




Article

Coarse Woody Debris Variability Due to Human Accessibility to Forest

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Abstract: Coarse woody debris (CWD) plays an important role in supporting biodiversity and assisting ecological processes. Sometimes local people intervene modifying the expected distribution of CWD components, harvested as fuel wood. The effect of the human accessibility (HA) on the volume and characteristics of CWD (snag, downed log and stump) was investigated in the natural uneven-age mixed hardwood stands of the Hyrcanian forests of Iran to quantify the impact on CWD. The HA was classified into three classes (easy, medium and difficult) on the basis of slope class, slope direction to the nearest road and road type. As expected, a negative relationship between the degree of accessibility was found with respect to the main qualitative and quantitative indices referring to CWD. The results showed that the volume of CWD decreased with an increase in human accessibility class (HAC), thus the mean volume of CWD in the difficult, medium and easy accessibility classes were 14.87 m³ ha⁻¹, 8.84 m³ ha⁻¹ and 4.03 m³ ha⁻¹, respectively. The decrease in CWD volume was more associated with the decreasing volume of small diameter of low decayed downed logs. The ratio of snag volume to standing volume, the ratio of downed log volume to the volume of trees and the ratio of CWD volume to standing volume increased with a decrease in HAC, while the ratio of downed log volume to snag volume decreased with a decrease in HAC. No selective behaviour on the botanical species of CWD was recorded. For ecological forest management, the effect of HAC on CWD should be considered. A constant supply of snags and downed logs must be preserved to assure a high level of biodiversity. To balance social needs and biodiversity requirements, an increased level of CWD retention might be needed in areas with easy accessibility. The obtained results may be useful when ecological and socio-economical needs have to be taken into consideration in future policy-making decisions.

Keywords: snag; downed log; stump; forest road; uneven-age mixed hardwood stands; Hyrcanian forests

1. Introduction

Coarse woody debris (CWD) plays an important role in supporting biodiversity [1] and assisting ecological processes [2]. CWD is produced by natural processes such as tree mortality and

decomposition, depending on site productivity and in managed forests, even throughout silvicultural activities. Sometimes the involvement of local people intervenes modifying the expected distribution of CWD components.

CWD was reported as an important environmental element and essential for maintaining biodiversity in forests [3–5]. On the other hand, CWD is used by local people as fuel wood, one of the primary energy source and the demand for fuel wood over the next few years in these forests is certain to increase [6]. In the Hyrcanian forests of Iran, there are approximately 3400 villages for about 74,000 households, whose annual consumption of wood is between 1.44 and 2.22 million m³, for heating, cooking and other uses [6].

Forest roads have a direct and indirect effect on the density and characteristics of CWD. Prasad [7] studied the role of roads on the tree community in a tropical dry forest and reported that tree death near roads was more than double that in distant areas, suggesting that roads may increase tree death. The construction of forest roads increases the tree mortality rate due to mechanical damage and increased snag (one element of CWD) density, especially along road edges [8–10]. Trees on embankment slopes are damaged by rock-fall during road construction, especially in the areas with steep slopes [9,11–13]. In addition, in forests managed by selection cutting, such as Hyrcanian forests, snag density on road edges is greater than on interior stands due to skidder-logging damage [14]. In contrast, forest roads decrease CWD density by facilitating accessibility to the cutting, collection and extraction of CWD for fuel wood by rural people [15,16].

In addition to the forest roads, stand density, slope degree and distance or proximity to villages are also factors affecting the amount of CWD consumed as fuelwood by local people. It is difficult to extract CWD in dense stands, residual trees may be damaged and injuries can lead to decay or mortality [17–19]. The collection and extraction of CWD is complex with increasing slope degree, especially when extraction is uphill. Wisdom and Bate [6] demonstrated that the number of snags in stands near villages is lower than in stands further away.

The succession stage of the forest was also reported as having an effect on the amount of CWD in the Hyrcanian mixed beech forests [2], with the amount of CWD higher at the end stages than at the early stage. Wisdom and Bate [16] reported a significant direct relationship between logging intensity and number of snags. Tavankar et al. [20] found out that management methods have a significant effect on the density and characteristics of snags.

Deadwood has a wide range of ecological values in forest ecosystems, offering habitats for many living organisms [21–25], according to some authors providing carbon sequestration [26,27] and forest productivity preservation, as well as contributing to soil development and to nutrient cycles [28–30]. A higher volume of deadwood in managed forests is often encouraged in best practice recommendations for sustainable management [31]. In many countries, silvicultural regulations have been introduced to create deadwood over time, conserving unhealthy and senescent trees as potential sources of CWD. Sometimes special laws are implemented to protect some trees from harvesting until natural death and decomposition. The amount and type of deadwood and its continuity were recognized as indicators of naturalness and estimators of human activity [32]. CWD is also included as biomass (only with ecological implications) to be measured in many National Forest Inventories [33–36]. The PEFC (Programme for the Endorsement of Forest Certification) and FSC (Forest Stewardship Council) certification schemes for forest management require CWD management. In recent years, CWD was also added as a proper indicator within criterion 4 (Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems) of Forest Europe [37]. Pan-European criteria recognize the value of deadwood as a sustainable management indicator and the standards for forest management certification point to its assessment but they also require an evaluation of the social impact attributed to active forest management.

Since wood is recognized as a resource for the rural community, the right to collect downed dry logs or branches for fuel wood from the forest floor, usually based on customary or consuetudinary law, is not only observed in Iran but also elsewhere. A decrease in decomposing inside forests could

become a critical issue for sustainable forest management. However, social instances must be taken into account along with economic and environmental aspects.

Forest management, timber harvest and human access can have substantial effects on CWD density [16,38,39]. Coarse woody debris (CWD) has high ecological and conservation value, such as maintaining biodiversity in forest ecosystems. Forest practices such as shorter rotations, firewood removal, timber stand improvement, insect and disease control efforts have limited the number of snags and downed logs available for wildlife habitat. Maintaining deadwood in suitable abundance and stages of decay is critical to the preservation of biodiversity and the sustained functioning of forest ecosystems [40].

In presented research accessibility was taken into consideration as a parameter that favours the removal of deadwood. The main goal of this study was to assess the effects of the level of human accessibility on the volume and structure of CWD in the Hyrcanian forests of Iran. Aims included acquiring further knowledge in regards of the management of CWD in relation to social aspects, in this case measured as forest accessibility. With these in mind, it was investigated whether accessibility had an effect on quantity, type (downed logs, snags or stumps) and characteristics (size, decay status, species) of CWD.

This research provides information for forest managers working to balance the community's need for firewood with the needs of the environment and sustainable forest resource use.

2. Materials and Methods

2.1. Study Area

This study was carried out in the Hyrcanian forests of northern Iran (Figure 1).

