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European ash (*Fraxinus excelsior* L.) secondary forests in Italy: management system and timber properties

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ABSTRACT

Secondary forests have recently reached a notable importance in terms of extension, increasing the forest area in central Europe, and opening new questions about their management. In the Italian pre-Alpine region ash-lime and ash-sycamore forests cover more than 150.000 hectares. Usually these new forests occupy private lands abandoned after agricultural practices. These forests are generally left to natural evolution or managed as coppice for firewood production.

To address possible uses of ash timber from secondary forests, we carried out a physical and mechanical characterization on logs from two study areas in north-eastern Italy. The timber characteristics of two ash stands, aged 37 and 60 years, have been obtained analysing 35 plant stems. We calculated wood density at 12% moisture content, wood basic density, radial and tangential shrinkage, the ratio between tangential and radial shrinkage and module of rupture and module of elasticity. Presence of black heart was estimated in the transverse area on each tested sample. Results show that timber obtained from the two studied stands present good mechanic and physic properties suitable for saw-timber and veneer uses. The high presences of black heart, especially in the older stand, modify wood physical properties and undervalue strongly the timber for aesthetical applications.

A different forestry approach has been applied to obtain trunks of commercial dimension in shorter rotation (< 70 years), reducing in this way the incidence of black heart. Single tree oriented silviculture could be an interesting management able to increase diametric growth and to produce trunks of 60 cm in less of 70 years, decreasing the presence of black heart in the stems.

1. INTRODUCTION

In the last 50 years, Italian forest area have been growing at the annual rate of 15.000 hectares per year (Piussi 2006). The main reason explaining this trend is the abandonment of agricultural lands and pastures allowing new forests to spread out. A large part of these forests has been driven by secondary successions, in which sycamore, linden and ash represent typical species. Secondary forests reached a notable territorial importance in northern Italy mainly in the pre-Alpine region. According to IFNC (National Forests and Forest Carbon Sinks Inventory) sycamore-linden and ash forests occupy a surface of 153.904 hectares, mainly (88%) located in northern Italy (MIPAF 2007). A large part of these stands are secondary forests (Del Favero *et al*. 1998) and have colonized agricultural lands and pastures. These post-pioneer species have shown a strong dynamism able to colonize after a short time fertile and fresh abandoned agricultural and pasture lands (Bernetti 1995, Dobrowolska 2011).

Nowadays, these forests are not managed and they are left in natural evolution and subsequently managed with coppice system to produce only fire-wood without enhancing the remarkable potentiality for high quality timber production obtainable from these two species. Ash stands in natural evolution show high densities and strong competition between plants and low diametrical increments in dominant trees. In these forest, ash reach

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merchantable dimension only after more than 60 years, with frequent presence of black heart in the stems (Thill 1970, Petrucci and Uzielli 1984, Duflot 1995, Kerr 1995 and 1998, Del Favero 1999, Kadunc 2005).

The aim of this work is to evaluate the physical and mechanics characteristics of ash timber and verify the presence of black hearth in ash secondary forests, at different ages, unmanaged or managed in traditional way. Different forestry approach can be applied to verify if it is possible to produce ash logs with commercial dimensions (DBH 50 cm) in shorter rotation, with management system characterized by early and frequent thinnings from above around a limited number of target trees (50-100 per hectare) (Duflot 1995,Bastien and Wilhem 2000, Wilhem 2003, Spiecker *et al*. 2009). This new silvicultural approach (Single Trees Oriented Forest Management - STOFOM) rather common in central Europe but almost unknown in Italy, has been recently applied in same stands of the pre-Alpine region (Pelleri 2000, Pividori 2002, Pelleri and Fontana 2004, Pelleri *et al.* 2009, Giulietti *et al*. 2009).

