

Article

The Effects of Forest Accessibility on the Quantitative and Qualitative Characteristics of Deadwood: A Comparison between Recreational and Natural Forests

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Abstract: Deadwood is one of the main structural features of forest ecosystems and plays an important role in the nutrient cycle, in maintaining production and environmental heterogeneity, and acts as an indicator for assessing the biodiversity of forest ecosystems. This research was conducted with the aim of evaluating the quantitative and qualitative characteristics of deadwood according to the influence of forest accessibility indicators in a comparison between natural and recreational forests. The studied area was divided into three accessibility classes based on the slope gradient range, the slope direction towards the nearest road, the road type, and distance from the road. These classes were: Easy-recreational forest (RE-F), Medium-natural forest 1 (NA-F1), and Difficult-natural forest 2 (NA-F2). In each accessibility class, three transects (750 × 50 m) were established, and three deadwood groups (snag, log, and stump) were recorded along the transects and their volume was calculated. The results of the analysis of variance show that accessibility has a significant effect on the presence of deadwood. The number and volume of snags, logs and dead stumps per hectare was higher in NA-F2 than in NA-F1 and RE-F. In each of the investigated classes, logs and stumps had the highest and the lowest number and volume of deadwood per hectare, respectively. The snag longevity index (= log volume/snag volume) decreased with accessibility. NA F2 showed the greatest value, while REF and NA F1 were not significantly different from each other. The results show that decay classes DC2 in NA-F2 and DC3 in NA-F1 and RE-F had the highest percentage of decay frequency. Finally, the forest accessibility indicators have a significant effect on the quantity, quality and distribution of different groups of deadwood in the forest. This is related to the collection of deadwood by local people who remove deadwood with different levels of intensity.

Keywords: recreational forests; natural forests; deadwood; accessibility classes; decay classes



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1. Introduction

The composition and structure of forests evolve over many years, and with the increase in the complexity of the structure, the diversity and richness of species increase in the forest [1,2]. Accordingly, conservation of forests and existing diversity is one of the long-term goals of forest management [3–5]. In ‘close-to-nature’ forest management, the protection of forests as a genetic repository is a priority. What is more, this management method focuses on deadwood, the preservation of biodiversity, and endangered species [6].

One of the issues raised regarding the health of forests is the maintenance of a number of trees until they reach the stage of decay, because many studies have shown that the presence of deadwood is very important for forest health and fertility [7,8]. Deadwood is indeed an important structural characteristic of old natural forests that performs a wide range of ecological and biochemical functions [2,9]. Deadwood can be used as an effective and essential indicator in the nutrient cycle, as a means of carbon storage in the long term, promoting forest regeneration, maintaining production and sustainability, and assessing the biodiversity of forest ecosystems [10–12].

Despite the importance of deadwood, it is not always managed properly. This is due to management practices in commercial forests and protected areas. Based on the pan-European network known as the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), Puletti et. al. [13] estimated a mean value of deadwood in European countries to be $15.8 \text{ m}^3 \text{ ha}^{-1}$, with values ranging from 5.6 to $33.1 \text{ m}^3 \text{ ha}^{-1}$, but indicated that the values recorded by the National Inventories are lower. The average number and volume per hectare of deadwood are usually less than 5% in many forest stands, including the forests of Europe and the Caucasus Mountain region, except in virgin forests and forests with a low level of disturbance [14]. The amount and volume of deadwood in natural forests depend on the type of forest, its sequence stages, natural distribution pattern, the type and frequency of natural and human disturbances, the history of exploitation, the access index of the forest, the type of management and the climatic and soil characteristics of the habitat [15].

In the not-so-distant past, trees were harvested after reaching the stage of old age and before the beginning of decay using different silvicultural methods, but new findings by ecologists have shown that the presence of deadwood in forests is beneficial to the ecosystem [16]. Deadwood facilitates many positive outcomes, such as increasing the germination power of forest tree seeds [17], increasing the regeneration of plant species [18], creating a suitable habitat for birds and wildlife [9] and increasing the fertility of forest soils. Furthermore, deadwood plays a significant role in nutrient storage and water retention, and as a result, it creates a suitable microclimate in the understory of forests [19].

