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STAND STRUCTURE AND COARSE WOODY DEBRIS PROFILE OF «LA VERNA» FOREST (AREZZO, ITALY)

This study was carried out in the "La Verna" forest, located in the "Foreste Casentinesi, Monte Falterona, Campigna" National Park at the border between Arno and Tevere watersheds. The forest covers an area of 203 ha and it is owned by the Franciscan religious order. Since 1985 the "La Verna" forest has been managed by the "Casentino" Comunità montana.

In 2008 a sector of about 36 ha was selected for an intensive study of the stand structure, and the quality and quantity of coarse woody debris (CWD). A regular network of 33 sampling point was established.

The average stem density was 473 trees ha^{-1} (range 133-1283) and the growing stock of living trees was 657.1 m^3ha^{-1} (299-1452.9). The average volume of CWD was 66.9 m^3ha^{-1} ranging between 3.7 and 355.8 m^3ha^{-1}. Of the total volume of dead and living trees, CWD comprised 10.2%. Among the CWD the volume of logs (66.1%) was greater than the volume of snags (28.3%) and stumps (5.6%).

The study has emphasized that the "La Verna" forest, besides the historical and cultural value, has an important naturalistic value. The past low-intensity silviculture, traditionally applied by the Franciscan monks, has allowed the development of the current mixed structure and the co-existence in a managed forest of some structural "old-growth" characteristics e.g. the multi-layered vertical structure, the high living biomass and the quantity and quality of CWD.

Key words: dead wood; decay; forest dynamic; beech; silver fir; structure.

Parole chiave: legno morto; dinamica forestale; decomposizione del legno; faggio; abete bianco; struttura.

1. Introduction

Coarse woody debris (CWD) is generally considered as dead woody materials (snags, logs and stumps) of a certain minimum size (e.g. diameter > 5 cm) in various stages of decomposition. In the last decades the ecological

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role of CWD has been fully recognized (HARMON *et al.*, 1986; SPIES and FRANKLIN, 1988) and many studies have analysed the ecological value of CWD for biodiversity (HANSEN *et al.*, 1991; OHLSON *et al.*, 1997; CHRISTENSEN *et al.*, 2005; JONSSON and JONSSON, 2007) and its importance in the functioning and productivity of a forest ecosystem (JANISCH and HARMON, 2002; SPEARS *et al.*, 2003; LAIHO and PRESCOTT, 2004).

The total amount (biomass) and the quality (type, size and stage of decomposition) of CWD occurring in natural forests depends on the forest type, the stage of development, and the disturbance regime (SPIES and FRANKLIN, 1988). In the managed forests quantity and quality of CWD depends on type and intensity of silvicultural practices (GUBY and DOBBERTIN, 1996; SIITONEN *et al.*, 2000). In the last centuries in the Italian forests natural disturbance regimes have been replaced by the human land-use. In the past most of these human activities removed almost completely the CWD from the forests and, consequently, the volume of CWD in Italian forests is considerably low if compared to forests left to evolve naturally (MOTTA *et al.*, 2006; LOMBARDI *et al.*, 2008).

In recent decades, socio-economic organization and public attitudes towards the forest have changed dramatically and forestry has been addressed towards a more near-to-nature approach with the aim of developing forest stands that are comparable to natural ones in so far as structure, composition and regeneration processes are concerned (HARVEY *et al.*, 2002; MOTTA, 2002; BAUHUS *et al.*, 2009; LONG, 2009). In this perspective silvicultural restrictions on CWD removal or silvicultural treatments consistent with the enhancement of the quality and the quality of CWD have been proposed or introduced in many regions (KOHM and FRANKLIN, 1997; LAIHO and PRESCOTT, 2004; KEETON and FRANKLIN, 2005).

The importance of CWD has also been recognized at the political level by the Ministerial Conference on the Protection of forest in Europe (MCPFE - Ministerial Conference on the Protection of Forests in Europe, 2003). Within the MCPFE process a set of Pan-European Criteria and Indicators for sustainable forest Management has been developed (MARCHETTI, 2004). Under criterion 4 "Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems" nine indicators have been adopted and one of them (Criterion 4.5) addresses CWD: "Volume of standing dead wood and lying dead wood on forest and other wooded land classified by forest type".

