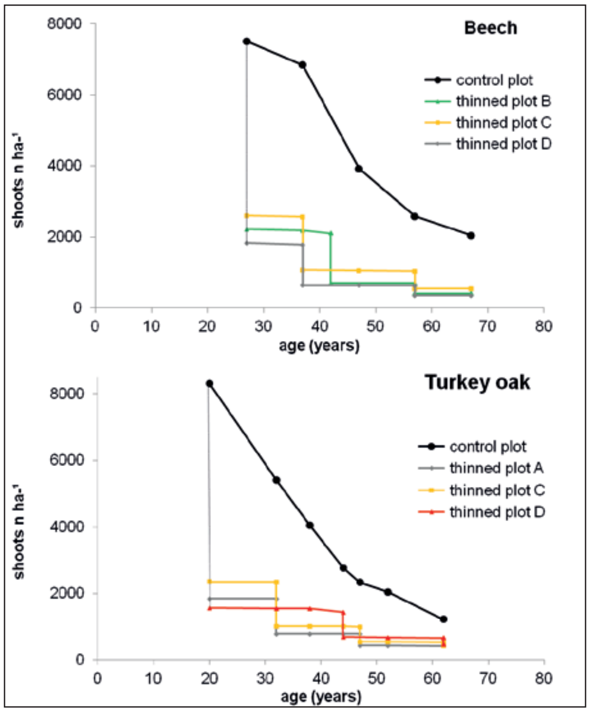

Figure 5 - Trend of shoots density at increasing stand ages at control and thinned plots in a beech and a Turkey oak outgrown coppice forest.

are compared with natural tree mortality (Fig.5). Thinning to control densities are quite similar at the last age recorded in Turkey oak, whilst a marked difference is still present in beech plots, due to the specific shade-tolerance of the latter. The growth dynamics in terms of current and mean volume increment (Fig.6) in one beech (A) and two Turkey oak (B, C) experiments points out that management changes both incremental values and their course, whilst the age of culmination control vs. thinning remains nearly unchanged at each site. Beech stand shows a delayed age of culmination (60 years) as compared to Turkey oak. A marked difference exists between the Turkey oak sites: site B, located in the pre-Apennine range at an elevation of 700 m asl, showed the mean annual volume increment culmination close to 40 years, whilst site C, located close to the Thyrrenian coast at 200 m asl, culminates earlier, at about 30 years. There is also evidence of an abrupt drop in current annual volume increment following the culmination age at control plots.

Standing volume and standing volume plus intermediate harvestings (Tab.4) describe wood allotment at control and thinned plots, respectively. Intermediate yields suggest the economic feasibility within well-accessible sites and average production levels. Patterns of periodical thinnings aimed at promoting the recovery of the high forest physiognomy and triggering the sizing of final crop trees to better address the regeneration from seed are outlined (Fig.7). Intermediate harvestings show to be not negligible, even if the current wood destination is still firewood. The mean stand dbh throughout

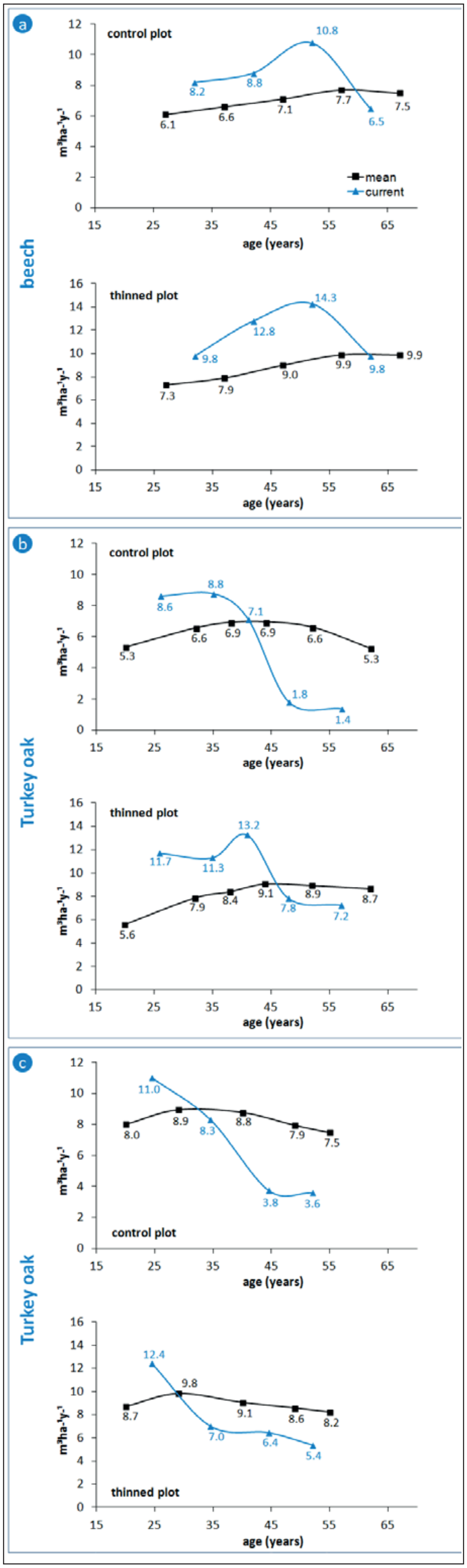

Figure 6 - Trends of current and mean volume increment of a beech (a) and Turkey oak (b, c) outgrown coppice forests at control and a thinned plot, respectively.