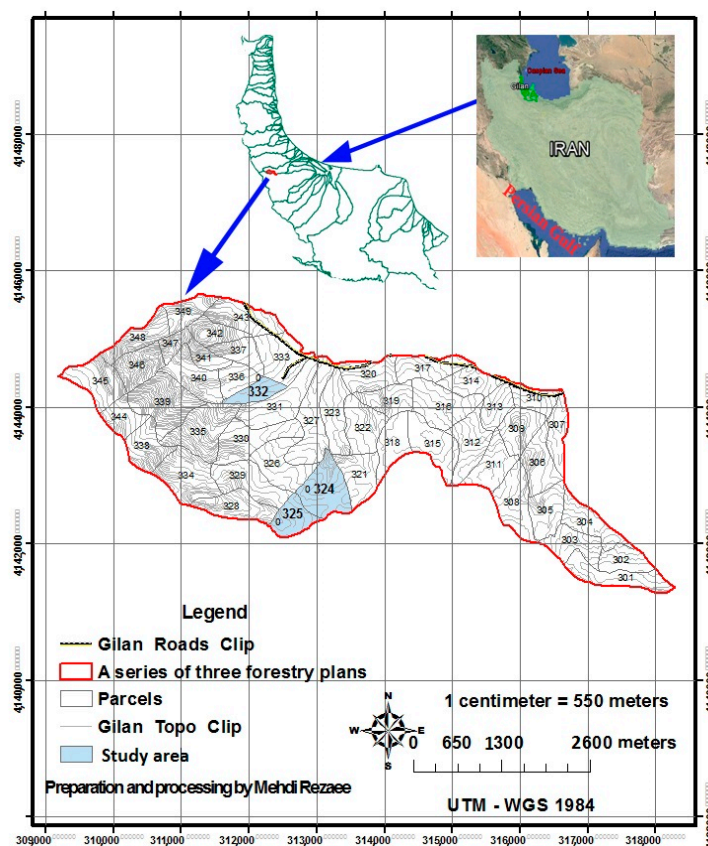


Figure 1. Study area in Hyrcanian forests of Iran.

They are suitable habitats for a variety of hardwood species (approximately 80 forest species) and include various forest types. These stands were managed until 2000 by shelter wood cutting and then by selection cutting silviculture (close to a natural method) until 2015. Afterwards, timber harvesting from these forests was limited to the harvesting of damaged trees, including broken, fallen, uprooted, infested and infected trees. Logging operations in these forests were generally performed using a ground-based skidding system. Chainsaws and cable skidders were two of the main logging equipment for wood harvesting and extracting. The study area was located in District No. 3 of the Shanderman forests in the Guilan province. Three parcels, numbers 324 (47.3 ha), 325 (54.0 ha) and 332 (51.0 ha) were selected (Figure 1). The vegetation of this area was made up of uneven-age mixed forest dominated by beech (*Fagus orientalis* Lipsky) (46%) and hornbeam (*Carpinus betulus* L.) (23%), with the companion species Alder (*Alnus subcordata* C.A. May) (13%), Norway maple (*Acer platanoides* L.) (7%), Cappadocian maple (*Acer cappadocicum* Gled.) (6%), Wych elm (*Ulmus glabra* Huds.) (3%) and lime-tree (*Tilia rubra* DC.) (2%). The canopy cover was ca. 90% and the parcels were at the mid successional stage.

The elevation in the study area ranges from 1150 to 1350 m a.s.l. in North and North-West areas. The mean annual precipitation is approximately 1100 mm and the average annual temperature is 8.9 °C. The vegetation period lasts for 7 months on average. The soil of the study site is classified as a brown soil (*Alfisols*), which is well-drained and the soil texture varies between sandy clay loam to clay loam.

2.2. Data Collection

Data collection was carried out through a design-based approach, a statistical approach that establishes the choosing methods and uses of the sites, allowing possible pseudo-replication problems to be overcome [41]. The study sites (parcels) were stratified according to accessibility level on the basis of three importance factors: slope degree, slope direction (taking into account wood collection uphill or downhill) and road type [15,16], attributing each plot to a class of accessibility: easy (EAC), medium (MAC) and difficult (DAC) (Tables 1 and 2).

Table 1. Classification of the sample plots on the base of slope degree, slope direction and road type.

Slope (%)	Slope Direction	Road Type	No of Sample Plots in Total	No of Sample Plots Selected for Study	HAC
<20	Flat	Adjacent Open	30	30	EAC
<20	Flat	Adjacent Closed	1	0	-
<20	Flat	Not Adjacent	2	0	-
20–40	Uphill	Adjacent Open	2	0	-
20–40	Uphill	Adjacent Closed	3	0	-
20–40	Uphill	Not Adjacent	2	0	-
20–40	Downhill	Adjacent Open	3	0	-
20–40	Downhill	Adjacent Closed	45	30	MAC
20–40	Downhill	Not Adjacent	3	0	-
>40	Uphill	Adjacent Open	3	0	-
>40	Uphill	Adjacent Closed	4	0	-
>40	Uphill	Not Adjacent	43	30	DAC
>40	Downhill	Adjacent Open	3	0	-
>40	Downhill	Adjacent Closed	3	0	-
>40	Downhill	Not Adjacent	3	0	-

HAC = human accessibility class; EAC = easy accessibility class; MAC = medium accessibility class; DAC = difficult accessibility class.

Table 2. Accessibility class characteristics in the study area.

HAC	Slope (%)	Slope Direction	Road Type
EAC	<20	Flat	Adjacent, open
MAC	20–40	Downhill	Adjacent, closed
DAC	>40	Uphill	Not adjacent

HAC = human accessibility class; EAC = easy accessibility class; MAC = medium accessibility class; DAC = difficult accessibility class.

Data were collected from circular sample plots with an area of 0.1 ha. The sample plots were located in the parcels using a systematic grid (100 m × 100 m) with a random starting point in each parcel.

Each parcel was characterized by measuring slope percentage using a clinometer along each 10 m segment in the direction of the sample plot centre to the nearest road. The average of these slope measurements was considered as slope percentage for each sample plot and then classified into three slope classes: <20, 20–40 and >40%. This classification was done on the basis of the average effective capacity for a man to extract 30 kg of wood on these slopes.

Slope direction for collecting wood was characterized during field sampling as (I) flat, (II) uphill or (III) downhill to the nearest road in each sample plot. In other words, the plots, which were situated below the nearest road and in which the direction of CWD extraction was towards the top of the slope, were considered as “uphill” (difficult extraction). The plots, which were situated above the nearest road, with a downward CWD collecting direction, were considered “downhill” (easy extraction).