This study was conducted in the La Verna forest located at the border between Arno and Tevere watersheds in the northern Apennines. The La Verna forest has been managed for the last centuries with a low intensity silviculture (based mainly on single tree or small group selection) aimed to promote not

only the productivity but also its social and scenic values according to the expectation of the Franciscan monks (MIOZZO and BORCHI, 2009).

Our objectives were: a) to characterize the amount and the distribution of CWD in the La Verna forest, b) to delineate the CWD profile e.g. CWD type and decay stage (STOKLAND, 2001) and c) to analyse connections between CWD, land-use, topography and forest structure.

2. MATERIAL AND METHODS

2.1. Study area

The "La Verna" forest (lat. 46°18'N, long. 11°45'E) is located at the border between the Arno and the Tevere watershed (Arezzo, Italia) at an elevation between 1112 and 1266 m a.s.l. The average yearly rainfall is 1224.6 mm and the bedrock is limestone. The forest covers an area of 203 ha and has been owned by the Franciscan religious order since 1203. Since 1985 the "La Verna" forest has been managed by the "Casentino" Comunità montana.

The study area covers 36.3 ha in the upper part of the forest between 1115 and 1247 m a.s.l. (Fig. 1). The tree layer mainly consists of beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.) with sporadic sycamore maple (*Acer pseudoplatanus* L.), ash (*Fraxinus excelsior* L.) and other species, mainly broadleaves with the exception of a relatively small Douglas fir [*Pseudostsuga menziesii* (Mirbel) Franco] stand of artificial origin that has been included in the sampling.

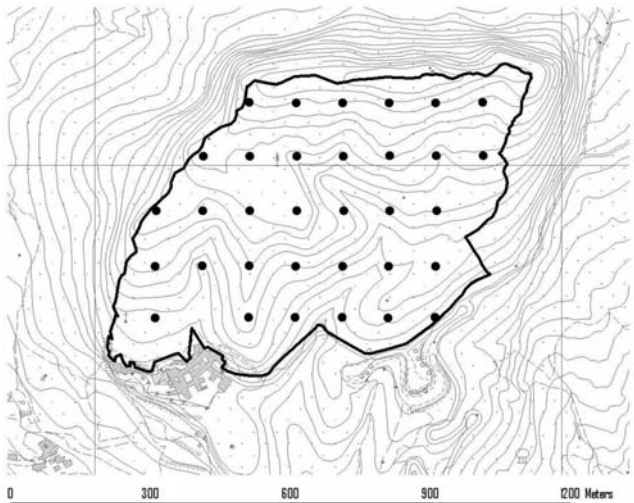

Figure 1 – The "la Verna" forest study area and the sampling point grid.

2.2. Amount of living biomass and amount and quality of CWD in the forest reserve

Sampling points (n = 33) were located on a 100 x 120 m wide regular grid (Fig. 1). Slope aspect and elevation variables were derived from a digital elevation model (10-m resolution) for each sampling plot using ArcGIS geographic information system. In each sampling point, three types of measurement were applied: (1) a circular sampling plots (12-m radius) for live trees measurement, (2) two rectangular plots (50 x 8 m) for the stumps and the snags and (3) two 50 m long transects for line intersect sampling (LIS) for the logs (VAN WAGNER, 1968). For each live tree having diameter at breast height (dbh) > 7.5 cm, dbh and height were recorded. Regeneration (h>19 cm and dbh < 7.5 cm) for each species was counted in the 12-m radius plot.

CWD has been grouped into downed logs (defined as piece of stem or branch that have fallen and have at least 5 cm diameter and length > 1 m), standing dead trees or snags (dead standing trees, dbh> 5 cm and taller than 1.3 m) and stumps (short, vertical pieces created by cutting or by windthrow, diameter at the top > 5 cm and height ≤ 1 m). The separation of snags from logs was at a 45° angle.