Table 4 - Dynamics of conversion to high forest vs. natural evolution (control plot). Current standing volume, intermediate and total yields at two permanent monitoring sites.

treatment	standing volume m³ ha⁻¹	Σ thinned volumes m³ ha⁻¹	total yield m³ ha⁻¹
BEECH (monitoring span = 27 - 67 years)			
plots under conversion (average)	354	273 (3 thinnings)	627
control plot	505	-	505
TURKEY OAK (monitoring span = 20 - 62 years)			
plots under conversion (average)	287	215 (3 thinnings)	502
control plot	326	-	326

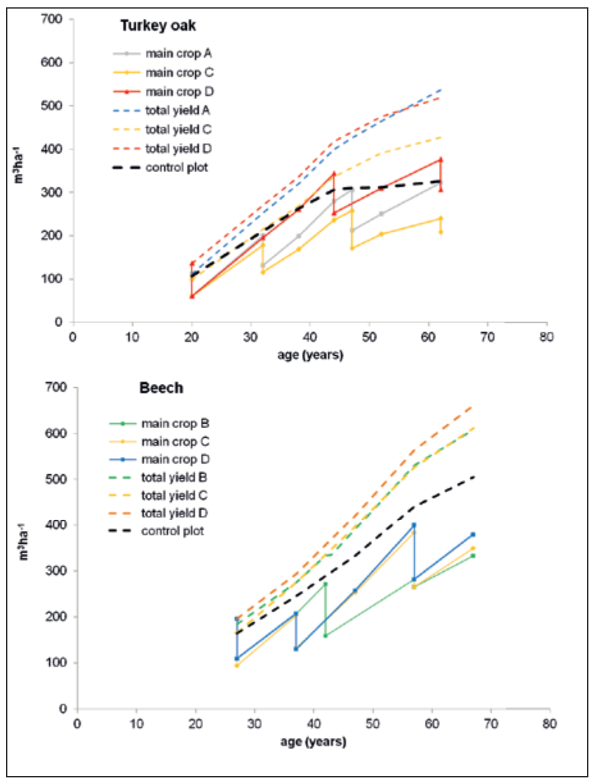

Figure 7 - Growth pattern of standing, main and total volumes at control plot and thinned plots in beech and Turkey oak outgrown coppice trials.

the explored life-span ranges from 9 to 34 cm (age 27-67 years) and from 9 to 26 cm (age 20-62 years) for beech and Turkey oak, respectively. The size of harvestable stems fits well and enhances the productivity of current handling-hauling systems.

The below ground process

The relationship between root system and above-ground biomass has a special significance in the coppice system since the prompt resprouting following the clear-cutting of stools in short time spans needs to be well supported belowground. A few hypotheses by Bernetti (1980, 1981) and Clauser (1981, 1998) regarding the development of outgrown coppice stands both in the above and underground components have produced original theoretical contributions. However, no field surveys and analyses studied the root system prior to the 1980's. A first digging trial was carried out (Fig.8-9) on a beech 'transitory crop', i.e. a coppice under conversion to high forest aged 43 years, thinned the first time at the age of 27 years, and the second time ten years later (at 37 years). The customary rotation was at 24. Therefore, the first thinning took place within the early establishment of the 'ageing period'. Two shoots were released at the first thinning and one at the second thinning on each of the sampled stools (Amorini et al. 1990).

Stem analysis was carried out for all living main (1st order) root branches (Fig.10). The age of each horizontal and vertical branch at the stool insertion, the annual radial increment, and the lengthening rate were determined. The shoot (stem) radial growth was also assessed at the height of 50 cm above ground level. Data refer to a stool living in the upper canopy layer, i.e. carrying at least one dominant shoot, which means a 'candidate' to be standing over the full conversion cycle. The results (Fig.11) apply to the time of coppice rotation (age 1-24 years) and to the transitory crop time (age 27-43 years).

- Horizontal rooting: only one living root aged before the last coppicing (1945) was detected; the new root branches sprouted as follows: +7 (age of 9), and +14 (age of 18). Three more branches sprouted before the first thinning, i.e. +17 in total (age of 27). No other branches developed over the transitory crop span (age > 27).
- Vertical rooting: no living branches aged more than the last coppicing were found. The development of new roots is slower in this sub-system +6 (age of 18), and +12 (age of 27). Only one new entry was detected within the transitory crop phase, i.e. +13 in total (age of 43).

At the age of survey (43 years), nearly all the main living root branches were developed after the last coppicing. This means that all the branches aged more, and still living during the last coppice cycle, ended their lifetime within the analysed time-span.

The resulting evidence of re-growth ability draws attention to the root system turnover as stool resprouting takes place after coppicing. These findings contribute a further understanding of stools' capacity to regrow several times without any depletion of their own regeneration potential. The same survey protocol, repeated a few years later in a Turkey oak ageing coppice, produced similar results.

Figure 8 - The digging trial of a beech coppice stool (1988).

