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STRUCTURAL BIODIVERSITY AND DEAD WOOD IN VIRGIN FORESTS FROM EASTERN CARPATHIANS

SUMMARY

Owing to the high rate of global industrialization, widely distributed forest areas have decreased. Few of these natural forests have succeeded to remain untouched by human activities. The primary ecosystems are characterized by advanced age, high biodiversity and climax condition. These virgin forest, are found in Buzau Mountains, in the Eastern Carpathians of Romania. For understanding and develop the functional principles of virgin forests, field information was collected from three permanent research plots of one hectare area.

Gini index (G = 0,68 – 0,84) and Camino index (H = 1,62 – 1,74) were recorded for all permanent study plots. The obtained values reveal high heterogeneity. Total volume of dead wood is between 54,93 m^3•ha^{-1} (Șapte Izvoare) and 123, 34 m^3•ha^{-1} (Penteleu – Viforâta 2), most of it came from coniferous species (fir and spruce). There have been analyzed the relationships between dead wood and alive components using different statistical distribution functions (Beta, Gamma, Weibull), and the quantity of dry biomass and CO_2 stock from dead wood was estimated.

Keywords: virgin forests, structural biodiversity, Carpathians, dead wood CO_2 stock.

INTRODUCTION

Owning to the high rate of global industrialization widely distributed forest areas has been diminished. Few of these natural forests have succeeded to remain untouched by human activates. Natural ecosystems which have not been influenced by human activities, like virgin stands, have a more complex structure due to their natural dynamics (Hett and Loucks, 1976, Valbuena et al., 2012). The virgin forests present in Romanian Carpathians have a significant importance for the entire Europe, because they keep the natural values which have been lost from other countries' heritage and are very important in protecting, maintaining and monitoring the biodiversity (Ozcelik, 2009).

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An important aspect in stand evolution is the structural biodiversity (Roibu et al., 2008), that is why this element is vital in the research and understanding of the virgin forests functionality.

For describing the biodiversity of stands were used Gini and Camino indexes. Gini index was developed for economical purposes (Sen, 1973, Rouvinen and Kuuluvaien, 2005), but it was also used in ecological studies (Weiner, 1985, Knox et al., 1989, Nilsson, 1994, Stocker, 2002), being the most representative index for structural diversity (Roibu et al., 2008) due to its strictness (Cenușă et al., 2002, Lexerod and Eid, 2006, Roibu et al., 2008).

Dead wood has been recognized to have an important ecological function as a resource for the ecosystems, structural components of the forest and in providing resources and habitats for a wide range of organisms (Ferris and Humphrey, 1999, Saniga and Saniga, 2004, Schuck et al., 2005, Humphrey et al., 2005, Merganičová and Merganič, 2010, Tomescu et al., 2011, Seibold et al., 2015). Dead wood also plays an important role in absorbing carbon (Kueppers et al., 2004, Merganičová and Merganič, 2010) and by this in slowing down the process of global warming.

MATERIAL AND METHODS

Study area

Research areas are situated in Southern Carpathians, in Romanian Curvature Mountains, more specific in Penteleu Mountains which are a subdivision of Buzău Mountains (Figure1). One plot has been installed in 2014 (Penteleu – Viforata 2) and the other two were installed in 2015 (Penteleu – Viforata 1 and Sapte Izvoare). All plots are characterized by high naturalness and they have relevant criteria's to enclose these forests in virgin forest category from the point of view of Romanian Environmental and Climate changes Ministerial Order 3397/2012 regarding the selection and identification of virgin and cvasi-virgin forests.