On the basis of the authors’ knowledge and in order to implement this study, road types were classified as (I) adjacent open, (I) adjacent closed and (III) non-adjacent. Adjacent was defined as any road within 5 m of the stand boundary. Non-adjacent referred to stands without any adjacent roads. The open roads were those open to public use throughout the year. Closed roads were those not open to public use throughout the year.

Initially, 150 plots were classified by the factors influencing accessibility: slope, slope direction for wood collection and road type (Table 1). The plots showed different frequencies, so the three more frequent cases were chosen as the three Human accessibility classes (Table 1). 30 sample plots were randomly selected in each accessibility class. The final number of sample plots selected for study was 90.

The diameter at breast height (dbh) of all the tree species was measured in each sample plot and their stem volumes were calculated by local volume tables [42]. Snags (dbh ≥ 10 cm), downed logs (minimum diameter ≥ 10 cm and length ≥ 1 m) and stumps (defined as cut tree remains) were examined in each plot as Coarse Woody Debris (CWD). Species, dbh, height, volume, percentage of bark cover and decay class were recorded for each sampled snag, downed log and stump. The botanical species of the CWD was assessed from the bark and anatomical wood characteristics. The dbh was recorded to the nearest cm using a dbh tape. The height of the snags and the length of the downed logs were measured with a meter stick. For snags taller than 4 m, a clinometer was used to estimate the height. Volume was calculated using Huber’s formula: $V = A_m h$, where V was volume (m^3), A_m was mid-point cross-sectional area (m^2) and h was height (m). Bark coverage was visually estimated. The decay class of the snags, logs and stumps was divided into 5 classes [43] (Table 3) later named: DC1, DC2, DC3, DC4 and DC5.

Table 3. Classification system of coarse woody debris (CWD) types in decay classes.

Types	Character	Decay class				
		1	2	3	4	5
Snags	Leaves	Present	Absent	Absent	Absent	As logs
	Bark	Tight	Loose	Partly present	Absent	
	Crown, branches and twigs	All present	Only branches present	Only large branch stubs present	Absent	
	Bole	Recently dead	Standing, firm	Standing, decayed	Heavily decayed, Soft and block structure	
	Indirect measure	Cambium still fresh, died <1 year	Cambium decayed, knife blade penetrates a few millimetres	Knife blade penetrates <2 cm	Knife blade penetrates 2–5 cm	Knife blade penetrates all the way
Logs	Structural integrity	Sound	Sapwood slightly rotting, heartwood sound	Sapwood missing, heartwood mostly sound	Heartwood decayed	Soft
	Leaves	Present	Absent	Absent	Absent	Absent
	Branches	All twigs present	Larger twigs present	Larger branches present	Branch stubs present	Absent
	Bark	Present	Present	Often present	Often present	Absent
	Bole shape	Round	Round	Round	Round to oval	Oval to flat
	Wood consistency	Solid	Solid	Semisolid	Partly soft	Fragmented, powdery
	Colour of wood	Original colour	Original colour	Original colour to faded	Original colour to faded	Heavily faded
	Portion of log on ground	Elevated on support point	Elevated on support point	Near or on ground	Whole log on ground	Whole log on ground
Indirect measure	Cambium still fresh, died	Cambium decayed, knife blade penetrates a few mm	Knife blade penetrates <2 cm	Knife blade penetrates 2–5 cm	Knife blade penetrates all the way	
Stumps	Indirect measure	Cambium still fresh, died <1 year	Cambium decayed, knife blade penetrates a few mm	Knife blade penetrates <2 cm	Knife blade penetrates 2–5 cm	Knife blade penetrates all the way

2.3. Data Analysis

The ratio of snag volume to stand volume (RSS) was calculated according to a snag-creation index (snag-dynamic indicator) (Equation (1)). For the downed-log creation index, the ratio of downed-log volume to volume of standing live trees (RDT) was also used (Equation (2)). For comparing snag longevity, the ratio of downed-log volume to snag volume (RDS) was calculated for each snag species and for each accessibility class (Equation (3)). In addition, the ratio of stump volume to volume of standing live trees (RST) was calculated as harvest intensity (Equation (4)) and the ratio of CWD volume to stand volume (RDW) was calculated for each accessibility class (Equation (5)).

$$\text{RSS} = \text{SGV}/\text{SDV} \quad (1)$$

$$\text{RDT} = \text{DLV}/\text{LTV} \quad (2)$$

$$\text{RDS} = \text{DLV}/\text{SGV} \quad (3)$$

$$\text{RST} = \text{SPV}/\text{LTV} \quad (4)$$

$$\text{RDW} = \text{CWDV}/\text{SDV} \quad (5)$$

where RSS is snag-creation index, RDT is downed-log creativity, RDS is snag longevity index, RST is harvest intensity index, RDW is CWD volume index, SGV is snag volume, SDV is stand volume, DLV is downed-log volume, LTV is volume of standing live trees, SPV is stump volume and CWDV is volume of CWD.

After checking for normality (using the Kolmogorov-Smirnov test) and homogeneity of variance (the Levene test), the means of the CWD (snag, downed log and stumps) density, volume, dbh, decay, species and CWD ratios (RSS, RDT, RDS, RST and RDW) were compared using one-way ANOVA in the areas of accessibility class. Multiple comparisons post hoc analysis were made using the Tukey HSD test (significance at $\alpha < 0.05$). SPSS 19.0 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Non-metric multidimensional scaling (NMDS) was applied to compare the three accessibility classes, for the main quality-quantitative indices referring to the CWD situation. The results of the analyses were also presented using descriptive statistics.

3. Results

3.1. Accessibility CWD Classes and CWD Amount

The plots were associated with one of the three human accessibility classes (HAC) and the slightly lower stand volume was observed in the MAC (Table 4).

Table 4. Stand characteristics (average \pm SD) in the human accessibility classes (HAC).

HAC	Area of HAC (ha)	Tree Density ¹ (stem ha ⁻¹)	Stand Volume ¹ (m ³ ha ⁻¹)
EAC	25.0	166.1 \pm 23.2	309.2 \pm 31.7 ^a
MAC	74.2	169.0 \pm 22.8	262.8 \pm 25.3 ^b
DAC	53.1	171.5 \pm 19.8	298.6 \pm 28.6 ^a
F-value	-	0.386 N.S.	21.463 **

¹ Different lower case letters indicate differences statistically significant between the human accessibility classes (HAC) according to the Tukey HSD test, N.S: no significance, ** significance at $\alpha = 0.01$. EAC = easy accessibility class; MAC = medium accessibility class; DAC = difficult accessibility class.

ANOVA tests showed no statistically significant difference in tree density between the HAC's, while a statistically significant difference was found in stand volume between the HAC's. The highest density was in the DAC (171.5 stem ha⁻¹) and the lowest was in the EAC (166.1 stem ha⁻¹). In addition,

the highest stand volume was in the EAC ($309.2 \text{ m}^3 \text{ ha}^{-1}$) and the lowest amount was in the MAC ($262.8 \text{ m}^3 \text{ ha}^{-1}$).