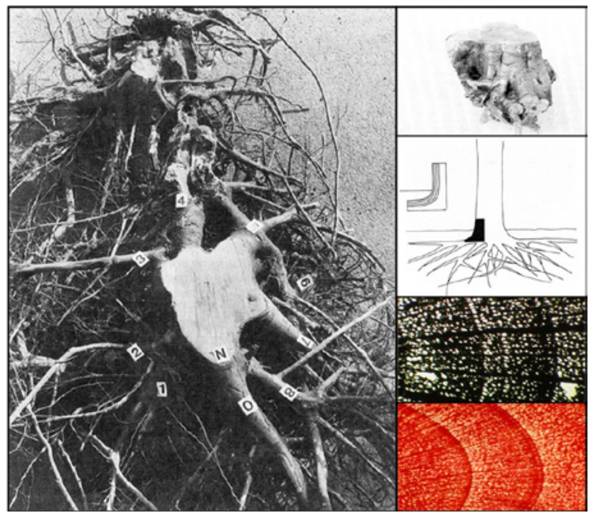

Figure 9 - Details of a beech root system.

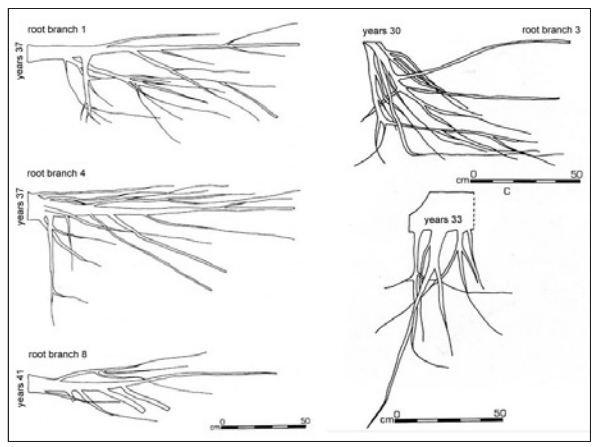

Figure 10 - Profile and age of main root branches at the insertion on the stool in a beech coppice.

An additional focus was on the development of the current radial increment at the shoot (stem) section at 50 cm above ground level and the total radial increment of the root branches measured at 10 cm from the stool insertion (Fig.12). The resulting patterns were quite similar over the full coppice cycle and also following each thinning in terms of reactive ability and growth rate. If the effect of growing space made available by the thinning on radial stem growth and crown sizing of released stems (the above ground component) was clear, there was

Root system mapping at digging out operations in a beech coppice stand (Tuscany).

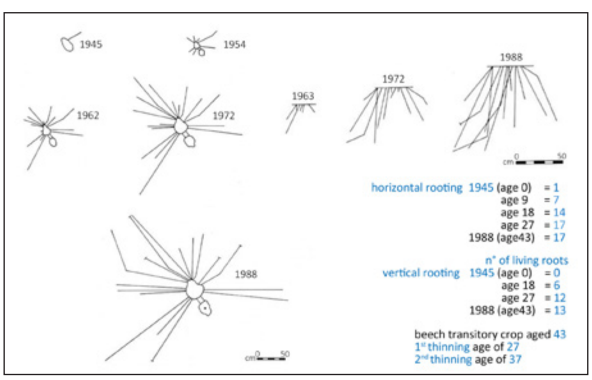

Figure 11 - Pattern of root branches development since last coppicing in a beech coppice. Age and number of living roots detected at the time of survey are reported.

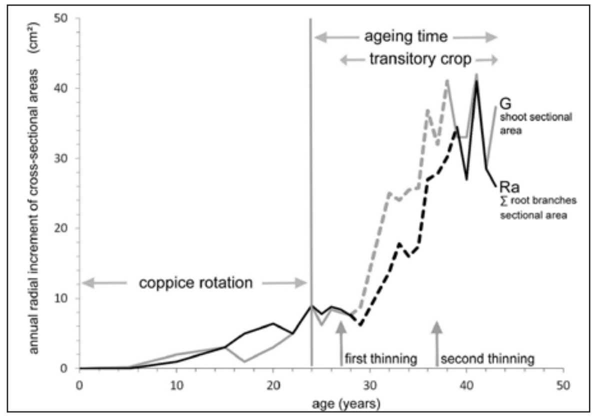

Figure 12 - Comparison between current radial increment (G) at the shoot section (height 50 cm) and total radial increment of root branches (ΣRa) at 10 cm from the stool insertion of a sampled stool in a beech coppice.

no evidence that a similar, synchronous reaction takes place below ground. The adaptive ability of the new-established root system fully accomplished the development of the above ground tree biomass according to a consistent functional significance.

This finding also helps the understanding of the fulfilment of trophic autonomy by the inherent regenerative ability hastened here by thinnings, drastically anticipating the reduction of the number of shoots on the stool by natural mortality.

Other attributes of relevance

Further evidence from the same sites stress the auto-ecology of main tree species as a principal driver in the outgrown coppice's lifetime. This trait rules the quantitative outcome of growth patterns. Shoots' mortality is anticipated in light-demanding species (e.g. Turkey oak) as compared with shade-tolerant species (e.g. beech) (Fig.13a) according to the average speed of variation (Odum 1973). The different behaviour is also highlighted by the contrasting trend of the 'auto-tolerance' or 'intra-specific competitive ability' (Zeide 2005) diverging from the ages of 45-50 years when a sharp increase occurs for the oak (i.e. a higher mortality rate under similar radial increment), whilst the competitive ability remains steady for beech (Fig. 13b). Further evidence of the auto-ecology – shade tolerance in this case – as the main driver of shoots' mortality is shown by the overlapping dbh distributions of standing dead shoots in outgrown beech and holm oak coppices aged likewise but living in quite different environments (Fig. 13c).