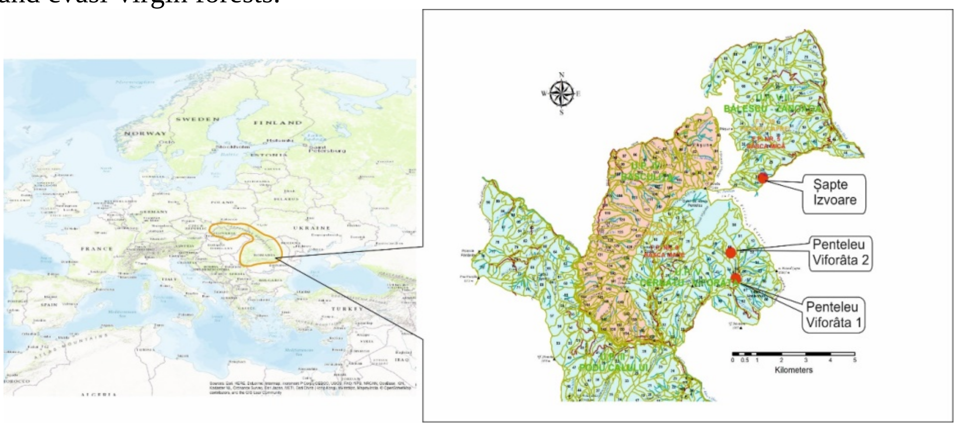

Figure 1. Permanent research plots from Curvature Carpathians (Natural Earth, Esri, ICAS)

Research method

Each one of the three researched plots has an area of one hectare - one having a circular shape (Penteleu – Viforâta 2) and the other two having a rectangular shape (Penteleu – Viforâta 1 and Șapte Izvoare). All live trees with diameter at breast height (dbh) higher than 80 mm were measured and the main dendrometrics characteristics (dbh, height, cenotic class, quality class) were registered. Standing dead wood with dbh higher than 8 cm and lying dead wood with top diameter higher than 8 cm were also measured and sampled (Table 1). Standing dead wood volume was calculated using the following regression equation:

$$\log v = a_0 + a_1 \log d + a_2 \log^2 d + a_3 \log h + a_4 \log^2 h$$

Where: h – height of standing dead wood; d – dbh; v- volume of standing dead wood; a_0, a_1, a_2, a_3, a_4 - regression coefficients (Giurgiu, Decei, Drăghiciu, 2004).

Lying dead wood volume was determined using Huber formula:

$$v = 0.785 \cdot l \cdot \sum d_i.$$

Table 1. Sampling dead wood

Dead wood category	Description	Notation
Snag 1	Standing tree died recently, with the majority of the branches intact or beginning to break, and intact or almost intact bark and intact top	S 1
Snag 2	Standing tree, died a while ago, without top and branches and also without bark or less bark remained	S 2
Log 1	Lying dead wood, still solid, with bark or beginning to lose bark	L 1
Log 2	Lying dead wood, soft and without bark	L 2

Descriptive statistics was made with help of PASTECS (Grosjean & Ibanez, 2014) package from RStudio program. Dry biomass and CO_2 was sampled for each category of dead wood. For standing dead wood, volume was transformed in biomass using the relation:

$$DB = V \bullet WD \text{ (Goslee et al., 2014)}$$

Where:DB is dry biomass; WD is wood density

WD was taken from wood density Romanian tables (Giurgiu, Decei, Drăghiciu, 2004) and was applied a reduction density factor according to the level of deterioration (UNFCC, 2013). Thereafter DB was transformed into CO_2 stock (C_{SDW}) using the relation:

$$C_{SDW} = DB \bullet CF \text{ (Goslee et al., 2014)}$$

Where: CF - carbon fraction usually used in the literature (IPCC 2006) GL,V4, CH4, (Table 4.3) with the value of 0,47 t/ha.

The relation used to determine dry biomass from lying dead wood was:

$$BM = V \cdot Dc \text{ (Goslee et al., 2014)}$$

Where:BM represents the dry biomass; V is volume of lying dead wood; Dc is medium density class (Walker et al., 2012).

Lying dead wood carbon stock (C_{LDW}) was determined using a relation which is composed of dry biomass (BM) and carbon fraction (CF):

$$C_{LDW} = BM \cdot CF \text{ (Goslee et al., 2014)}$$

Where: CF value used was 0,47 t/ha (IPCC 2006 GL, V4, CH4, Table 4.3).

Structural biodiversity analyzes were made using Gini (Gini, 1912) and Camino (Camino, 1976) indexes, and the graphic representation was attained using Lorenz curve (Lorenz, 1905). Gini biodiversity index, unlike other indexes, has a high quality in describing the structural diversity, (Cenusa, 2002, Lexerod and Eid, 2006, Roibu, 2008, Duduman, 2011, Klopcic and Boncina, 2011). Lorenz curve is a good indicator, used for describing the equitability of stands (Studeny et all, 2011, Valbuena, 2012).