It is very important to evaluate the abundance and characteristics of deadwood and provide quantitative guidelines for which type and amount of deadwood is needed in forest stands to maintain a certain level of productivity and other ecosystem processes. Therefore, management methods close-to-nature are the best choice for managing natural stands (such as Hyrcanian forests). Management close-to-nature requires basic data on the condition of habitat trees and deadwood in natural conditions for planning and choosing appropriate measures. The local studies of Zolfeghari [20] in the Kheyroud forests of Mazandaran and Habashi [21] in the Vaz forests of Mazandaran reported the amount of snag as 26% and 23% of the total deadwood volume, respectively. Similarly, according to the results of Kooch et al. [22] in the Chalus temperate forests, 68% of deadwood was log-type and 32% was snag-type.

In the genetic forest reserve and protected areas of Iran, information about deadwood has been documented, but in managed forests and recreational areas, there is less information about this fundamental parameter of forest ecosystems. Despite the prohibition of forest harvesting in recent years, deadwood has been used by the local population and even harvested in cases of necessity with permission from relevant organizations. In Iran, with the exceptions of protected and managed forests, there is no law or guideline that prohibits deadwood harvesting. It was hypothesized that accessibility of the forest, measured as slope and distance from the viability network, has a significant influence on the presence of deadwood. Therefore, the purpose of this study is (1) to investigate the quantitative characteristics (abundance and volume per hectare) of different groups of deadwood in relation to accessibility in recreational and natural forests, and (2) to determine the different stages of deadwood decay and their distribution in diameter classes in relation to forest accessibility.

It is important to highlight the fact that the term ‘forest accessibility’ can have different meanings [23,24], and in the present manuscript, we refer to the meaning mostly used in the framework of forest engineering, i.e., the combination of topographic and logistic factors (mostly slope and distance from the existing road network) that influences the possibility of easily reaching a forest stand [25–27].

2. Materials and Methods

2.1. Study Location

This research was conducted in a recreational forest in the Sisangan Forest Park and in a natural stand in a part of the last remaining forests in northern Iran in the proximity of Sisangan Park. The recreational forest has a gentle slope (0–10%), while slope in the natural forest is in the range of 10–60%.

The study area was selected because it possesses the peculiarity of having, in a very limited area, both a recreational forest completely dedicated to alternative forest functions (such as tourism), and a natural forest which was previously actively managed until a few years ago. The location of each recreational and natural forest in the study area is shown in Figure 1.