Clear proof of Zeide's statement 'shade tolerance affects the survival of trees but not their growth' (1985, 1991, 2005) is provided by shoots' radial increments in a beech outgrown coppice forest (Fig. 14a). One-quarter of living shoots (27%) is alive but no longer able to produce new tissue and its radial

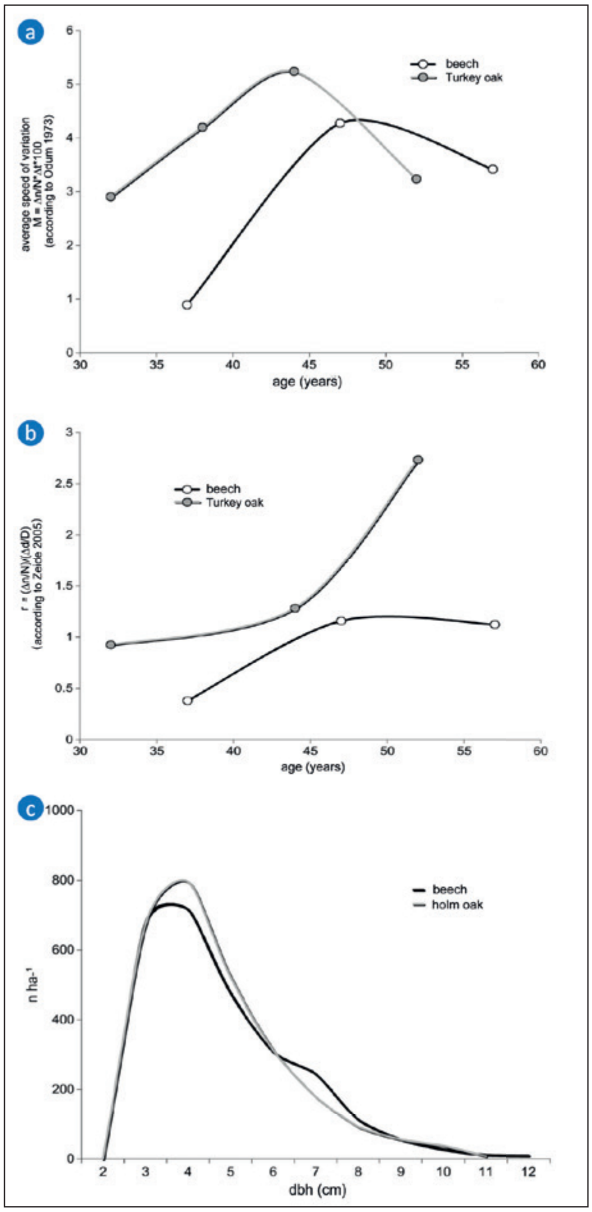

Figure13 - (a) Average speed of variation of shoots number in a shade-tolerant (beech) and a light-demanding tree species (Turkey oak) according to Odum (1973). (b) Trend of the 'auto-tolerance' or 'intra-specific competitive ability' according to the Zeide algorithm (2005). (c) Dbh frequency distributions of standing dead shoots in outgrown beech and holm oak coppices aged likewise.

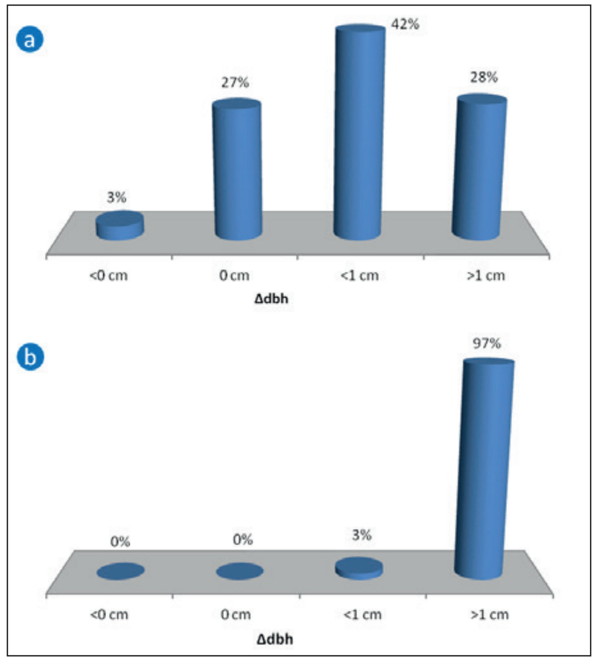

Figure 14 - Distribution of dbh growth under the natural evolutive pattern (control plot) (a) and in a thinned plot (b) within an outgrown beech coppice forest over the same life-span (age from 47 up to 57 years).

increment is zero within the not-negligible time span of ten years, whereas the standing dead population is only 3%. The quite different growth pattern within the same stand under conversion to high forest (Fig. 14b) highlights the change promoted by the repeated standing crop thinning causing a one-layered stand structure physiognomically similar to a pole stand from seed.