To determine heterogeneity were also used other structural indexes like Shannon (Shannon, 1948) and Evenness (Pielou, 1969) using package BiodiversityR (Kindt and Coe, 2005) from RStudio program. The experimental dead wood (DW) volume distribution was computed using the program Mathwave EasyFit. In order to compare the experimental values with the theoretical ones were used Exponential, Gamma, Lognormal and Weibull functions and the goodness-of fit was tested using hi square criterion (χ^2), Kolmogorov Smirnov (KS) and Anderson-Darling (AD) tests.

RESULTS

Relationship between dead wood and alive trees

The presence of dead wood in virgin forest is very important and to highlight its role it was correlated with alive trees (Table 2).

Table 2. Relation between dead wood and alive trees

Research Plot	Volume, m^3						% DW from AT		
	Dead wood (DW)			Alive trees (AT)					
	Coniferous	Beech	Total	Coniferous	Beech	Total	Coniferous	Beech	Total
Șapte Izvoare	50,060	4,876	54,936	743,112	162,342	905,454	7	3	6
Penteleu – Viforâta 1	65,001	7,350	72,351	835,212	298,311	1133,523	8	2	6
Penteleu – Viforâta 2	96,891	26,458	123,349	446,614	357,218	803,831	22	7	15
Total	211,952	38,684	250,636	2024,938	817,871	2842,808	37	12	27
Mean	70,651	12,895	83,546	674,979	272,624	947,603	10	5	9

In all research plots, most of dead wood comes from coniferous species with a volume between 50.060 $m^3 \cdot ha^{-1}$ (Șapte Izvoare) and 96.891 $m^3 \cdot ha^{-1}$ (Penteleu – Viforâta 2). Beech dead wood volume is between 4,876 $m^3 \cdot ha^{-1}$ (Șapte Izvoare) and 26,458 $m^3 \cdot ha^{-1}$ (Penteleu – Viforâta 2), less significant than dead wood derived from coniferous. Total volume of dead wood it varies between 54,936 $m^3 \cdot ha^{-1}$ (Șapte Izvoare) and 123,349 $m^3 \cdot ha^{-1}$ (Penteleu – Viforâta 2), with an average of 83,546 $m^3 \cdot ha^{-1}$. The percentage of DW from AT for coniferous is between 7% and 22 %, with an average of 10%, while for beech is between 2% and 7% with an average of 5%. The total percentage between dead wood and alive trees varies between 6% and 15%, having an average of 9%.

Descriptive statistics of volume for dead wood

Number of samples of dead wood is between 63 (Penteleu – Viforâta 2) and 237 (Penteleu – Viforâta 1)(Table 3). Analyzing the results, it may be observed that lowest volume value of dead wood is 0,003 cubic meters (Penteleu – Viforâta 1) while the highest volume value is around 17 cubic meters (Penteleu – Viforâta 2 -volume which corresponds to a piece of lying dead wood having 104 cm breast diameter and 34 m length). The Șapte Izvoare research plot has the lowest volume value of dead wood (54,936 m^3) while Penteleu – Viforâta 2 registers the highest volume value of dead wood (123,349 m^2). The coefficient of variation is between 1,588 (Șapte Izvoare) and 3,076 (Penteleu – Viforâta 1), and standard deviation is between 0,364 (Șapte Izvoare) and 3,240 (Penteleu – Viforâta 2).

Table 3. Descriptive statistics of volume of dead wood

Research Plot	number of values	Min	Max	Range	sum	median	mean	Var	std.dev	coef.var
Șapte Izvoare	218	0.005	3.059	3.054	54.936	0.091	0.229	0.132	0.364	1.588
Penteleu - Viforâta 1	237	0.003	8.210	8.208	72.351	0.049	0.305	0.882	0.939	3.076
Penteleu - Viforâta 2	63	0.052	17.390	17.338	123.349	0.643	1.958	10.498	3.240	1.655

Dead wood volume in relation with decay class

Depending on the category of decay (Table 4), in Șapte Izvoare and Penteleu – Viforâta 2 research plots it may be observed that most of dead wood falls into the category *Snag 2* (Standing tree, died a while ago, without top and branches and also without bark or less bark remained) (Table 2), whereas in Penteleu Viforâta 1 most of dead wood volume falls in *Log 1* (Lying dead wood, still solid, with bark or beginning to lose bark).