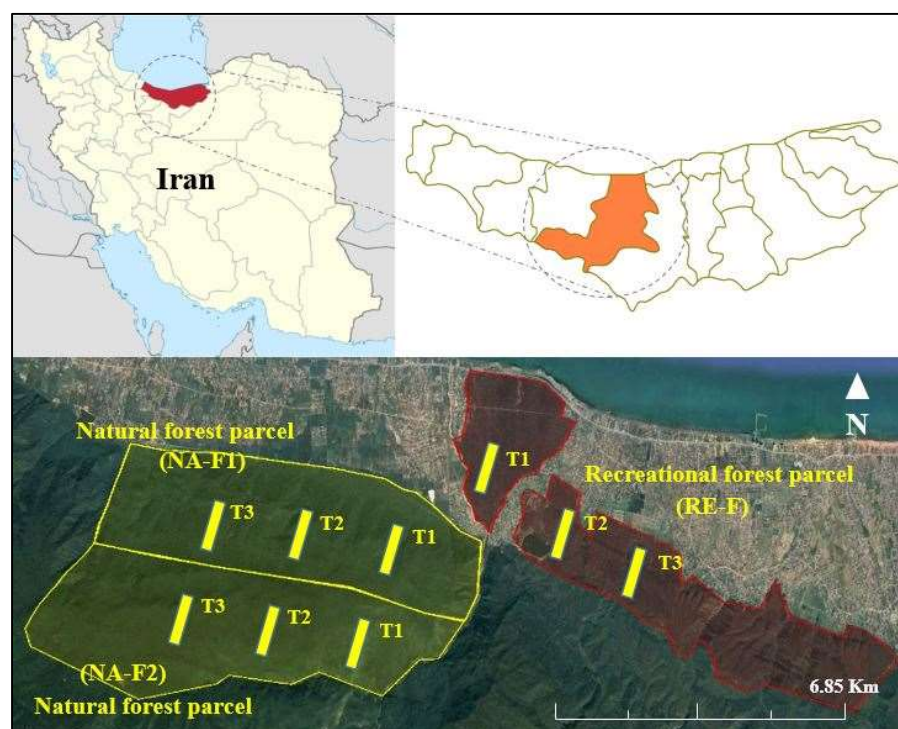


Figure 1. The study area (Sisangan recreational forest and Hyrcanian natural forest) in northern Iran. In this experimental design, the factor “accessibility class” has three levels: easy, represented by the recreational forest parcel (RE-F); medium, represented by the first parcel in the natural forest (NA-F1); and difficult, represented by the second parcel in the natural forest (NA-F2). In each forest parcel (each accessibility class), three transects were established (Transect 1: T1, Transect 2; T2 and Transect 3; T3).

Sisangan Forest Park is a reserve in terms of ecology and biodiversity. On the other hand, it is one of the parks under a great deal of pressure in terms of ecotourism. Although the natural forest has an important economic and social function, the harvesting of live trees is prohibited according to the laws of the country in the last decade. In this area, therefore, wood is mainly collected by local inhabitants for their own consumption and thus there is significant pressure on deadwood as a consequence of the easy access to this forest.

2.2. Data Collection

Data collection was conducted in both types of forests to investigate the quantitative (abundance and volume per hectare and number in diameter classes) and qualitative (different classes of decay) characteristics of deadwood in relation to the access index. One forest parcel was selected in the recreational forest and two forest parcels were selected in the natural forest, each with an area of 30 hectares. Based on the slope gradient range, the slope direction towards the nearest road, the road type, and the distance from the road, the studied area was divided into three access classes [2]: Easy-recreational forest (RE-F), Medium-natural forest 1 (NA-F1), and Difficult-natural forest 2 (NA-F2). The specifications of each access class are explained in Table 1. The classification of forest access indicators in this study are based on a retrospective view of the study by Lo Monaco et al. [2] and the study's exact measurement of each of the effective criteria (slope, slope direction towards the road, road type and distance from the road).

Table 1. Classification of study areas based on accessibility indicators [2].

Accessibility Indicators	Forest Type		
	Recreational Forest (RE-F)	Natural Forest (NA-F1)	Natural Forest (NA-F2)
slope gradient	0–10%	10–30%	30–60%
slope direction to road	flat	downwards	downwards
road type	asphalt and forest road	forest road and animal trails	animal trails
distance from the road	0–500 m	500–1000 m	more than 1000 m
Accessibility classes	easy	medium	difficult

In general, there is no accepted standard deadwood assessment [28]. Therefore, in this study, the linear transect method was used to investigate the characteristics of deadwood. In each of the forest parcels, three linear transects with dimensions of 750×50 m were designed randomly. In each of the transects, the surveyed structural characteristics of the stand included: the diameter at breast height ($d_{1.30}$), the type of tree species, the distribution of deadwood in different diameter classes, the height of the trees, the type of deadwood (snag, log, and stump) and the number and volume of deadwood with a diameter of more than 7.5 cm. The examination of the decay classes of deadwood was performed according to the method used by Motta et al. [29] as follows: decay 1 (DC1: young), decay 2 (DC2: middle-aged), decay 3 (DC3: mature) and decay 4 (DC4: old). The dimensions of the deadwood were organized into three groups: (1) Snag-diameter > 7.5 cm, height > 1.30 m, (2) Log-diameter > 7.5 cm, length > 1.30 m, and (3) stump-diameter > 7.5 cm, height < 1.30 m. Snag is a tree that is dry and lifeless, however, it still has a part of its stem and roots in the soil, which causes it to stand on the ground [28]. Logs are the dry limbs of trees that are uprooted and fall on the ground after rotting due to the influence of physical factors such as wind, storms, snow, etc. [14]. Finally, the deadwood may occur in the form of stump due to tree cutting or windfall and tree breakage [28]. In order to measure the height of snags, a Vertex device was used with decimeter accuracy [30], while log length was measured using a tape with centimeter accuracy. The volume of logs and stumps was calculated using Huber's formula according to Equation (1):