Tree biomass and standing/lying deadwood are complementary functional attributes along with stand age, especially in outgrown coppices. Their dynamics have a noticeable effect on deadwood accumulation on the forest floor. Tree biomass and standing/lying deadwood allocation for light-demanding (Turkey oak) and shade-tolerant (holm oak, beech) species are provided in Tab.5. The light-demanding species is characterised by the early shift of standing to lying deadwood ratio, whilst the opposite takes place for the shade-tolerant species. All of this is in spite of the quite similar mean

Table 5 - Standing shoots biomass, total, standing/lying deadwood, mean annual increments of standing biomass and deadwood according to stand age and main tree species.

main tree species	stand age	standing biomass	standing biomass mean annual increment	deadwood			standing to lying deadwood ratio	deadwood mean annual increment
				total	standing	lying		
	years	Mg ha^{-1}	Mg ha^{-1} year^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}		Mg ha^{-1} year^{-1}
Turkey oak	52	238.8	4.59	22.4	6.1	16.3	1/3	0.43
Turkey oak	55	313.0	5.69	30.0	9.8	20.2	1/2	0.55
holm oak	55	225.3	4.10	25.3	18.5	6.8	3/1	0.46
beech	57	321.6	5.64	27.7	19.5	8.2	2/1	0.49

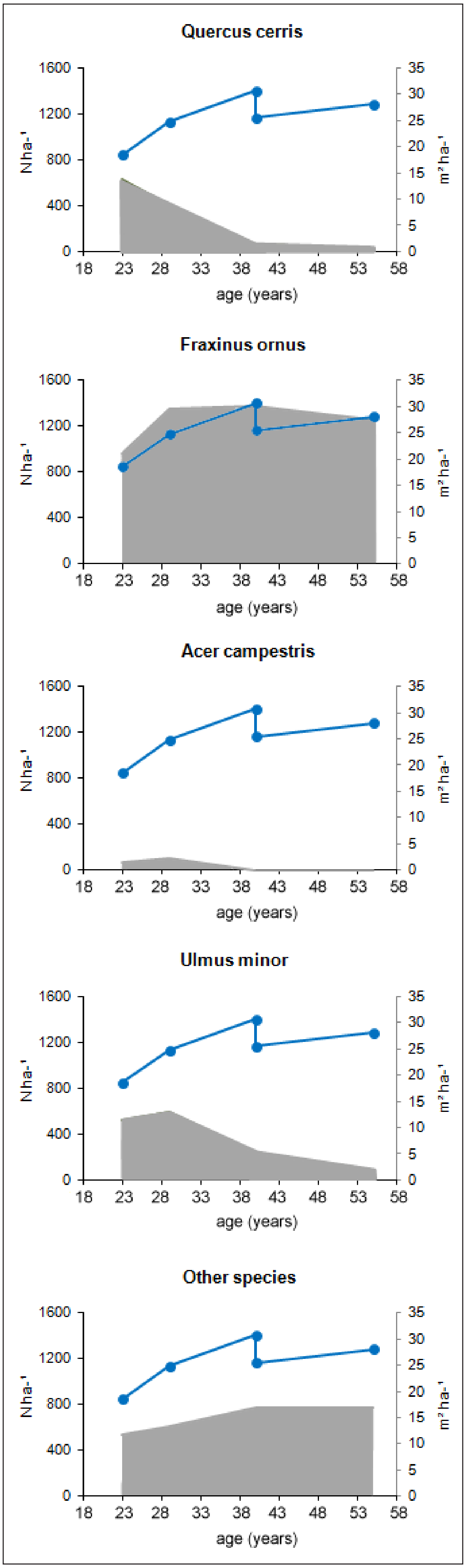

Figure 15 - Compositional diversity (number of trees per species = grey area) in the understory of a Turkey oak-dominated coppice under conversion to high forest and its change as a function of stand age and basal area in the main crop layer (blue line) used here as a proxy of upper canopy cover.

deadwood accumulation rate of about 0.5 Mgha-1 at all the sites (Bertini et al. 2010, 2012). This value ranges from 1/9 to 1/11 of the mean above ground biomass accumulation rate.

Also, compositional diversity follows different patterns under the same conditions according to specific ecological requirements. The presence-abundance and the time trend of complementary tree species living in the understory of a Turkey oak-dominated coppice under conversion into high forest are shown in Fig.15 (Fabbio and Amorini 2006).

Within the level II-ICP network in Italy, the outgrown coppice plots showed cases of dynamic-specific and structural stand rearrangement and among the highest values of tree richness (Fabbio et al. 2006b).

Another attribute relevant to the dynamics of coppice forests aged 40 to 60 years is the production of litterfall and leaf litter as compared with temperate-warm and temperate-cold forests (Fig.16). The ratio of leaf litter to total litter is about 70%; a typical figure for young, productive forests. In thinned stands, Leaf Area Index reduction to 4-5 optimises the Net Assimilation Rate and increases the Net Primary Production (Cutini and Hajny 2006). The amount of seed production and the frequency of mast years are species-specific traits. Turkey oak shows an annual production five times higher than beech on average (0.70 vs. 0.13 Mgha-1), which is also due to the much more frequent occurrence of

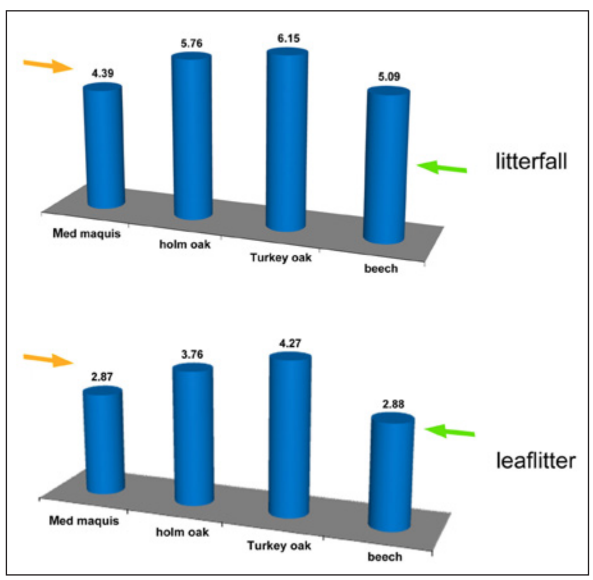

Figure 16 - Average litterfall and leaflitter production (Mgha-1) in coppice stands aged 40 to 60. Arrows show the average for temperate-warm (left) and temperate-cold (right) forests (sources: Bray and Gorham 1964, O'Neil and De Angelis 1981, in Cutini and Hajny 2006).

mast years (Cutini 2000 and 2002). These attributes become of major concern at the time of stand regeneration from seed.