Fitting of experimental DW volume distribution

To compare experimental and theoretical values Exponential, Gamma, Lognormal and Weibull theoretical functions were used (Figure 2).

Table 4. Dead wood volume according to decay class

Dead wood category	Volume, m^3			Mean
	Şapte Izvoare	Penteleu – Viforâta 1	Penteleu – Viforâta 2	
Snag 1	11,181	12,701	13,658	12,513
Snag 2	25,582	29,060	91,513	48,718
Log 1	17,532	30,590	-	16,041
Log 2	0,641	-	18,178	6,273
Total	54,936	72,351	123,349	83,545

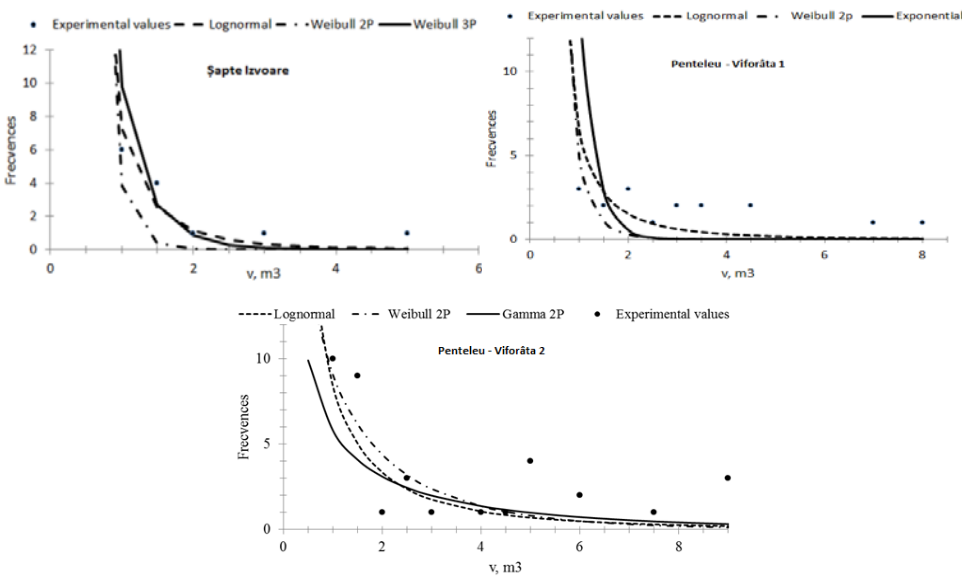

Figure 2. Dead wood volume distribution adjusted with theoretical functions

In order to determine which theoretical frequencies law is most suitable for describing this type of distribution the goodness of fit was tested, using χ^2 criterion, K-S and A-D tests (Table 5).

Table 5. Experimental values of specific goodness-of-fit tests

Research plot	Distribution	Kolmogorov Smirnov Test KS)		Anderson Darling Test (AD)		χ^2 Criterion (χ^2)	
		Experimental Values	Theoretical Values	Experimental Values	Theoretical Values	Experimental Values	Theoretical Values
Şapte Izvoare	Lognormal	0,069	0,092	1,086	2,501	5,474	14,067
	Weibull 2P	0,129	0,092	5,329	2,501	22,546	14,067
	Weibull 3P	0,099	0,092	3,194	2,501	39,084	14,067
Penteleu Viforâta1	Lognormal	0,061	0,088	1,074	2,501	8,819	14,067
	Weibull 2P	0,116	0,088	7,498	2,501	15,561	14,067
	Exponential	0,409	0,088	104,92	2,501	283,07	14,067
Penteleu-Viforâta2	Lognormal	0,07	0,168	0,383	2,501	0,837	5,991
	Weibull 2P	0,101	0,168	1,471	2,501	5,473	5,991
	Gamma 2P	0,212	0,168	3,011	2,501	0,018	5,991

Estimating dry biomass and CO_2 sequestration from dead wood

For all research plots dry biomass and CO_2 stock were obtained using allomeric equations (Table 6) related to dead wood volume.