$$V = g_m \times h \quad (1)$$

where V is the volume (m^3), g_m is the mid-point cross-sectional area (m^2), and h is the height (m). The volume of snags was calculated according to Equation (2) (Harmon and Sexton, 1996) [27]:

$$V = g_m \times h \times f \quad (2)$$

where V is the volume (m^3), g_m at 1.30 m height (m^2), f is the snag's shape coefficient and h is the height (m).

2.3. Data Analysis

In the first stage of our analysis, the normality of the data was checked using the Kolmogorov–Smirnov test ($\alpha = 0.05$) [31] and the homogeneity of the variance of the data was checked using Levene’s test ($\alpha = 0.01$) [32]. A one-way analysis of variance (ANOVA) was used to verify the presence of statistically significant differences between the mean values of experimental treatments. Data with non-normal distribution, or those which presented heteroscedasticity, were analyzed using the non-parametric ANOVA Kruskal–Wallis test [33]. Duncan’s test ($p < 0.05$) was used for multiple comparisons of means [34].

3. Results

According to the results listed in Table 2, the total number of deadwood pieces in the recreational forest with easy accessibility (RE-F), natural forest with medium accessibility (NA-F1), and natural forest with difficult accessibility (NA-F2) were 118, 155, and 182, respectively. Similarly, the total volume of deadwood in the recreational forest with easy accessibility (RE-F), natural forest with medium accessibility (NA-F1), and natural forest with difficult accessibility (NA-F2) were 167.8, 280.4, and 371.5 m³, respectively (Tables 2 and 3). Furthermore, the number and volume of deadwood per hectare were higher in NA-F2 than in NA-F1 and RE-F. In each of the investigated forests, the number and volume of logs were greater than those of snags and stumps. Among the three classes, the stumps were the lowest in number and volume (Tables 2 and 3).

Table 2. Classification of the frequency of deadwood types (Snag, Log, and Stump) in the studied forests based on accessibility classes.

Accessibility Classes		Deadwood Type			
		Log	Snag	Stump	Total
RE-F	Number	54	40	24	118
	Percentage	45.76	33.9	20.34	100
	Number per hectare	1.8	1.33	0.8	3.93
NA-F1	Number	84	50	21	155
	Percentage	54.19	32.26	13.55	100
	Number per hectare	2.8	1.66	0.7	5.16
NA-F2	Number	122	42	18	182
	Percentage	67.03	23.08	9.89	100
	Number per hectare	4.06	1.4	0.6	6.06

Table 3. The volume of different deadwood groups (Snag, Log, and Stump) in the studied forests based on accessibility classes.

Accessibility Classes		Deadwood Type			
		Log	Snag	Stump	Total
RE-F	Volume (m ³)	67.6	56.7	43.5	167.8
	Percentage	40.29	33.79	25.92	100
	m ³ h ^{−1}	2.25	1.89	1.45	5.59
NA-F1	Volume (m ³)	116.7	102.5	61.2	280.4
	Percentage	41.63	36.55	21.82	100
	m ³ h ^{−1}	3.89	3.42	2.04	9.35
NA-F2	Volume (m ³)	169.4	125.1	77	371.5
	Percentage	45.6	33.67	20.73	100
	m ³ h ^{−1}	5.65	4.17	2.56	12.38

The results of analysis of variance showed that the number and volume of deadwood is significantly influenced by the forest accessibility (Table 4).

Table 4. One-way analysis of variance of the effect of accessibility indicators on the number and volume of deadwood. (SS: Sum of squares; MS: Mean squared error, df: degrees of freedom; Sig: significance).