2. Materials and Methods

The investigation was carried out in the Agno-Chiampo forest district (Veneto pre-Alps, north-east Italy), and specifically in Recoaro Terme Municipality where mainly ash-sycamore secondary forests are located. The climate of the area is temperate-cold with ocean influence, annual rainfall is high (Recoaro Terme 2149 mm); the mean annual temperature reaches 10.4° C. The geology of the area is very variable: metamorphic rocks prevail on the higher portion of the Agno river basin while near the Little Dolomite mountain range dolomite rocks are prevalent. The soils are also variable in composition and depth and with pH from sub-acid to sub-alkaline (Pelleri and Fontana 2004).

The study plots are two ash secondary forests with different ages (37 and 60 years), both are in high forest stage and were thinned in 2005. In both stands the silvicultural approach was oriented to improve the structure and the stability of the whole stand applying traditional management procedures characterized by thinning from below.

The younger stand (MS aged 37 years), was previously thinned in 2000, followed from a second mixed thinning in 2005 (Tab.1a). The older stand (LR aged 60 years) is an ash high forest characterized by the presence of sycamore (*Acer pseudoplatanus* L.), grey alder (*Alnus incana* (L) Moench) and a by an irregular brush layer of hazel (*Corylus avellana* L.). This stand had colonized an abandoned wet pasture. In 2005 a thinning from below was applied to the whole stand, together with the opening of new little gaps and the enlargement of previous gaps present in the canopy cover. This type of forest management (preparatory cutting) has been realized in order to prepare this stand, till now unmanaged, to the regeneration phase (Tab.1b).

Table 1a: Forest stand characteristics in MS plot during the second thinning (dgm: diameter of mean basal area; Hgm: mean height; HD: dominant height; BA: basal area; V: volume).

MS	**Unit**	**2nd thinning**		
		before	**felled**	**after**
Trees	n ha^{-1}	1020	368	652
dmg	cm	18.2	17.8	18.4
Hmg	m	25.8	25.5	26.0
HD	m	33.3	-	-
BA	m^2 ha^{-1}	26.56	9.16	17.40
V	m^3 ha^{-1}	299.1	101.6	197.5
ash	n%	77	97	71
sycamore	n%	8	3	12
other species	n%	15	0	17

Table 1b: Forest stand characteristics in LR plot during the preparatory cutting (dgm: diameter of mean basal area; Hgm: mean height; HD: dominant height; BA: basal area; V: volume).

LR	**Unit**	**preparatory cutting**		
		before	**felled**	**after**
Trees	n ha^{-1}	552	234	318
dmg	cm	23.7	20.3	25.9
Hmg	m	26.4	24.9	27.2
HD	m	33.4	-	-
BA	m^2 ha^{-1}	24.36	7.57	16.79
V	m^3 ha^{-1}	245.7	79.8	165.9
ash	n%	80	93	70
other	n%	20	7	30

Another young stand (COV) has been considered because managed with STOFOM system (Giulietti *et al*. 2009). COV is a young dense mixed ash-sycamore stand grown in a former fertile agricultural land and pasture. At the moment of the first thinning (2001) it was still in the thicket-pole stage and later other two thinning in 2004 and 2010 have been carried out. This stand have been thinned three times at the age of 14, 18, 24 years (Tab. 2).

Table 2: Forest stand and target trees characteristics in COV plot during the thinnings.

COV	Unit	1st thinning (yr 2000) before	after	2nd thinning (yr 2004) before	after	3rd thinning (yr 2010) before	after
Trees	n ha^{-1}	5851	4660	4315	3581	3000	2485
BA	m^2 ha^{-1}	19.09	17.32	20.2	12.68	17.92	11.43
100 target trees							
DBH	cm	11.8		15.5		20.1	
Height	m	13.0		16.4		19.1	
Crow insertion	m	5.8		7.1		8.9	

2.1. PRESENCE OF BLACK HEART (BH) IN THE BASAL SECTIONS OF FELLED TREES

The wood characteristics of two ash stands have been obtained analysing 35 mean DBH stems (10 and 15 respectively). For each tree sampled three trunks (70 cm long) were collected and than delivered to the laboratory for the following mechanical and physical analysis.