Table 6. Values of dry biomass and CO_2 estimated

Research Plot	DW volume $m^3 \cdot ha^{-1}$	Dry biomass tones • ha^{-1}	CO_2 stock tones • ha^{-1}
Şapte Izvoare	54,93	19,65	9,23
Penteleu – Viforâta 1	72,35	24,12	11,34
Penteleu – Viforâta 2	123,34	29,91	14,06
Average	83,54	24,56	11,54

Quantity of dry biomass is between 19.65 tones • ha^{-1} and 29.91 tones • ha^{-1} with an average of 24.56 tones • ha^{-1}. The dead wood from research plots sequesters approximatively a quantity on CO_2 ranging from 9.23 tones • ha^{-1} to 14.09 tones • ha^{-1}, with an average of 11.54 tones • ha^{-1}.

Analyzes of structural biodiversity

Structural biodiversity it is an important component of virgin forests and Lorenz curve succeeds to represent this in a graphical way (Figure 3).

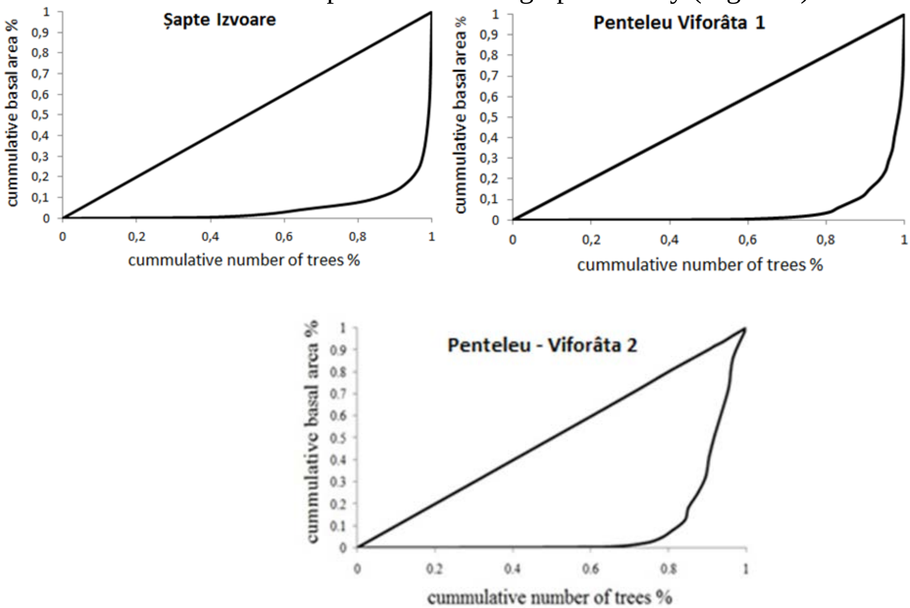

Figure 3. Lorenz curve for research plots Şapte Izvoare, Penteleu – Viforâta 1, Penteleu – Viforâta 2

Collected data from research plots were verified using special tests to indicate the level of heterogeneity. The values for G index from research plots are between 0.69 and 0.84 and the values for H index are between 1.62 and 1.74 (Table 7).

Table 7. Values of G and H indexes for testing structural homogeneity

Research Plot	Gini index (G)	Camino index (H)
Șapte Izvoare	0,69	1,71
Penteleu – Viforâta 1	0,71	1,62
Penteleu – Viforâta 2	0,84	1,74

To describe structural biodiversity using diameter data, were calculated indexes like Evenness and Shannon, which are the most popular among all alternative indexes (Valbuena et al., 2012). In our research plots, Shannon index (SH) is between 2.69 and 2.80, and values of Evenness index (E) is between 0.78 and 0.81 (Table 8).