Variables	Accessibility Classes	SS	MS	df	F Test	Sig
Deadwood number	RE-F	1.185	0.228	2	4.568	0.011
	NA-F1	2.356	0.126	2	3.690	0.000
	NA-F2	2.602	0.122	2	12.012	0.000
Deadwood volume	RE-F	3.112	0.398	2	2.809	0.003
	NA-F1	3.544	0.208	2	2.885	0.004
	NA-F2	2.623	0.388	2	9.311	0.00

The results displayed in Figure 2 show that DC2 in NA-F2 and DC3 in NA-F1 and RE-F had the highest percentage of decay frequency. In contrast, DC1 had the lowest percentage of decay frequency overall. Changes in the decay frequency from the difficult to easy accessibility class showed that DC1 had a greater decrease than other decay classes (Figure 2).

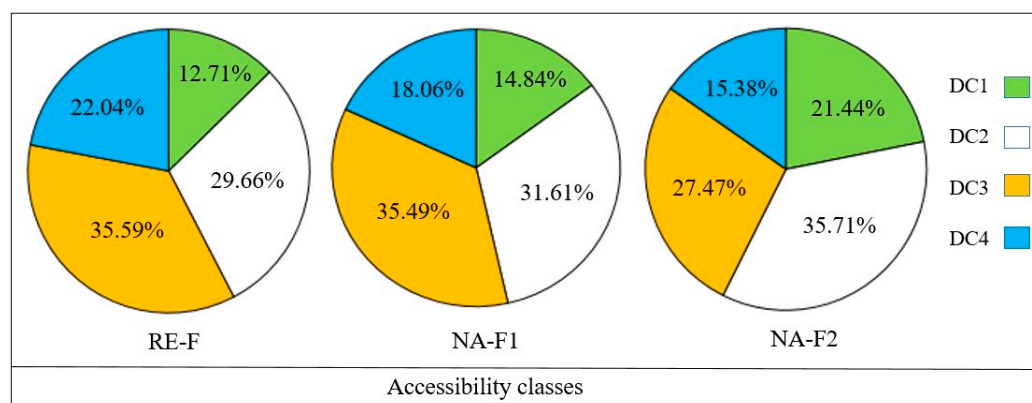


Figure 2. Percentage share of decay classes in the studied forests based on accessibility indicators.

Moreover, the snag longevity index (=log volume/snag volume) decreased with accessibility. NA F2 showed the greatest value, while REF and NA F1 were similar (Table 5). The volume of both snags and logs increased as stand accessibility decreased, however, the reduction in downed logs was greater than the reduction in snags, and therefore the snag longevity index is reduced in the areas which are difficult to access.

Table 5. Snag longevity index in relation to the accessibility classes and Kruskal-Wallis analysis with Duncan's post hoc test of the effect of accessibility. Different letters indicate significant differences between the means according to Duncan's test at $\alpha = 0.05$.

Accessibility Classes	Snag Longevity Index	p-Value
RE-F	1.19a	<0.05
NA-F1	1.14a	
NA-F2	1.35b	

The diameter distribution of different deadwood categories in Figure 3a shows that the highest number of logs in all three accessibility classes of forest was in the 10–15 cm diameter class. The number of logs per hectare in all three accessibility classes of forest

ranged from 15 cm to 20 cm in diameter and had a decreasing trend. In the diameter class of 60 cm, the log number per hectare increased in NA-F1 and NA-F2 and decreased in RE-F. With the increase in diameter of up to 100 cm, the decrease in the number of snags per hectare is greater (Figure 3a).