For each snag the height and dbh were measured, while the measurement of logs consisted of the diameter at each intersection point. Volume for living trees were calculated according to volume tables from the local Management plan. The volume of logs was calculated using Van Wagner's formula (1968). The volume of standing dead trees was estimated from volume tables, while the volume of the broken snags and stumps was estimated as a frustum of a cone. The decay stage of logs, and snags was classified according to a five classes system and the decay stage of stumps was classified according to a four classes system (MOTTA *et al.*, 2006).

2.3. Statistical analyses

Relationships between forest structure, human disturbance, topography and CWD were investigated adopting a multivariate approach. Principal component analysis (PCA) was used to summarize CWD variability in few uncorrelated variables and to assess their correlations with stand structure, human disturbance, topography and CWD. Each dataset was relativized by the standard deviate in order to put variables, that were measured in different units, on an equal footing (MCCUNE and GRACE, 2002). PCA was performed using PcOrd 5 statistical package (MCCUNE and MEFFORD, 2006) and statistical significance of the axes was tested by a Monte Carlo test (9999 permutations). Moreover, Pearson's correlation between explanatory

variables and the principal components (PCs) was calculated to find out explanatory variables more related to CWD variability.

3. Results

The average density of live canopy trees was 473 ha^{-1} (Tab. 1). Silver fir comprised 47.2%, beech comprised 30.3%, sycamore comprised 6.8%, ash comprised 12.9% and other species comprised 2.8% of live stems. The average volume was 657.1 m^3ha^{-1} (Fig. 2). Beech comprised 60.2%, silver fir comprised 26.5%, sycamore comprised 5.2%, ash comprised 5.3% and other species comprised 2.7% of the total volume. The regeneration density was low having an average of 280 individuals ha^{-1} and ranging between 0 and 995 individuals ha^{-1}. Among the regeneration the most represented species were silver fir (50%) and beech (46.4%).

Table 1 – Density of trees, basal area, volume and density of regeneration in the "La Verna" forest study area.

	Density [n ha^{-1}]	Basal area [m^2 ha^{-1}]	Volume [m^3 ha^{-1}]	Regeneration [n ha^{-1}]
Abies alba	223	13.3	174.3	140
Fagus sylvatica	143	24.3	395.8	130
Acer pseudoplatanus	32	2.4	34.4	1
Fraxinus excelsior	61	2.9	35.1	7
Others	13	1.3	17.5	3
Total	473	44.2	657.1	280
Range	133-1283	24.6-87.3	299.3-1452.9	0-995
St. dev.	277	13.7	260.3	268

The average volume of CWD was 66.9 m^3ha^{-1} ranging between 3.7 and 335.8 m^3ha^{-1} (Tab. 2; Fig. 3). CWD represents 10.2% of the total volume of living trees,. Among the CWD, the volume of logs (44.2 m^3ha^{-1}, 66,1%) was much greater than the volume of snags (18.9 m^3ha^{-1}, 28.3 %) and stumps (3.7 m^3 ha^{-1}, 5,6%).

Decay class III was the modal value for logs followed by classes I, IV and II (Tab. 3). The most decayed class (V) comprised 9.3% of the logs. Decay class II was the modal value for snags followed by class I; together these two classes represent about 90% of the snags. We didn't find any snag in the most decayed class (V). Decay class IV was the modal value for stumps followed by classes III, II and I. The absence of bark and the decay rate made field identification of the species almost impossible for most of the samples (Classes III, IV, V).