Table 8. Values of E and SH indexes for testing structural homogeneity

Research Plot	Shannon index (SH)	Evenness index (E)
Șapte Izvoare	2,77	0,81
Penteleu – Viforâta 1	2,80	0,82
Penteleu – Viforâta 2	2,69	0,78

DISCUSSION

The large number and quantity of dead wood samples highlight a high heterogeneity of the researched stands. The amount of dead wood volume mentioned in literature falls into a range between 50 m^3 ha^{-1} and 200 m^3 ha^{-1} (Jedicke, Scherzinger, 1996). The high heterogeneity of dead wood is indicated by low values of standard deviation and the variation coefficient. Regarding the dead wood distribution according to the decay class, it may be observed that the forest stands weren't influenced by anthropic activities, dead wood was never harvested. The presence of considerably quantities of dead wood in different decay stages stabilizes the ecosystems and are providing food and habitats for many species as well as maintaining the health status (Tomescu et al., 2011).

Distribution of dead wood volume has a descending trend, with high values at small categories and a shape of reverse "J" (Westphal et al, 2006) characteristic for virgin stands. Goodness of fit for Șapte Izvoare and Penteleu - Viforâta 1 plot shows that all the conformity tests, indicate that the most suitable functions is Lognormal. Testing experimental values of Penteleu-Viforata 2 with theoretical function Lognormal, Gamma and Weibull, the $\chi 2$ criterion shows that all functions studied are suitable for describing the stand.

Also, Kolmogorov-Smirnov test show no differences between experimental and theoretical distribution for Lognormal and Weibull functions.

The relationships between dead and alive trees are influenced by the development stage of the stand, and the natural factors like wind, snow and insect's attacks. For all researched plots, most dead wood comes from coniferous, fact explained by the physiological age differences of beech and coniferous. The quantity of DW is important because it maintains the entomologic balance between predators and parasites (Tomescu, 2011, 2013) and in this way, is demonstrated the superiority of virgin forests.

The carbon stock from dead wood, determined in our research, is higher than the one reported by Karankina et. al (2002), from Russian boreal forests (0.1-0.7 tones • ha^{-1}). Comparative to other research of virgin forests, the quantity of stocked carbon in dead wood fall in the lower limit of the interval, respective from 1.6 to 64.4 tones • ha^{-1} (Merganicova and Merganic, 2010), highlighting the high capacity of virgin forests in absorbing carbon.

The heterogeneity of researched plots is high, fact demonstrated by the large area between Lorenz curve and Equality line, specific to uneven aged stands and implicit to virgin stands. Also, Equality line represents a reference point for studying forest dynamics and stand development (Valbuena et al, 2012).

In our research, values of G index are higher than the lower limit (> 0.51) found in other research (Duduman, 2011, Valbuena et al., 2012) and close to maximum in others (Chivulescu et al., 2014). Regarding the coefficient of heterogeneity H for uneven aged stands, this was established to be between 1.3 and 2.8 (Ozcelik, 2009). The obtained values of H index in our research plots (1,62-1,74), demonstrate that the diversity is high and the stands have the characteristics of virgin uneven aged forests.

Shannon index has been used widely in the past for describing heterogeneity in ecological studies (LeMay and Staudhammer, 2005, Barbeito and Cañellas, 2009, Ercanli and Kahriman, 2015). Values between 0.0 and 2.30 for Shannon index are specific to uneven aged forests (Ercanli and Kahrimon – 2015, Roibu – 2010). In all researched plots the structural heterogeneity is high, fact demonstrated by the values of Shannon index (the obtained values are between 2.07 and 2.91.

CONCLUSIONS

This research highlights the capacity of virgin forests to maintain the stability of stands by its biodiversity. Biodiversity also maintained by the quantity of dead wood which provides food and habitats for many species. The presence of dead wood, in different decay stages, indicates that the ecosystems haven't been influenced by anthropic activities.

The dead wood distribution has a descending trend and the most suitable function to describe this type of ecosystems, in most cases, was Lognormal theoretical function. Also, was demonstrated that the stage development of stand and natural influences like snow, wind and insect attacks, influence the relationship between dead and alive trees.

The quantity of carbon stocked in dead wood was higher than the one registered in other research.

The high heterogeneity of the researched stands is demonstrated by the large area between Lorenz curve and Equality line, which is specific to uneven aged stands, but also by the values obtained using Gini, Camino, Evenness and Shannon indexes.

The most important fact demonstrated in this research is that the virgin forests are superior to managed forests and preserving this type of ecosystems is very important to humankind.

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