A paradox is finally evident if we account for the damage due to wildlife browsing on stools resprouting. The 86% of Turkey oak stools browsed the first year after coppicing did not survive over the following two years (Cantiani et al. 2006). An average reduction of standing volume up to 57% and 41% was determined six and eleven years after coppicing, respectively (Cutini et al. 2011). The issue is of even greater concern when it becomes the driver for the successful resprouting of outgrown coppice stools as reported by Pyttel (2015) for sessile oak stands aged 80-100 years. This 'modern' disturbance may be heavier than the past practice of grazing by domestic animals and is can compromise the whole wood production cycle. The issue at hand puts forward the critical question of wildlife conservation practice, i.e. protection or breeding?

The most recent research issues at the CREA trials dealt with: forest management and water use efficiency (Di Matteo et al. 2010), environment-induced specific adaptive traits and C and N pools by different compartments (Di Matteo et al. 2014ab), seed production patterns (Cutini et al. 2010, 2013), management of the final phase of conversion into high forest, i.e. the implementation of regeneration cuttings (Cutini et al. 2015), the long-term response of coppice conversion to high forest experiments (Chianucci et al. 2016) and, again, the wildlife browsing impact on stools' resprouting (Chianucci et al. 2015).

Main traits and role of the management areas established on the former coppice cover

Land use and land use change

The original coppice system area underwent a significant reduction some fifty years ago. Land use and land use change are consistent with the dynamics of social and economic context. Both originate from factual needs and when the related commodities can be usefully replaced, produced elsewhere or the customary use is no longer profitable, land use is abandoned (Del Favero 2000) or changed (Mottet et al. 2006). Other spontaneous or man-induced changes have taken place in the landscape matrix since the time of coppice abandonment on less accessible and less fertile sites. The natural afforestation of open areas (abandoned fields and rangelands) contributed to the steady increase of forest-type cover, reduced the patchy distribution of open areas and homogenized the forest cover over the last decades. The establishment of agro-forestry systems and, more recently, of short rotation forestry on lands set aside by the agricultural practice have modified the human-imprinted landscape. The newly-established tree farming created further interfaces between rural and urban areas on the plains or hilly sites no longer favourable for agriculture, but fertile enough and with good access with respect to intensive wood production. This sequence contributes recent traits of landscape dynamics. Our perception of land use is first supported and consolidated by the long-lasting direct, visual/physiognomic experience and then transferred by documental sources. This is the way a common 'heritage' value is established over generations.

If the balance between practice and its profitability and/or replaceability historically dictated land use, the modern acknowledgement of complementary societal benefits arising from its maintenance can move, to some extent, the point of balance. In this case, the community should reward the fulfilment of shared common benefits and contribute to the feasibility of the use in concern. This seems to be the basic condition for answering some questions. Reference is made to the manifold calls for coppice recovery as a heritage value or the driver of 'bio-cultural diversity' (Burgi 2015) where it was historically present, but independently of its current, profitable implementation. Also, the frequently asked question about the evidence of vegetational and faunal diversity loss (Kopecky et al. 2015, Vild et al. 2013, Mullerova 2015ab) being closely linked to the short-term opening of patchy clearings in the forest cover as in the former coppice system (Kirby 2015) should be settled within the same frame of reference.

The area managed under the coppice system

Easily-accessible areas to make profitable wood harvesting, good site fertility allowing sustained growth and closeness to the market are the basic requirements for effective management of today's coppice system. The updating of management criteria includes: (i) lengthening customary rotations, (ii) recovery of technical function for 'standards' release (i.e. reducing their number, effective selection of dendrotypes, and suitable spatial arrangement), (iii) obtaining certified productions, and (iv) search for the optimal size, shape and contiguity of clearings according to the different physical environments.

The main purpose of maintaining a coppice system is still firewood production, but there are other complementary benefits such as the contribution to the landscape mosaic texture providing specific habitats, types, and patterns of diversity (Mairota et al. 2014, Burgi 2015, Hédl et al. 2015) which is also linked to the early successional stages inside the clearings (Kirby 2015).

The emerging green economy issues (Marchetti et al. 2014), the structural change from a fossil-based economy to a bio-based economy (Corona 2014), and the increased demand for renewable energy resources may be the turning point which addresses the forthcoming role of coppice forests. Positive factors remain the basic attributes of the system, i.e. the easy management technique, the guarantee of natural regeneration, the flexibility/reversibility, and the resistance/resilience. In this regard, the adaptability of oak coppice forests to changed conditions, namely water management, is reported by Splichalova (2015), whilst the higher drought tolerance of sessile oak resproutings vs. seedlings under soil moisture limiting conditions is underlined by Holisova et al. (2015) and Pietras et al. (2016). It is also worth recalling that resprouting ability has been one of the most important keys to the building up of the paradigm of resilience and post-disturbance auto-successional nature of Mediterranean coppice forests (Espelta et al. 1999, Konstantinidis et al. 2006, in Lopez et al. 2009).