3.2. Components of CWD

Total volume of CWD was the highest in DAC and the lowest in EAC (Table 5).

Table 5. Volume (average \pm SD) of CWD ($\text{m}^3 \text{ ha}^{-1}$) components (snag, downed log and stump) in the accessibility classes and results of ANOVA and Tukey HSD tests ¹.

HAC	Snag	Downed Log	Stump	Total (CWD)
EAC	0.90 ± 0.28^c (22.3%)	1.96 ± 0.29^c (48.6%)	1.17 ± 1.07 (29.1%)	4.03 ± 1.17^c
MAC	4.11 ± 0.72^b (46.5%)	3.01 ± 0.54^b (34.0%)	1.72 ± 1.29 (19.5%)	8.84 ± 1.54^b
DAC	8.24 ± 1.13^a (55.4%)	5.23 ± 0.59^a (35.2%)	1.40 ± 1.01 (9.4%)	14.87 ± 1.31^a
ANOVA				
F-value	645.4	342.6	1.78	485.5
p-value	<0.001	<0.001	0.174	<0.001

¹ Different lower case letters indicate differences statistically significant between the human accessibility classes (HAC) according to the Tukey test. EAC = easy accessibility class; MAC = medium accessibility class; DAC = difficult accessibility class.

The ANOVA results showed that stand accessibility class had a significant effect on the total volume of CWD, snag volume and downed-log volume ($p < 0.01$), while it had no significant effect on stump volume ($p = 0.174$). The results of the Tukey test showed that the mean volume of CWD in the difficult accessibility class (DAC) ($14.9 \text{ m}^3 \text{ ha}^{-1}$) was significantly higher than the mean volume of CWD in the medium accessibility class (MAC) ($8.8 \text{ m}^3 \text{ ha}^{-1}$) and the mean volume of CWD in the easy accessibility class (EAC) ($4.0 \text{ m}^3 \text{ ha}^{-1}$). The mean volume of CWD in the MAC was significantly higher than the mean volume of CWD in the EAC (Table 5).

The mean volume of snags in the DAC ($8.2 \text{ m}^3 \text{ ha}^{-1}$) was significantly higher than the mean volume of snags in the MAC ($4.1 \text{ m}^3 \text{ ha}^{-1}$) and EAC ($0.9 \text{ m}^3 \text{ ha}^{-1}$). In addition, the mean volume of snags in the MAC was significantly higher than the mean volume of snags in the EAC.

The mean volume of downed logs in the DAC ($5.2 \text{ m}^3 \text{ ha}^{-1}$) was significantly higher than the mean volume of downed logs in the MAC ($3.0 \text{ m}^3 \text{ ha}^{-1}$) and EAC ($1.7 \text{ m}^3 \text{ ha}^{-1}$). Furthermore, the mean volume of downed logs in the MAC was significantly higher than the mean volume of downed logs in the EAC.

The mean stump volume in the MAC ($1.7 \text{ m}^3 \text{ ha}^{-1}$) was higher than in the DAC ($1.4 \text{ m}^3 \text{ ha}^{-1}$) and EAC ($1.2 \text{ m}^3 \text{ ha}^{-1}$) but these differences between the mean values of stump volumes were not statistically significant. The snag volume was the highest in the MAC (46.5%) and DAC (55.4%), while the downed-log volume was the highest in the EAC (48.6%). The stump component exhibited the lowest volume in each accessibility class.

3.3. Decay Class of CWD

The ANOVA results indicated that the accessibility class had a significant effect ($p < 0.01$) on CWD volume in all decay classes (Table 6).

The mean volume of CWD in the DAC was greater than the mean volume of CWD in the MAC, and in the MAC it was greater than in the EAC in each decay class. The volume of CWD increased from DC1 to DC5 in the EAC and MAC, while this trend was not found in the DAC, where the highest CWD volume was in DC3 and the lowest was in DC2.

Table 6. Volume (average \pm SD) of CWD ($\text{m}^3 \text{ha}^{-1}$) in decay classes and accessibility classes and results of ANOVA and Tukey HSD tests ¹.

HAC	DC1	DC2	DC3	DC4	DC5
EAC	0.35 \pm 0.10 ^c (8.7%)	0.36 \pm 0.13 ^b (9.0%)	0.72 \pm 0.21 ^b (17.9%)	1.08 \pm 0.28 ^b (26.8%)	1.52 \pm 0.31 ^b (37.7%)
MAC	0.78 \pm 0.26 ^b (8.8%)	1.02 \pm 0.34 ^a (11.5%)	1.11 \pm 0.19 ^b (12.6%)	2.59 \pm 0.49 ^a (29.3%)	3.34 \pm 0.34 ^a (37.8%)
DAC	2.52 \pm 0.58 ^a (16.9%)	1.15 \pm 0.23 ^a (7.7%)	4.23 \pm 0.46 ^a (28.4%)	2.87 \pm 0.41 ^a (19.3%)	4.10 \pm 0.34 ^a (27.6%)
ANOVA					
F-value	266.7	87.9	1133.5	170.7	383.6
p-value	<0.001	<0.001	0<.001	<0.001	<0.001

¹ Different lower case letters indicate differences statistically significant between the human accessibility classes (HAC) according to Tukey test. EAC = easy accessibility class; MAC = medium accessibility class; DAC = difficult accessibility class; DC = decay class.

3.4. Species of CWD

The ANOVA results indicated that the accessibility class had a significant effect ($p < 0.01$) on the CWD volume of all tree species (Table 7).

Table 7. Volume (average \pm SD) of CWD ($\text{m}^3 \text{ha}^{-1}$) in tree species and accessibility classes and results of ANOVA and Tukey HSD tests ¹.

Tree Species	EAC	MAC	DAC	F-Value	p-Value
Beech	3.10 \pm 0.39 ^c (76.0%)	6.13 \pm 1.24 ^b (69.3%)	9.40 \pm 1.62 ^a (63.2%)	218.8	<0.001
Hornbeam	0.62 \pm 0.18 ^c (15.2%)	1.22 \pm 0.30 ^b (14.6%)	3.13 \pm 0.91 ^a (21.0%)	173.2	<0.001
Alder	0.22 \pm 0.05 ^c (5.4%)	0.64 \pm 0.20 ^b (7.7%)	1.20 \pm 0.55 ^a (8.1%)	64.8	<0.001
Maple	0.09 \pm 0.04 ^c (2.2)	0.50 \pm 0.18 ^b (6.0)	0.72 \pm 0.26 ^a (4.8)	95.4	<0.001
Other Sp.	0.05 \pm 0.02 ^b (1.2%)	0.35 \pm 0.15 ^a (4.2%)	0.42 \pm 0.11 ^a (2.8%)	88.0	<0.001

¹ Different lower case letters indicate differences statistically significant between the human accessibility classes (HAC) according to the Tukey test. EAC = easy accessibility class; MAC = medium accessibility class; DAC = difficult accessibility class.