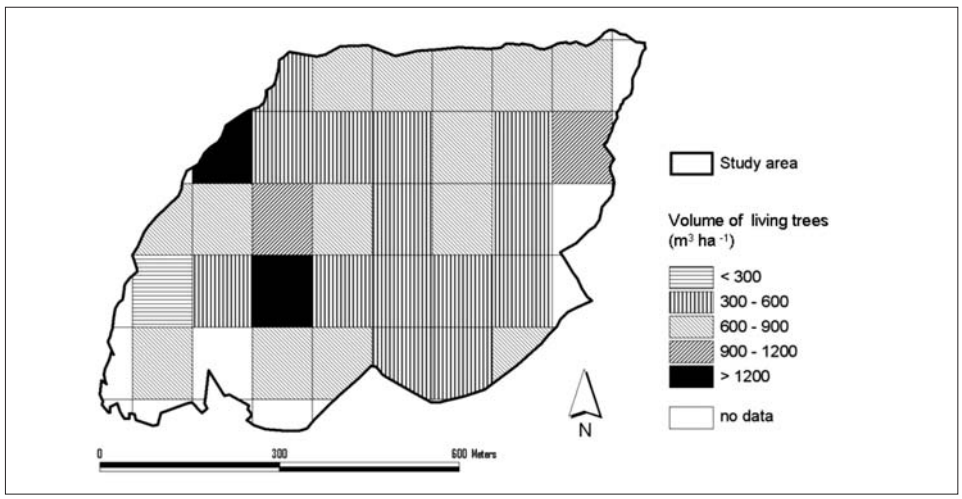

Figure 2 – Volume of living trees (data obtained from each single sampling point).

Table 2 – Volume of snags, logs and stumps in the "La Verna" forest study area.

	Snag [m^3 ha^{-1}]	Log [m^3 ha^{-1}]	Stump [m^3 ha^{-1}]	Total [m^3 ha^{-1}]
Average	18.9	44.2	3.7	66.9
% of the CWD	28.3	66.1	5.6	100
Range	0-199.5	0.9-224.7	0-22.3	3.7-335.8
St. dev.	43.9	58.3	5.5	85.1

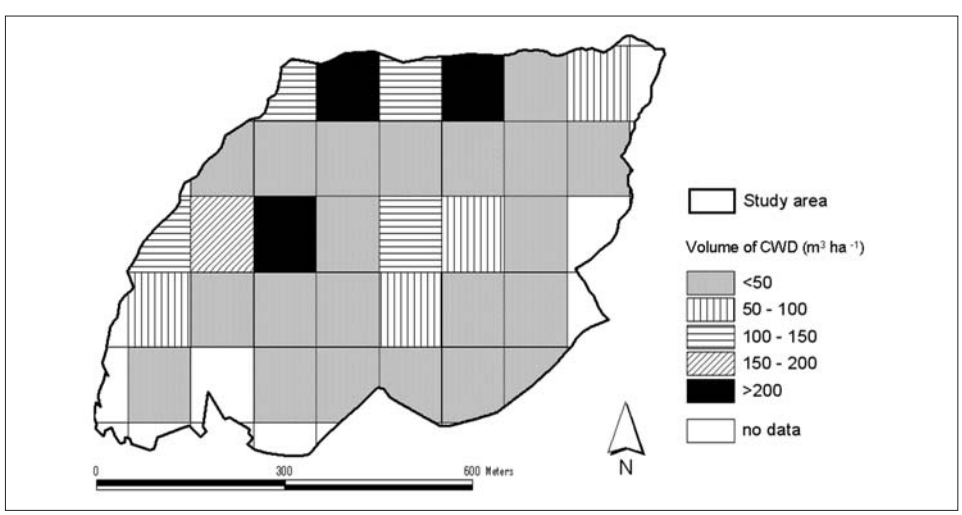

Figure 3 – Volume of CWD (data obtained form each single sampling point).

Table 3 – Percentage of CWD in each decay class.

Decay class	Snags % volume	Logs % volume	Stumps % volume	Total % volume
I	37.5	21.6	13.2	26.4
II	50.6	14.9	13.5	27.8
III	10.7	34.8	22.2	26.5
IV	1.2	19.5	51.2	13.8
V	0.0	9.3	–	5.5

PCA reduced CWD measures into uncorrelated components that explained most of the variation in the original dataset (83.2%). PC 1 extracted 64.44% of the variation in the dataset, and was significantly associated with quantitative CWD variables, particularly with CWD total volume (Tab. 4). PC 2 extracted a lower percentage of variation (18.7%), and was positively associated with log volume and negatively with snag volume. Both axes were highly significant ($p < 0.001$, Monte Carlo test). Elevation, distance from roads and mean DBH were positively correlated with the first component (PC 1) (Tab. 5). Slope was the only variable significantly ($r = 0.34$) correlated with PC 2. The majority of plots having low content of CWD were located at lower elevations were an open canopy structure favored the presence of light demanding species as sycamore maple and ash (Fig. 4).