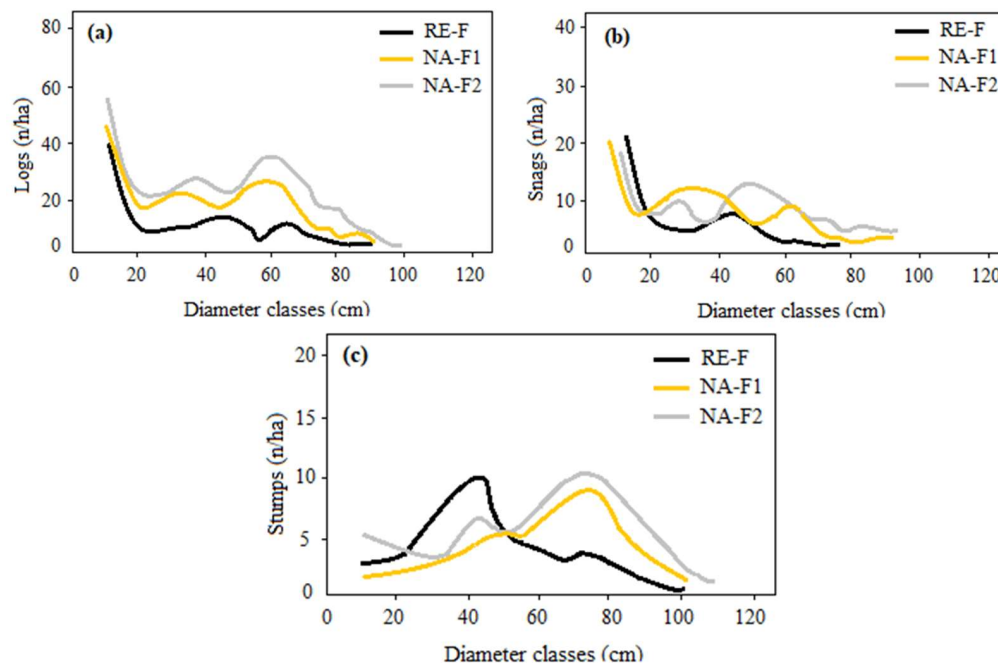


Figure 3. Frequency distribution of different groups of deadwoods (snag, log, and stump) in the diameter classes of each forest accessibility class. (a) number of logs by diameter classes, (b) number of snags by diameter classes and (c) number of stumps by diameter classes.

Similar to the distribution of the logs, the snags had the highest abundance per hectare in the diameter class of 10–15 cm in each of the accessibility classes of forest (Figure 3b). In NA-F1 and NA-F2, snags in diameter classes greater than 20 cm were more abundant than in RE-F. By increasing the range of diameter classes in all three accessibility classes, the number of snags per hectare decreases (Figure 3b), however, snags showed a larger diameter in NAF1 and NA F2 than in RE F. The highest number of stumps per hectare was measured in NA-F1 and NA-F2 in the diameter class of 75 cm and for RE-F in the diameter class of 40 cm. The lowest number of stumps per hectare for all three accessibility classes of forest was measured in low diameter classes (15 cm) and high diameter classes (100 cm) (Figure 3c).

4. Discussion

Previous studies on deadwood in similar forests show a high level of variability. This is due to several factors, such as intensity and management style, ecosystem productivity, and types of natural disturbance. These can all affect the amount of deadwood [35]. In the classic method of forest management, deadwood is removed from the forest, while in the case of single-selection forest management, it remains in the stand to allow it to play its positive role in the ecosystem [36]. Previous research conducted in the forests of Northern Iran has shown that the quantity and quality of deadwood in the protected stands are greater than in managed ones [37].

According to the obtained results, we found that maintaining and increasing deadwood in the RE-F forest is a priority compared to NA-F1 and NA-F2. The ratio of the number of deadwood in NA-F2 forest is higher than in NA-F1 and RE-F, which is due to the lack of intervention and harvesting, which affects the density of the stand in these forests, causing some trees to die due to competition. Keren and Diaci [38] stated that high amounts of deadwood are expected in natural forests in the study area, as these forests

represent old montane forest reserves that were not directly affected by humans, even before their official protection in 1954.

In other words, in the RE-F forest, due to easier access in terms of a shorter distance to the road, suitable communication roads, and low slopes, the use and harvesting of deadwood has increased, and as a result, the number and volume per hectare has decreased. Previous studies also showed that managed forests had significantly lower amounts of deadwood compared to natural forests [38–40]. The results of this study showed that all three groups of deadwood in NA-F2 forest are greater than in NA-F1 and RE-F forests. This is consistent with the results of Reid et al. [41], according to which the average volume of deadwood in natural stands is higher than protected stands.