The presence of black heart (BH) was estimated in the trunks coming from both the stands, analysing also the basal section of 69 felled trees. For each tree one of the following category has been attributed on the base of BH incidence: 1- absent, 2- presence of black heart in less than 20% of the stem diameter, 3- presence of black heart between 20% and 30% of diameter, 4- present of black heart more than 30% of diameter.

2.2. MECHANICAL AND PHYSICAL CHARACTERIZATION

The basal stems were sawed longitudinally to obtain 4 radial boards 3 cm in thickness and pith to bark wide. The boards were stack up and conditioned at 20°C and 65% air relative humidity. After the boards reached a constant weight, they were sawed and planed in 2x2 cm sticks, which were cut to obtain the samples to perform mechanical tests. Sampling methods and general requirements for the physical and mechanical tests were based on ISO 3129. Small clear samples were obtained for density (ISO 3131), bending strength and modulus of elasticity (ISO 3133), and dynamic modulus of elasticity. The mechanical tests were performed on an Instron universal testing machine. All specimens were loaded under displacement control. For all specimens the load and the crosshead displacement of the testing machine were recorded continuously. After the mechanical strength tests the moisture content of the samples was measured according to ISO 3130 and the strength values corrected accordingly.

To investigate the possible role of the black heart of the physical and mechanical properties in ash wood, we compared the variable in tested samples having 0% and 100% of incidence of black heart as evaluated by naked eyes directly on the tested sample. The comparison was possible only for physical wood properties. We performed T student test to compare the mean value of each variable and tell if they differ or not.

2.3. DIAMETER INCREMENTS ANALYSIS OF DOMINANT TREES

During the thinning operation in each stand a sample of DBH sections was carried out to analyse the trend of diameter increments of dominant trees. The sampling operations have been carried out in MS (during the first thinning1999), in COV (during the first thinning 2000) and in LR (during the preparatory cutting 2005). The DBH sections have been analysed using e dendrocronograph SMIL 3. The mean annual increments of 4 radial readings from each tree have been averaged and transform in diameter. The series of mean annual increment (MAI) of each tree has been synchronized (according to the age) and averaged with the other trees of the stand.

The effect of different types of management (traditional and STOFOM) has been analysed comparing MAI derived from dendrochronological investigation with the MAI derived from the monitoring of dominant trees DBH selected in MS and dominant target trees DBH selected in COV. In particular in MS the effects of thinning on DBH growth has been evaluated monitoring a sample of 69 dominant trees (270 trees per hectare) from 1999 to 2006. In COV a sample of 25 target trees (100 TT per hectare) in the thinned plot and 11 trees (100 TT per hectare) in the control plot has been monitored from 2001 to 2011.

In figure 1 for each stands the series of MAI measured in the DBH sections sampled during thinning (continuous line) and those directly measured in the sample of dominant ash trees selected (dotted line) has been plotted together.

3. RESULTS AND DISCUSSION

3.1. PRESENCE OB BLACK HEART IN THE BASAL SECTIONS OF THE FELLED TREES

In the younger stand (MS aged 37 yr.) none of the analysed trees present black heart in the basal section. In the older stand (LR aged 60 yr.), black heart was found in 52% of the sampled basal section: 26% of tree was in category 2, 12% in the category 3 and 14% in the category 4.