Table 4 – Principal component loadings for the first three axes for the La Verna study area. Loadings greater than 0.5 (in absolute value) are indicated in bold.

Axes % of variance	PC1 64.44	PC2 18.75	PC3 16.81
CWD	**0.61**	0.03	0.23
Stump	0.41	0.06	**-0.90**
Log	**0.50**	**0.61**	0.31
Snag	0.44	**-0.79**	0.17

Table 5 – Pearson's correlation coefficients of the explanatory variables (topography and forest structure variables) with the first 2 ordination axes (principal components of CWD characteristics). Pearson's r values greater than 0.3 (in absolute value) are indicated in bold.

Axes	PC1	PC2
Elevation	**0.49**	0.18
Slope	-0.01	**0.34**
Distance from roads	**0.33**	0.14
Mean DBH	**0.54**	-0.07
Stand volume	0.21	-0.16
Abies alba volume	0.09	0.01
Fagus sylvatica volume	0.22	-0.16
Acer pseudoplatanus volume	**-0.32**	0.04
Fraxinus excelsior volume	**-0.37**	-0.01

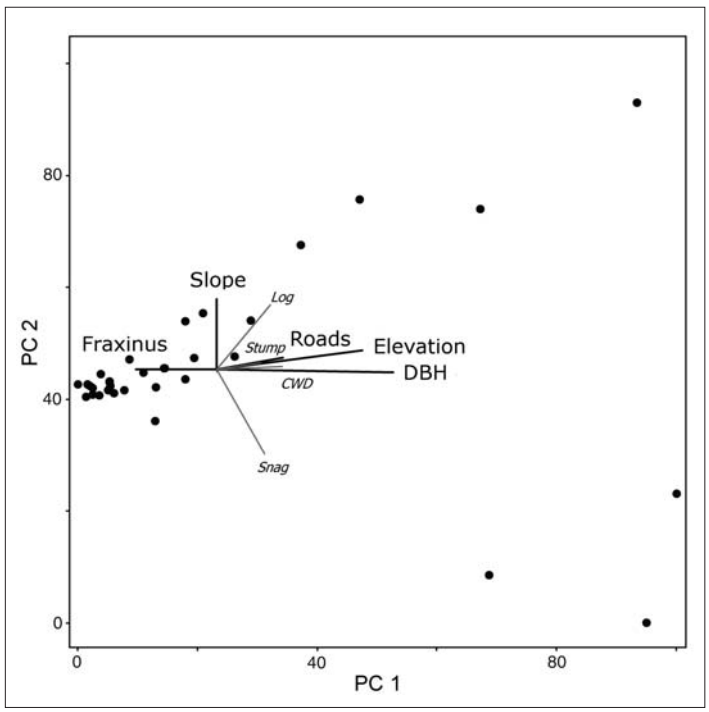

Figure 4 – Biplot from principal components analysis of 30 plots at "La Verna". Correlations of explanatory variables (topography and stand structure) with PCA axes (CWD characteristics) are shown as linear vectors (explanatory = black lines; CWD variables = grey lines). The first and second principal component accounted for 64.44% and, 18.75% of the total amount of variation, respectively.

4. Discussion

Late-seral and old-growth forests are characterized by large volumes of CWD in different stages of decay (Harmon *et al.*, 1986; Spies and Franklin, 1988). The amount and the quality of the three types of CWD in managed forests or in forests that have been withdrawn from regular management represents an historical archive that tells us the recent land-use and disturbance history of the forest and the present forest dynamic and could give us useful information regarding the intensity of the past human disturbances and their present naturalness or hemeroby (Groven *et al.*, 2002; Hill *et al.*, 2002; Çolak *et al.*, 2003; Burrascano *et al.*, 2008).