The results of the Tukey tests also showed that the mean CWD volume of each species in the DAC was significantly higher than in the MAC and in the MAC, it was significantly higher than in the EAC.

3.5. Diameter of CWD

The results of the ANOVA tests indicated that accessibility class had a significant effect ($p < 0.01$) on snag volume and downed-log volume in all diameter classes (Table 8).

Accessibility class had a significant effect ($p < 0.01$) on stump volume only in dbh classes higher than 26 cm. The results of the Tukey test showed that the snag volume and downed-log volume in the DAC was significantly higher than in the MAC and in the MAC, it was significantly higher than in the EAC. Snag and downed log volumes increased with an increase in their diameters in the three accessibility classes.

Table 8. Volume (average \pm SD) of CWD ($\text{m}^3 \text{ha}^{-1}$) in diameter classes and accessibility classes; results of ANOVA and Tukey HSD tests ¹.

CWD Component	HAC	Diameter of CWD (cm)				LINE SUM
		7.5–25	26–50	51–75	76–100	
Snag	EAC	0.05 \pm 0.03 ^b	0.09 \pm 0.04 ^b	0.15 \pm 0.07 ^c	0.67 \pm 0.09 ^c	0.96
	MAC	0.25 \pm 0.09 ^b	0.38 \pm 0.13 ^b	0.63 \pm 0.11 ^b	2.85 \pm 0.39 ^b	4.11
	DAC	0.87 \pm 0.19 ^a	1.05 \pm 0.30 ^a	1.66 \pm 0.27 ^a	4.66 \pm 0.67 ^a	8.24
ANOVA	F-value	361.2	200.8	583.4	580.3	
	p-value	<0.001	<0.001	<0.001	<0.001	
Downed log	EAC	0.09 \pm 0.06 ^c	0.19 \pm 0.06 ^{b,c}	0.25 \pm 0.09 ^c	1.43 \pm 0.06 ^b	1.96
	MAC	0.25 \pm 0.07 ^{a,b}	0.47 \pm 0.08 ^{a,b}	0.77 \pm 0.11 ^b	1.52 \pm 0.14 ^b	3.01
	DAC	0.48 \pm 0.14 ^{a,b}	0.79 \pm 0.18 ^a	1.21 \pm 0.14 ^a	2.75 \pm 0.44 ^a	5.23
ANOVA	F-value	122.5	173.0	484.9	546.2	
	p-value	<0.001	<0.001	<0.001	<0.001	
Stump	EAC	0.09 \pm 0.08	0.25 \pm 0.08 ^b	0.40 \pm 0.08 ^b	0.43 \pm 0.07 ^c	1.17
	MAC	0.11 \pm 0.07	0.39 \pm 0.10 ^a	0.55 \pm 0.09 ^a	0.67 \pm 0.09 ^a	1.72
	DAC	0.09 \pm 0.05	0.30 \pm 0.08 ^a	0.46 \pm 0.12 ^b	0.55 \pm 0.09 ^b	1.40
ANOVA	F-value	1.3	20.7	14.6	52.2	
	p-value	0.270	<0.001	<0.001	<0.001	

¹ Different lower case letters indicate differences statistically significant between the human accessibility classes (HAC) according to the Tukey test. EAC = easy accessibility class; MAC = medium accessibility class; DAC = difficult accessibility class.

3.6. RSS, RDT, RST, RDW and RDS

The ANOVA and Tukey tests showed that the human accessibility class (HAC) had a significant effect ($p < 0.01$) on the RSS (Snag/Standing volume) (Figure 2a). The RSS value in the DAC was significantly higher than in the MAC and in the EAC. The ANOVA and Tukey tests also showed that the human accessibility class (HAC) had a significant effect ($p < 0.01$) on the RDT (Downed logs/Trees) (Figure 2b). The RDT value in the DAC was significantly higher than in the MAC and in the EAC. Furthermore, the ANOVA and Tukey tests showed that the human accessibility class (HAC) had a significant effect ($p < 0.01$) on the RST (Stump/Trees), (Figure 2c). The RST value in the MAC was significantly higher than in the DAC (0.47%) and in the EAC. In addition, the ANOVA and Tukey HSD tests showed that the human accessibility class (HAC) had a significant effect ($p < 0.01$) on the RDW (CWD/standing volume) (Figure 2d). The RDW value in the DAC was significantly higher than in the MAC (3.37%) and in the EAC.

Finally, the ANOVA and Tukey tests showed that the human accessibility class (HAC) had a significant effect ($p < 0.01$) on the RDS (Downed logs/Snag) (Figure 3). The RDS value in the EAC (217.6%) was significantly higher than in the MAC (73.2%) and in the EAC (63.5%).

Principal non-metric multidimensional scaling (NMDS) tests produced a 2-dimensional ordination that provided significantly more reduction in stress than expected by chance ($\alpha = 0.05$). When considering RSS, RDT, RST and RDW, the 2 axes explained 94.9% of the overall variance. Four parameters correlated well with the ordination axes. The parameters explaining most of the coarse wood debris (CWD) composition and distribution along axis 1 were RSS, RDT and RDW (Figure 4).

The CWD arrangement along axis 2 was dominated by RST (Figure 4). The NMDS for the three accessibility classes (Figure 4) showed a negative relationship between the degree of accessibility and the main indices referring to CWD (RSS, RDT, RST and RDW). In particular, the class MAC was the most heterogeneous in terms of quantity for types of CWD, while in the class DAC, the environmental quality of CWD was higher than in the other two classes.