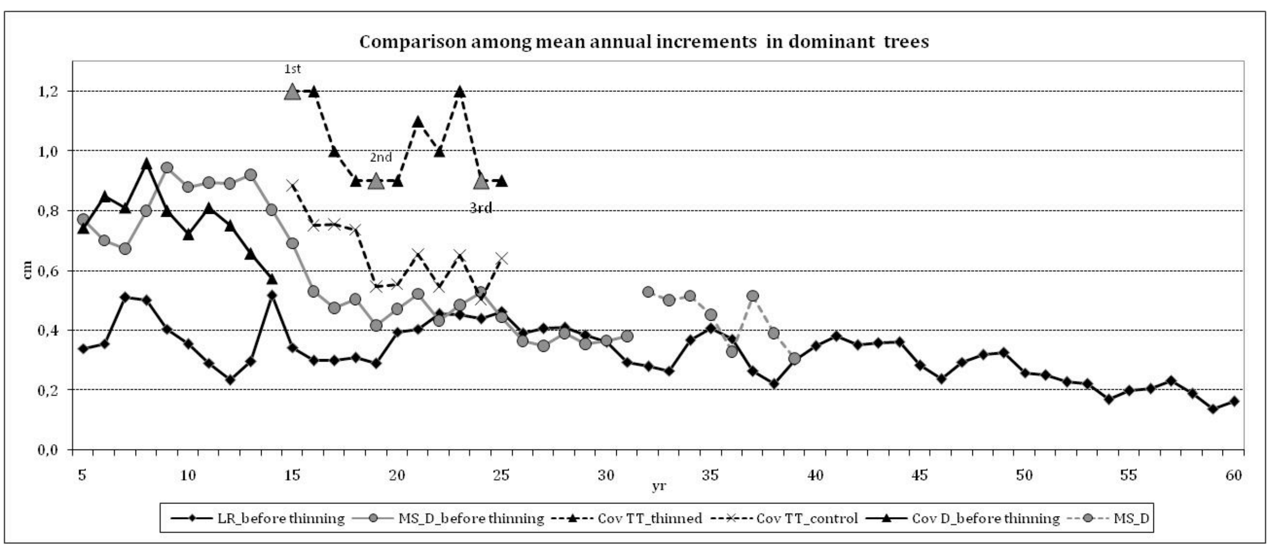
3.2. DENDROCHRONOLOGICAL ANALYSIS OF DOMINANT TREES

In LR the ash natural colonization of abandoned pasture was more slow and irregular caused by an articulate morphology and different vegetation cover of soil. In the wet low land, young seedlings remain under the cover of the typical vegetation of wet pasture (dominated by *Veratrum* spp. and *Petazites* spp.). In other part of the area an irregular cover of hazel have initially reduced the speed of the colonization of the tree species and also the growth in height and diameter. In the slope and in the hill, where hazel wasn't strong, the regeneration was more rapid. These different situations have caused a more slow and irregular growth during the first competition cycle. In the following years, increments decrease progressively until around 0.2 cm (Figure 1).

COV and MS, stands characterized by a rapid colonization of the area, present a similar initial trends (Figure 1). MAI shows a first maximum (1.0 cm for both stands,) around 10 years and than decrease. Similar results have been obtained in other research in the Italian pre-Alps (Pelleri 2000).

In COV after the first competition cycle the dominant competitor, felled during the first thinning, present at the age of 14 years a MAI of 0.6 cm. At this age the effects of heavy and localized thinning from above are immediately evident and the target trees react with increment of 1,0 cm and more. This growth rhythm can be kept constant repeating similar thinning every 4-6 years according to Single Trees Oriented Forest Management (STOFOM).

Figure 1: Comparison among mean annual increments in dominant trees felled during thinnings and dominant trees monitored after thinning occurrences (1st, 2nd, 3rd: COV thinnings).



3.3. *MECHANICAL AND PHYSICAL CHARACTERIZATION*

The results from the physical and mechanical characterization confirm, in general, previous data on ash properties (Giordano 1987), but also present new values such as green wood moisture content (Tab 3).

Table 3: Mechanical and physical characterization of ash wood.