The "La Verna" forest has a high volume of living trees but the volume of CWD, as expected, is lower than in the old-growth forests, for similar forest type and altitudinal belt, from central Europe (Szwagrzyk *et al.*, 2006; Motta *et al.*, 2008; Holeksa *et al.*, 2009; Motta *et al.*, submitted) where the CWD can be > 300 m^3ha^{-1} (Tab. 6). In the same time the amount and the quality of the dead wood are remarkable if compared not only with the average values of the reference forest type from the National Forest Inventory (Pignatti *et al.*, 2009), or other managed and unmanaged forest of

Table 6 – Stand characteristics for some mixed montane forest from the Apennines, the Alps and the Carphatians. All the stands are late seral but have a different development stage and a different past land-use. The lowest measured dbh was ranging from 7 to 10 cm.

	Country	Density [n ha^{-1}]	Species*	Developmetal stage and land-use	Basal area [m^2ha^{-1}]	Volume [m^3ha^{-1}]	Highest trees [m]	Altitude [m s.l.m.]	CWD [m^3ha^{-1}]	CWD/living o trees rati %	Reference
Lom	Bosnia-Herzegovina	489	Fs, Aa, Pa	Pristine forest, Old-growth	47.1	763.1	50	1250-1522	327.3	42,9	MOTTA *et al.*, submitted
Suchy Zleb	Poland	442	Fs, Aa, Pa	Pristine forest, Old-growth	36.7	446.8	44	1070-1120	159.0	35,6	SZWAGRZYK *et al.*, 2006
Hrončkovský grú	Slovakia	243	Fs, Pa, Fe, Ap, Aa	Pristine forest, Old-growth	41.8	724.4	53	730-1050	306.0	42,2	HOLEKSA, 2009
Val Cervara	Italy	532	Fs	Mature stand withdrawn from regular management	39	497	29.6	1200-1850	61.0	12,3	PIOVESAN *et al.*, 2005
Val Navarza	Italy	688	Fs, Aa, Pa	Mature stand withdrawn from regular management	53.1	594.9	40	1300-1570	45.8	7.7	CASTAGNERI *et al.*, in press
Ludrin	Italy	768	Aa, Pa, Fs	Mature stand withdrawn from regular management	48.3	531.3	42	1250-1350	68.4	12.9	CASTAGNERI *et al.*, in press
La Verna	Italy	473	Fs, Aa, Fe, Ap	Mature stand, low intensity management	44.2	657.1	40	112-1266	85.1	13,0	This paper

*: Fs *Fagus sylvatica*, Pa *Picea abies*, Fe *Fraxinus excelsior*, Ap *Acer psudoplatanus*, Aa *Abies alba.*

the Apennines (MARCHETTI and LOMBARDI, 2006; LOMBARDI *et al.*, 2008; SALVADORI *et al.*, 2009) but also with other Italian forests (PIOVESAN *et al.*, 2005; CASTAGNERI *et al.*, in press) that have been withdrawn from regular silvicultural management and have developed without direct human influence for many decades (Tab. 6).

Decay stage for snags is concentrated in the first two classes while in the logs the modal class is the third. The high proportion of logs in the third and fourth decay stage is the consequence of the fact that most trees have naturally fallen and have never been removed. Furthermore many logs reach the ground when they already are in the third decay class, after a first step as a snag (first and second decay classes) because in the La Verna forest most trees, especially the larger ones, die when they are still standing.

The modal class in the stumps is the fourth and this is probably due both to the fact that in the last decades the silvicultural interventions have been relatively rare and to the fact that in 1943 there has been an important windthrow followed by salvage logging that has partially affected the studied stands (MIOZZO BORCHI, 2009). As expected dead wood is often very unequally distributed across landscapes (LÕHMUS *et al.*, 2005) which causes large variations among sampling plot measurements even on stands having had the same past land-use and belonging to the same forest type and (Fig. 3).

CWD accumulation, both in natural and managed forests, is influenced by a large number of factors, resulting in a complex correlation structure between the involved variables. Thus, few studies have been done developed addressing this issue (HELY *et al.*, 2000; STORAUNET *et al.*, 2000). In "La Verna" forest variables like elevation, distance from roads and mean DBH were positively correlated with CWD total volume. This trend was probably related to the negative elevation effect and to the positive road effect on management intensity (Fig. 4). Human impact on forest ecosystem is generally higher at low elevation, due to proximity to human settlement, accessibility and higher forest productivity (GARBARINO *et al.*, 2009). Stands at higher elevation had higher basal area and lower human impact, and consequently higher CWD volume while stands at lower elevations were more open favoring the presence of light demanding species as sycamore maple and ash.