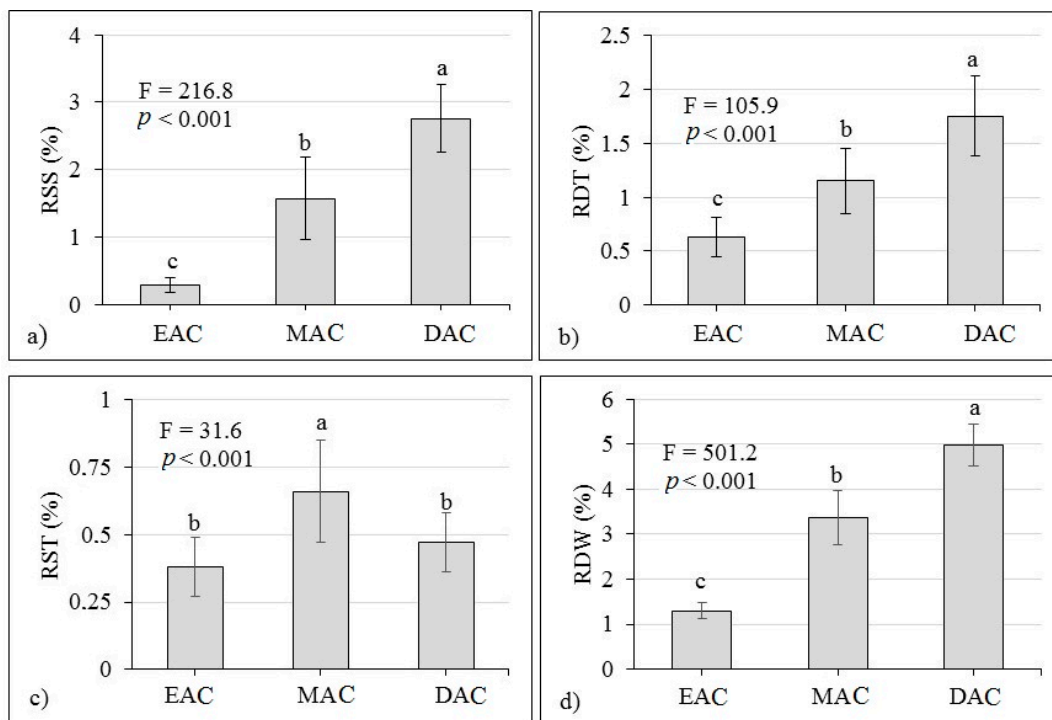


Figure 2. (a) Values of RSS (Snag/Standing volume), (b) RDT (Downed logs/Trees), (c) RST (Stump/Trees) and (d) RDW (CWD/standing volume) in the human accessibility classes: EAC = easy accessibility class, MAC = medium accessibility class, and DAC = difficult accessibility class.

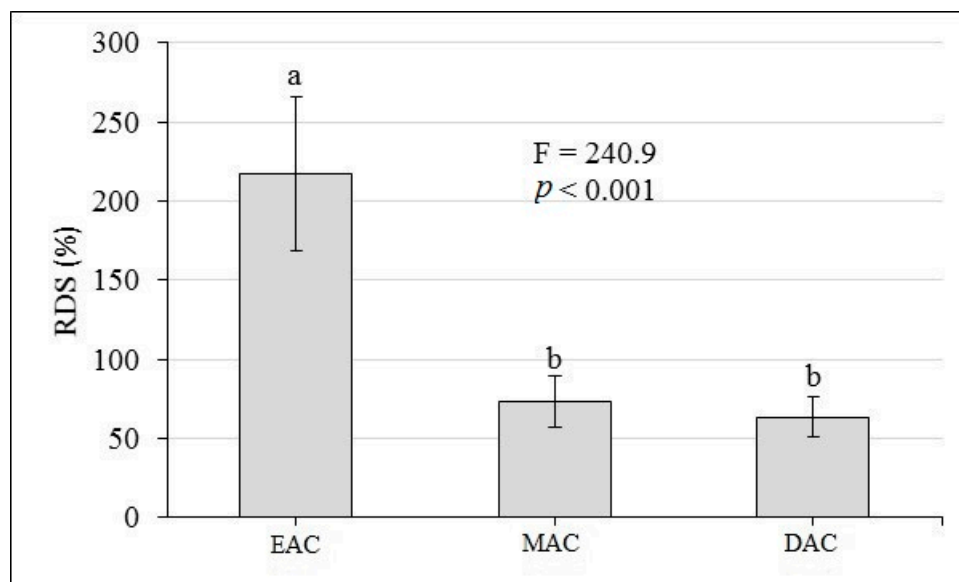


Figure 3. RDS (Downed logs/Snag) in the human accessibility classes: EAC = easy accessibility class, MAC = medium accessibility class, and DAC = difficult accessibility class.

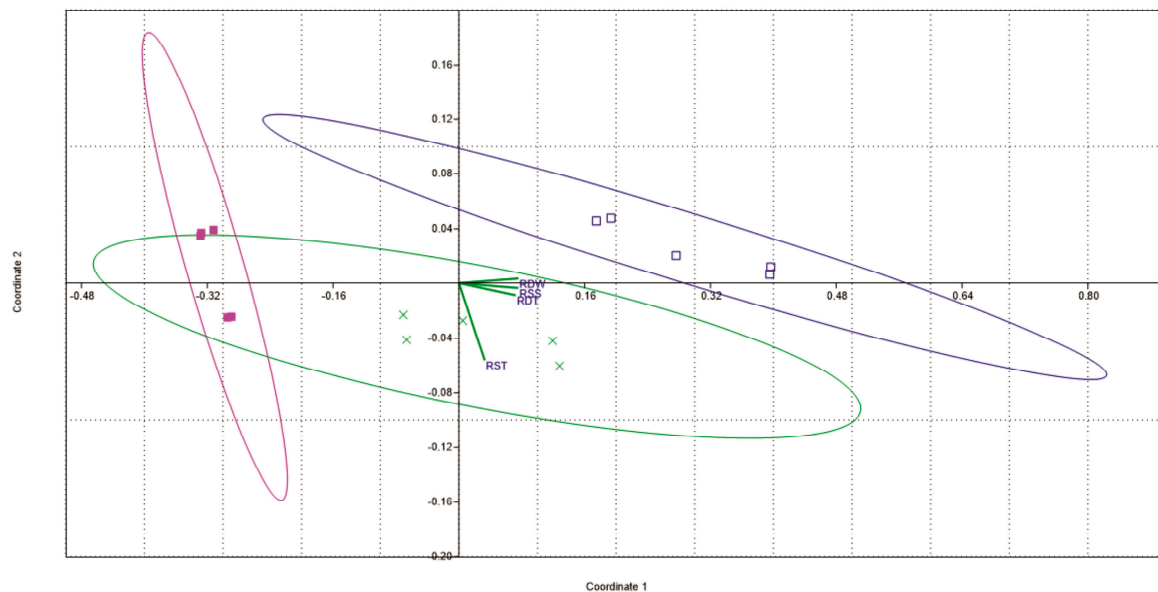


Figure 4. NMDS analysis for the three human accessibility classes (violet ellipse: EAC; green ellipse: MAC; blue ellipse: DAC), for the main indices referred to CWD (RSS, RDT, RST and RDW). EAC = easy accessibility class; MAC = medium accessibility class; DAC = difficult accessibility class; RSS = Snag/Standing volume; RDT = Downed logs/Trees; RST = Stump/Trees; RDW = CWD/standing volume.

4. Discussion

The data collected demonstrate that the human accessibility level affects the volume and characteristics of CWD. The fuel wood collection modifies the characteristics of CWD in total volume amount, in volumes of both snags and downed logs, in decay class distribution as well as in species and diameter class distribution. Local people operates a selection on CWD driven by accessibility and decay condition.