The more manageable length of stand lifespan compared with the high forest system widens the options for handling the risk and unpredictability of climate shift in the primary phase (regeneration) and throughout the forest cycle.

Further concurrent elements today are the chance to select contexts optimal to cultivation within the former coppice area, the reduced impact of historical overlapping uses, the reasonable less intensive management ruling the system, the improved knowledge achieved so far about the bio-ecological functioning (drivers, limiting factors, and feedbacks), the above and below-ground dynamics, and the growth patterns.

Final harvesting: the irregular shape of the cutting areas edge results in a lower visual impact even in case of large clearings (northern Apennines).

Special focus is being developed and consistent techniques are applied to the effective tending of valuable, even sporadic tree species within coppice stands (Pelleri, *this paper*).

Besides all its positive traits, coppice remains a low-input, high-output energy system compared to other silvicultural systems because of the natural assurance of crop regeneration. This is why, looking back but ahead too, a consistent definition of coppice may be today ‘a very ancient but modern system as well’ (Fabbio 2015).

Conservation and enhancement of sporadic tree species living in coppice forests: the CREA experience

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‘Sporadic tree species’ means trees living both as individuals and small groups within a forest stand; they are often able to produce quality timber, and valuable broadleaved tree species are included within this category (Mori et al. 2007). Following the ageing of unmanaged coppice stands and the customary practices of conversion into high forest, the progressive reduction of sporadic tree species is usually recorded, since most of sporadic tree species are less competitive than dominant tree species (Mori and Pelleri 2012). Because of their attributes (light-demanding, poorly competitive, reduced growth), such species are very sensitive to any practice going to change stand structure parameters. Their maintenance and increase in value runs through practices targeted to complying with their auto-ecology. The tree-oriented silviculture, an approach developed in central Europe for oak, beech and spruce high forests (Abetz 1993, Sevrin 1994, Bastien and Wilhelm 2000, Abetz and Kladtke 2002, Wilhelm 2003), especially fits both conservation and enhancement of sporadic tree species in coppice forests (Spiecker 2006, Spiecker et al. 2009, Sansone et al. 2012, Pelleri et al. 2013 and 2015, Manetti et al. 2016).

Appropriate fields of application

The economically feasible and successful practice of tree-oriented silviculture in coppice forests is based on the selection of a limited number of suitable trees as for vigour, stem quality and crown quality. Prerequisites are the presence of these dendrotypes, well-accessible sites, favourable ecological conditions. Under these assumptions, tree-oriented silviculture can ensure the persistence of these species, their natural regeneration and the increase of valuable timber production. Thinnings localized around a limited number of selected trees allows to manage the remaining standing crop as in the customary way, without reducing noticeably the firewood production of the coppice system (Sansone et al. 2012, Mori and Pelleri 2014).

This approach was recently applied within the LIFE-PProSpoT in coppice forests in central Tuscany on an overall area of 53 hectares. Ten to twenty target trees per hectare were promoted by localized crown thinning to get their free crown expansion. Trials were undertaken both in young and ageing coppice stands.

The young coppice stands

The enforcement of tree-oriented silviculture in stands aged 10-15 years allows the conservation of compositional diversity, as well as the promotion of growth pattern and timber value of the selected trees. A notable increase of radial increment from 1-2 up to 5-7 mm per year has been reached in a few years in service tree and wild service tree, whilst the growth rate has increased from 2-4 up to 8-10 mm per year in field maple. Stem diameter increment similar or higher can be achieved by field elm and wild cherry (Wilhelm e Ducos 1996, Nicolescu et al. 2009, Manetti et al. 2016, Giuliarelli et al. 2016).

The maintenance of these growth rates implies heavy crown thinnings repeated every 6-8 years to get the crown release of 2-3 m, or less intense (1-2 m of crown release) but more frequent thinnings (4-6 years).

Wild cherry target tree in a chestnut coppice stand aged 16 years before thinning.

The ageing coppice stands

Practices are aimed at favouring more the conservation and fruiting of sporadic valuable tree species, whilst less achievable is the increase in value of wood production. Light-demanding species are especially unable to react to late thinnings (service tree, European ash, wild cherry, peduncolate oak, etc.), whilst the reaction ability is more evident for shade-tolerant species (wild service tree, linden, sycamore, holly tree, etc.) even in the late life-span; these are less-sensitive to tree competition and maintain a more deep and efficient crown, just able to react also to late openings (Rasmussen 2007).

Wild service target tree in a mixed coppice forest aged 15 years.

The 'standards' release

At coppicing, it is advisable to protect the young selected trees with a belt of shoots (grouped standards release) to avoid any damage due to the sudden isolation (stem quality worsening, e.g. growth of epicormic branches or stem breakage). Large-sized sporadic trees provided with well-developed crowns may be released as individuals without any significant risk. The grouping of standards may be supplemented by the customary release of individuals of the main and sporadic tree species (Mori and Pelleri 2014).

The use of the proposed tending techniques may result in the successful maintenance and improvement of wood production value as well as in the preservation of a higher compositional diversity.