The present structure, including the CWD profile, of the "La Verna" forest is strictly linked to its past land-use. The management applied by the Franciscan monks was the consequence of the rules and of the feeling that this order had, and still has, toward the forest (BORCHI, 1996). The Franciscan monks were not interested in increasing the properties of the abbey or in carrying out any form of trading since poverty was their most

important precept (AGNOLETTI and PACI, 2001). They cultivated the land necessary to their living collecting and using the amount of firewood or timber needed for this purpose. Timber trade was almost ignored except for the sale of limited amount of wood to local inhabitants. Furthermore, total respect of nature was part of the teachings of San Francis thus no intensive management rules were developed (BORCHI, 2000).

The low intensity silviculture applied has allowed the conservation of old-growth characteristics such as a multilayered vertical structure, large (more than 140 cm dbh) and old (more than 420 years) trees (BORCHI, 2000) and a remarkable amount of CWD (66.9 m^3ha^{-1}, 13% of the living tree volume). These old-growth characteristics are relevant even if compared with forests of the same forest type and of the same altitudinal belt that have been withdrawn from forest management for decades (Tab. 6).

The study has confirmed that the "La Verna" forest, besides the already recognized historical and cultural value, has an important natural value and can be placed among the stands that have maintained some legacies of the original forests that were once widespread throughout the Apennines (DI FILIPPO *et al.*, 2004; BURRASCANO *et al.*, 2008; BLASI *et al.*, 2010).

RIASSUNTO

Composizione, struttura, quantità e qualità del legno morto nella foresta della Verna (Arezzo, Italia)

La foresta della Verna si estende per circa 203 ettari di superficie ed è posta sullo spartiacque tra la valle dell'Arno e quella del Tevere all'interno del Parco Nazionale delle Foreste Casentinesi, Monte Falterona, Campigna. Proprietà dei Frati Minori Francescani dagli inizi del 1200 la foresta è gestita dal 1985 dalla Comunità Montana del Casentino.

Nell'autunno del 2008 all'interno della foresta è stata delimitata un'area di studio di circa 36 ha, ad una quota variabile tra 1100 e 1280 s.l.m., caratterizzata dalla presenza di boschi misti con faggio, abete bianco ed altre latifoglie, pluristratificati e maturi. All'interno dell'area di studio si è proceduto alla individuazione di un reticolo di campionamento sistematico con un passo di 100 x 120 m mediante il quale sono stati localizzati 33 punti di campionamento. In ogni punto sono stati effettuati dei rilievi sulla struttura della foresta e sulla quantità e sulla qualità della necromassa presenti.

L'area oggetto di studio è risultata avere 473 individui ad ettaro (con un range di variazione di 133-1283) con diametro a petto d'uomo > 7,5 cm ed un volume di alberi vivi pari a 657,1 m^3ha^{-1} (range di 299-1452,9). Il valore medio di volume ad ettaro di necromassa è risultato di 66,9 m^3ha^{-1}. Il valore minimo riscontrato è stato di 3,7 m^3ha^{-1} e quello massimo di 355,8 m^3ha^{-1}.

L'area di studio, oltre al riconosciuto valore storico e culturale, ha quindi evidenziato anche un notevole valore naturalistico. La selvicoltura, continua ma di bassa intensità ed indirizzata al mantenimento degli assetti naturali, che è stata

tradizionalmente applicata dai monaci francescani ha infatti mantenuto elementi strutturali tipici degli stadi di sviluppo più maturi: quantità e qualità di legno morto presente, dimensione degli alberi dominanti ed età raggiunta dagli esemplari più vecchi permettono di classificare questa foresta tra i boschi misti di faggio ed abete bianco dell'Appennino che presentano le migliori caratteristiche di vetustà.

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