4.1. Human Accessibility Classes and CWD Amount

The total volume of CWD in the study area showed a high variability in relation to human accessibility classes (HAC) and differences statistically significant between the classes. Several studies deal with the amount of CWD focusing on the causes of different management and environmental situations. Forest management intensity affects the deadwood volume, which decreases from extensive management to intensive management [44]. Several studies showed that the volume of CWD in natural forest stands is proportional to the biomass of living trees at the site [45–47], although an amount of CWD varying greatly was found. In reserves characterized by beech forests in Europe, Christensen et al. [48] indicated an average volume of $130 \text{ m}^3 \text{ ha}^{-1}$, a value varying greatly which can exceed $700 \text{ m}^3 \text{ ha}^{-1}$ in reserves with a long history of protection. In semi-natural temperate broadleaf woodland, Norden et al. [49] found an amount of deadwood similar to that found in this study, highlighting the great variability of the data. They also noticed that it was more than twice as much as in production forests. Managed forests show a CWD volume lower than in unmanaged forests [44,50,51]. High variability even characterizes the CWD amount in the Hyrcanian forests. In northern Iran, in uneven-age forest dominated by *Fagus orientalis* Lipsky, the deadwood ranged from 37 to $119 \text{ m}^3 \text{ ha}^{-1}$ in an unmanaged stand [52]. The Nav district, an area which has been protected since 1965, showed a CWD volume two times higher than in a managed forest with a selection cutting system [5]. Behjou et al. [53] detected a statistical difference in the CWD volume between managed forests ($8.62 \text{ m}^3 \text{ ha}^{-1}$) and unmanaged ones ($22.01 \text{ m}^3 \text{ ha}^{-1}$). In managed forests, Behjou et al. [53] found amounts similar to those found in the EAC in this study. Sefidi and Marvie Mohadjer [54] recorded the lowest CWD volume in the mid-successional

stage ($25.95 \text{ m}^3 \text{ ha}^{-1}$) along a chronosequence of secondary beech forest succession of Northern Iran. Sefidi et al. [2], for a beech-dominated forest located in the mid elevations of the Alborz Mountains, verified the volume of coarse woody debris ca. $15 \text{ m}^3 \text{ ha}^{-1}$. The study area was in a mid-successional stage and the tree density showed no difference statistically significant between the accessibility classes. Therefore, the stand conditions of the three cases were comparable. In addition, the stumps are the evidence of past harvesting activity and represent a proxy of removed trees and wood volume in recent times [55]. In the study area, the stump volumes are a clear indicator of the homogeneity of the management activity, since they show similar features [51,56]. It should be stressed that the local population does not have permission to cut standing trees, therefore stumps were not created by rural people. On the contrary, stumps were created by foresters during selection cuttings. The silvicultural treatment in the study areas was not a differentiation driver of CWD, as shown by the stand characteristics found. The human accessibility class (HAC) to the stand was the factor driving the amount of coarse woody debris (CWD). CWD decreased significantly with an increase in human accessibility level to the stand. Bate et al. [15] found similar evidence in the forests of North-eastern Oregon. Marquez-Reynoso et al. [57] noticed that the main criteria determining the collection of firewood were proximity and access to stands, located in the northwest part of Chiapas, Mexico.

4.2. Components of CWD

The total amount and the attributes of CWD in managed forests could be modified by anthropogenic disturbance [58,59].

In effect, in the study area, the stump contribution to the total volume of CWD increased due to the log and snag component decreasing with the ease of access. Similarly, the percentage distribution of stump volume in diameter class was similar in the different accessibility classes. Stump volume in each accessibility class increased with an increase in stump diameter but the increase was not equal in the different accessibility classes, therefore these had a significant effect on stump volume in higher diameter classes. Stump importance was recognised in the conservation of the biodiversity of organisms living in wood, even species on the red list. Andersson et al. [60] observed that stumps were occupied by assemblages of saproxylic beetles. Svensson et al. [61] determined that stumps were the most important substrate for wood-dependent lichens in the managed forest.

Generally, the amount of downed log volume is usually larger than snag volume [44,62,63]. In this study, only the EAC followed this pattern, while the MAC and DAC showed higher numbers of snags. Snags often originate through natural mortality due to tree competition which often depends on stand density [64]. Garbarino et al. [65] noted that stands with higher density were detected farther from roads. D'Amato et al. [66] observed a higher number of snags in steep terrain. Therefore, the greater density in the DAC and MAC might explain the higher number of snags. Wisdom and Bate [16] observed the highest mean density of snags in stands far from roads and found an evident cause-effect relationship between increased human access and reduced snag density. In the lowland forest in Iran, similar results were found. Tavankar et al. [20] observed that in open access forest, the snag number and volume were lower than in selectively-logged and in fully protected forest.

4.3. Decay Class of CWD

The results indicated that with increasing decay level, the volume of CWD increased in the EAC and in the MAC. In the EAC plots, the significantly lower amount of CWD in each decay class is due to human pressure in collecting firewood. The amount of lower decayed wood in the EAC and MAC is evidently caused by local people, which prefer wood of better quality and easy to extract.

The deadwood decay process is complex and depends on a great number of factors, sometimes inter-linked: botanical species, forest age and management, climate and moisture content, the insect and fungi community [67–69]; CWD size and fragmentation contributes to the decay rate [57]. It must be noted that snags show a decay rate lower than logs [70–72]. Decaying wood retains moisture and has an important role in forest regeneration and in microhabitat preservation [73,74]. Numerous

wildlife functions depend on decaying wood as a source of food, nutrients and protection for organisms at diverse trophic levels [72,75–78]. Suitable density and different decay stages of snags are critical for the preservation of biodiversity and the constant functionality of forest ecosystems [40,79]. Müller et al. [68] observed that many saproxylic beetles benefit from former fungal colonization, increasing species numbers in higher stages of wood decay. The level of snag decay is another important factor driving management decisions in sustainable forest management [62,77]. In order to maximize wildlife benefits and, more generally, biodiversity protection, a variety of CWD decay classes is necessary. The forest manager needs to know that the effect of removing deadwood in the more accessible areas is long lasting, as the CWD has been selected as more attractive for firewood. Management strategies are needed to allow the long-term maintenance of CWD to ensure suitable habitats for flora and fauna. Despite the fact that the rules and optimal levels of CWD have not yet been formulated, some authors have analysed strategies for enhancing the amount of CWD in intensively managed forests, as retention of living trees at harvest, producing high stump from lower quality tree, preserving the CWD after final harvest, prolonging rotation periods, retention of dying trees and stipulating temporal conservation contracts to compensate forest private owners [80–83]. Interventions in favour of local populations with the right to collect deadwood could be undertaken by the public owner, providing a part of the harvested wood.