	ID	Unit	Mean	s.d.	N
Wood moisture content in fresh wood	U_f	%	48.2	10.02	373
Equilibrium wood moisture content	U_{eq}	%	11.9	0.33	375
Wood density in fresh wood	D_f	g/cm^3	0.86	0.08	373
Wood density at equilibrium	D_e	g/cm^3	0.74	0.06	376
Wood density in anhydrous conditions	D_0	g/cm^3	0.70	0.06	376
Wood basic density	BD	g/cm^3	0.58	0.04	375
Longitudinal shrinkage	B_l	%	0.38	0.33	377
Tangential shrinkage	B_t	%	12.70	2.54	377
Radial shrinkage	B_r	%	6.24	1.52	376
Compression parallel to grain	C	MPa	47.44	4.43	85
Modulus of Elasticity - dinamic	MOE_d	MPa	14117	2123	85
Modulus of Elasticity - static	MOE_S	MPa	11096	2294	85
Modulus of rupture	MOR	MPa	102.00	7.99	85
Shear	Sd	MPa	17.74	1.60	85
Brinnell hardness	HB		4.03	0.48	85

The results of the comparison between samples without any visible sign of black heart and samples with 100% of black heart incidence are visible in the Tab. 4.

Table 4: Comparison of physical characteristics beteween ash wood having and having not black heart.

			0% black heart			100% black heart			P
	ID	Unit	Mean	s.d.	N	Mean	s.d.	N	
Wood moisture content in fresh wood	U_f	%	46.77	8.39	346	71.02	8.95	14	< 0.01
Equilibrium wood moisture content	U_{eq}	%	11.95	0.32	345	12.51	0.09	14	< 0.01
Wood density in fresh wood	D_f	g/cm^3	0.85	0.07	346	1.08	0.07	14	< 0.01
Wood density at equilibrium	D_e	g/cm^3	0.73	0.06	345	0.82	0.05	14	< 0.01
Wood density in anhydrous conditions	D_0	g/cm^3	0.69	0.06	346	0.78	0.05	14	< 0.01
Wood basic density	BD	g/cm^3	0.58	0.04	346	0.63	0.04	14	< 0.01
Longitudinal shrinkage	B_l	%	0.37	0.32	346	0.65	0.38	14	< 0.05
Tangential shrinkage	B_t	%	12.53	2.47	346	15.58	2.24	14	< 0.01
Radial shrinkage	B_r	%	6.15	1.47	346	6.84	1.41	14	> 0.05

All the physical properties analysed showed a statistically significant difference in the mean values between sample with and without black heart, beside radial shrinkage. In general ash wood affected by black heart shows higher moisture content in fresh wood, and consequently higher fresh wood density. Both moisture content and wood density at equilibrium conditions were much less different in absolute terms, showing that higher values of those variables in fresh wood are due to higher water content, not to modification at cell wall level. Anyway the basic density value, which show the dry mass in a green unit of volume, is again higher in samples with black heart. A possible explanation to this is the presence of extractives in the wood affected by black heart. These substances are possibly the same that modify the color of the wood.

The dimensional stability of ash wood also differ in relation to the incidence of black heart. We observed higher values of shrinkage values in all the three anatomical directions (only longitudinal and tangential being significantly different). This is also visible comparing the tangential to radial shrinkage ratio, which is lower in wood without black heart (2.03) compared to wood with black heart (2.27).

4. Conclusions

This study showed that the effect of black heart contains more water, it is heavier, and less stable under variations of its moisture content. We do not have any comparison for mechanical properties between wood with and without black heart, but mechanical test results for clear wood suggest similar mechanical properties to European ash from other provenances.

We suggest black heart ash wood to be used in applications that do not require extreme dimensional stability. Also thermal treatment on ash wood effected by black heart can be useful to overpass the coloration aesthetic problem end to stabilize the material.

To reduce the presence of black heart in ash and to obtain a best quality of its timber it is necessary to produce trunks of 60 cm in less of 70 years using a management system that able to have DBH increments around 1 cm; the application of single tree oriented management allows to maintain these growth rhythms.

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