The post-cultivation area or the outgrown coppice stands

Outgrown coppice stands are widespread under marginal conditions in terms of accessibility and site quality, but they are also widespread in public-owned areas and in areas designated for nature conservation. Here, main forest functions are the soil protection or its recovery, the re-establishment of habitats similar to those former to human-imprinting, the carbon stock and sequestration (mitigation), the contribution to landscape texture, and the maintenance of specific habitats for biodiversity conservation. Small-scale silvicultural practices should be introduced to allow the maintenance of target tree species, stand structural and compositional diversity into the abandoned mosaic-like structures where protection is also a target issue (Garbarino et al. 2015, Urbinati et al. 2015). New adaptive rules allowing the coexistence of gamic and agamic regeneration in the same stand have been recently introduced in northern Italy (Motta et al. 2015).

The increased forest area under different protection levels, the enforced regulations heavily limiting or making difficult the implementation of any form of management for wood production – independently of bio-ecological conditions and site location suitable for harvesting – have contributed to the unmanaged coppice area increasing. Hence, forests also susceptible to still being under sustainable coppice system rules but included in areas protected today as a whole, are not effectively manageable (Mairota et al. 2016b). Due to this conservative position, a non-defined permanence time of stands and minimal interventions addressed to promote seed regeneration are foreseeable at now.

A point of concern is provided by the high amount of standing and lying woody necromass in these overstocked types making them very sensitive to fire. This issue has to be taken into account by managers of large, continuous forest covers within environments prone to wildfire occurrence (Corona et al. 2015).

The coppicing of aged crops provides case studies of utmost importance in order to collect grounded evidence about the long-term resprouting capacity of stools. An inventory of these cases and their analysis would be the main source of knowledge for the time being. It might provide, in addition to the very few trials established in between, the necessary expertise to again undertake coppicing under suitable conditions, to meet the renewable bio-energy demand, and reduce the unmanaged areas.

Suitable conditions mean the occurrence of: (i) geomorphological and soil attributes allowing repeated clearcutting even with doubled rotation lengths, (ii) good site quality for sustained and sustainable firewood production, and (iii) well-accessible locations allowing the reduction of harvesting costs.

The area under conversion into high forest

The main goal of the conversion of coppice into high forest is to anticipate the recovery of former high forest structure managing timely the outgrown coppice crops. The choice is consistent with sites fertile enough and stand textures sufficiently dense to get the awaited outcome within the conversion cycle. The periodic revenues from thinnings make this option economically enforceable to different sizes and types of ownership. The presence of valuable, even sporadic, tree species is an added value here.

Less relevant in terms of total area, this option has special significance in the public domain, where a share of the wide forest cover which is no longer harvested is available to a pro-active, adaptive silviculture. The decision to undertake such silviculture should be pursued according to a few, logical steps. The mountain areas, where the coppice system has been suspended earlier because of lower profitability and higher environmental sensitivity, should be taken into account first. Then, the areas which are valuable because of tree-specific composition and of scenic value, or under-targeted conservation, may be included in this option. Management rules are the tending practices applied to standing crops up to their regeneration from seed (Amorini and Fabbio 1990, 1994, 2009, Alberti et al. 2015). Adaptive strategies may be usefully added to the thinning methods in use to implement a higher canopy differentiation of standing crops already in the second half of the conversion cycle. This implies the selective tending of best phenotypes to favour individual crown development and to reduce the evenness of the one-storied stands (Fabbio et al. 2014).

The main purpose of this choice remains a more suitable balance between wood, non-wood productions, and environmental functions as in the

Harvested coppice area a few years after coppicing. The irregular shape of clear-cut makes easier the physiognomical re-establishment within surrounding texture (holm oak forest, southern Italy).

traits of the high forest system. It implies a more extended lifetime and the implementation of the intermediate set of silvicultural practices ensuring the awaited growth pattern of the selected shoots in the main crop layer as well as their health and vitality throughout the conversion cycle and up to the regeneration from seed.

Conclusive remarks

Each management type which has arisen from the common coppice matrix shows peculiar and consolidated features. All of them have become established as a result of factual macro-economic conditions and provide a range of goods and benefits. They basically run according to different management criteria, intensity, and the type of applied practices up to post-cultivation. Further inherent or practice-driven dynamics will be determined by criteria prevailing at the multiple decision-making levels and by changing scenarios as well (Millar et al. 2007, Lindner et al. 2010).

Stakeholders, planners, and managers should envisage all the available options and their possible connections on the ground as well as their complementarities in landscape planning.

They should also acknowledge the consistency of each choice according to the prevailing local function(s), the site quality, and the bio-ecological conditions at the operational scales of silviculture and forest management, i.e. from the stand up to the forest compartment level.

This rationale accomplishes and supports many, already well-achieved, statements. Among these, worthy of mention are: [...] the establishment and mosaic of the different choices builds up the organic development of land matrix and its connections (Franklin 1993); [...] intensive to extensive cultivation systems up to pure conservation tailored at the local scale may coexist and implement diverse development stages and structural diversity from stand up to landscape level (Fuhrer 2000, Farrell et al. 2000); [...] the complex and varied physical context allows post-cultivation and pro-active management approaches as well, both of them being strategic and complementary (Di Castri 1996, Teissier Du Cros 2001, Palmberg-Lerche 2001, Fabbio et al. 2003).

The forthcoming challenge will be the tuning of management strategies so they are able to make the system function effectively under the new condition(s). Two main open questions remain for coppice forests as for any other biological system living within a changing growth medium. Are we moving from a steady state to a perennial transition? Furthermore, how much of the inherent ecological buffer has been/will be eroded in between?

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1988, the digging trial.

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