4.4. Species of CWD

Beech was the most frequent component of CWD pools. This species, in terms of volume, mostly contributed to the CWD in the three accessibility classes. In general observations, CWD mirrored the species composition of the area, as also observed in lowland forests in Iran [20]. The results revealed that the volume of different botanical species of CWD is proportional to the different species of the standing trees. This finding shows that the CWD species was not important to the local population. People did not make a selection based on the characteristics of botanical species but on the accessibility of the area, as the residual volume of CWD by species demonstrated. Each accessibility class was significantly different in terms of volume by species, although the amount in terms of relative frequency was similar in each accessibility class, reflecting the frequency of the living trees. The behaviour of low selection has also been noted in other contexts. Marquez Reynoso et al. [57] concluded that rather than the fuel wood characteristics of the species, what prevailed was availability, proximity to home and feasibility in the choice of species used for firewood. This behaviour is not constant. Sassen et al. [84] also observed a greater depletion of CWD volume in forests located in more densely populated sites but also noted that rural people operated a selection on preferred wood and collected fuel wood up to decay class 3.

4.5. Diameter of CWD

In the area where people can collect deadwood, an anthropogenic influence was noted at the expense of the most easily removable diameters. The results of the analysis of CWD diameter showed that the snag and downed-log volumes increased with a positive relation to their diameters, for the three accessibility classes. The richness in large diameter CWD provides greater potential benefits to wildlife [85]. Ylläsjärvi et al. [86] ascertained that the dbh increase of CWD was even more important than the CWD volume for wood-inhabiting fungal species. They related this evidence to the increasing colonization probability, greater numbers of resources and more stable microclimatic conditions. Large snags and dense canopy cover are habitat conditions for the black woodpecker, *Dryocopus martius*, in the Hyrcanian Forests [87]. A low richness of epixylic bryophytes was attributed to a low supply of deadwood in large diameter classes [88]. Dunn and Bailey [71] observed that the largest dbh class of snags had the slowest fall rate. Thomas et al. [89] observed that the dbh and height of snags determined which species would use the snag for nesting. Even the CWD size was noted as providing different substrate types. Anderson et al. [60] detected more saproxylic predators in snags and more saproxylic fungivores in logs and stumps. Tillon et al. [90] noted that both snags and logs had a significant

positive effect on the richness of the bat species and Svensson et al. [61] demonstrated that even stumps were important for wood-dependent lichens in managed forests.

4.6. RSS, RDT, RST, RDW and RDS

RSS (Snag/Standing volume), RDT (Downed logs/Trees) and RDW (CWD/standing volume) increased with a decrease in human accessibility class (HAC) to the stand. Higher amounts of CWD, as snags, logs and stumps, were related to biomass [45,64,82,91]. It is worth noting that in the study area, the stand volume in the EAC was the highest, consequently differences between the accessibility classes are again associated with differences in the accumulation of CWD. Banaś et al. [82] also observed that a discriminant in CWD accumulation was accessibility and different form of forest protection. In the studied area, stand accessibility allowed different amounts of CWD collection and extraction linked to the size of the fuel wood. Higher stump volume and lower stand volume caused higher RST values in the MAC than in the DAC and EAC. In reality, the harvest intensity index (RST) was higher in the MAC than in the EAC and DAC, because tree volume in the MAC was lower than in the EAC and DAC, while stump volume was almost equal in the three HAC's. As already underlined above, live tree cutting was carried out by forest operators based on the approved management plan. These high forests are treated by selection cutting and local people are not allowed to cut live trees.

RDS (Downed logs/Snag) value decreased with a decrease in the HAC to the stand. The volume of both snags and downed logs increased with a decrease in the HAC to the stand but the reduction in downed-logs was greater than the reduction in snags, therefore the RDS is reduced by reducing the HAC. The mechanical properties of wood change during decay [92,93], therefore high snags break down, creating logs. Snags of deciduous trees had a higher probability of trunk breakage during the time in temperate zones, particularly the higher and the thinner ones, with the consequence of decay acceleration due to ground contact [94]. Castagneri et al. [64] noted higher log richness in steep slope stands where tree uprooting was probably more frequent. Tavankar et al. [5] observed that snag longevity induced log dynamics, comparing RDS in managed and unmanaged stands, due to a lower volume of snags.

It is now widely accepted that forests should be managed in an ecologically sustainable manner [95]. Wildlife use snags, downed logs and stumps for nesting, roosting, foraging, perching, or territorial displays [16,96]. Senescent trees, snags, logs and stumps, in various sizes, decay classes and species are recognized as fundamental elements in biodiversity conservation, in the sustained functioning of forest ecosystems and evidence of sustainable forest management [40]. Only an adequate reserve of snags and logs can activate an appropriate dynamic that allows the maintenance over time of the transformation of the components of the CWD, preserving a composition that reflects the composition of the forest, a large amount of CWD and degradation states suitable to create biodiversity-friendly habitats.

5. Conclusions

The effect of human accessibility level on the volume and characteristics of CWD in the Hyrcanian forests of Iran was investigated, demonstrating that extraneous interventions in the forest management alter the characteristics of CWD. The volume of CWD decreased with an increase in human accessibility level to the stand. However, the volumes of both snags and downed logs decreased. This decrease in CWD volume was associated more with the decreasing volume of small diameter of low decayed downed wood. A constant supply of snags and downed logs must be preserved so as to sustain wildlife populations that depend on these resources and to assure high level of biodiversity.

Forest roads are the basis of the infrastructure for forest operations. However, their presence makes general human accessibility to the stand easier for other activities as well. They have had an impact on the volume of the CWD collected for firewood. Although local people benefit from forest roads for their own mobility, CWD is selectively reduced by the removal of firewood.

Deadwood retention, in terms of volume, type, species composition, diameter distribution, spatial allocation and decay stage, is specific for organisms and for conservation aims. Management policies for deadwood are recognized as necessary for conservation and the benefits in terms of environmental sustainability have been demonstrated. Forest managers need to monitor impact of local population on CWD changes.

Being conscious of the needs, rights or customary uses of the local population is crucial in order that the management of the forest resource can be effectively and fully sustainable. In sustainable forest management, it is necessary to know how legitimate collection influences the amount and type of deadwood left in the forest. New policies are needed which can make possible to achieve conservative goals with other divergent societal needs, such as the practice or the right to harvest deadwood. In this context, socio-economic aspects have to be taken into consideration. When introducing a policy with the aim of increasing biodiversity by increasing the volume of decomposing wood, it is necessary to take into consideration the needs of the local society. Therefore, in rural areas with good access to forests, there may be the need to increase the volume of decomposing wood, so there is also sufficient wood volume available for local people.

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