In three Hyrcanian lowland forests, snag density was found to be significantly higher in fully protected forests than in selectively logged and open access forests [42]. Logs are the major component of deadwood both in terms of number and volume in each accessibility class. They derive from the breakage of snags, of branches, and downed trees. Large diameter logs derive from snags, living trees or dead trees with equally large diameters. In other words, large logs cannot be found without there having been large trees that died and subsequently suffered breakage. Most likely, the objective difficulty of extracting large diameter logs without mechanical means has also allowed the permanence of large logs in the RE F, which constitute an important functional attribute of the forest structure. Due to the fact that most of the wood-inhabiting species are affected by the diameter of the deadwood, the diameter is one of the most important characteristics of deadwood biodiversity [43].

The distribution of different deadwood groups in the diameter classes shows that the forest with easy accessibility (RE-F) has less snags and logs per hectare, while the stumps had a higher distribution in the lower diameter classes. These results are evidence of the different uses of deadwood by local people. In the Guilan province, north of Iran, Tavankar et al. [44] showed that the snag and downed-log number in higher diameter classes was higher and increased as the diameter class increased in the protected area, more so than in the managed one. According to the local laws, the harvesting and use of snags and logs with a large diameter is prohibited (except in special cases with permission from the relevant organization), although the deadwood is nevertheless harvested. This is shown in easy accessibility (RE-F), moderate (NA-F1) and difficult (NA-F2) forests with more stumps in the 40 and 75 cm diameter classes, respectively. In line with this study, Karen and Diaci [38] showed that in different deadwood groups, logs were measured greater than the 65–70 cm diameter class, while snags and stumps were larger in other diameter classes.

The classification of deadwood into different decay classes is organized according to the richness of decayed wood in terms of its nutrients [45], which play an important role in increasing the richness and diversity of wood-inhabiting species [43]. Furthermore, different classes of decay in deadwood provide an index of the history of a forest [46]. Tavankar et. al. [42], comparing a protected uneven-aged broadleaf mixed forest to a managed one in northern Iran, noted that the volume of snags and logs in each decay class was higher in protected forests than in managed forests. However, they found that there were only significant differences in higher decay classes. The percentage of deadwood abundance with decay class 1 (DC1) increased from the forest with easy access to that with difficult access, but under the influence of easier access and use (especially in RE-F forests), these forests have the lowest share in terms of deadwood quality among the decay classes. This is most likely related to the fact that it is deadwood in the D1 class, which is the most interesting for collectors, considering its low degree of decomposition. The lack of D1 deadwood is particularly alarming, considering that it represents the base for the future development of all other decay classes [2]. In line with the results of this study, von Oheimb et al. [47] showed that two-thirds of snags are in DC3. Furthermore, Seidling et al. [3] found that the share of DC2 and DC3 was 24% and 38% of the investigated deadwood, respectively. The results show that it is probable that small-diameter deadwood is used for local consumption, and large-diameter, good-quality deadwood is used illegally

for sale and other uses. In explaining this issue, it can be said that due to the prohibition on harvesting live trees, the use of deadwood has naturally increased, which has intensified use given the easy access to the forest and the lack of legal guidelines regarding the preservation of deadwood. Therefore, under the influence of forest accessibility indicators, the removal of deadwood affects the quantity and distribution of different groups of deadwood in the forest.

The obtained results suggest that it is necessary to implement management strategies to ensure the maintenance of a proper amount of deadwood in the forest stands. However, these strategies should be balanced with the needs of the local inhabitants and to their right to collect deadwood for domestic uses. Such strategies should begin with the proper monitoring of the collection of deadwood by local inhabitants. In particular, collection for energetic purposes should be still allowed, however, it should be controlled in order to ensure that it does not specify only, or mostly, deadwood in the D1 class. Moreover, some limitations on the amount collectable by a single-family group should be regulated by proper legislation. On the other hand, considering its importance for the conservation of biodiversity [48], the collection of large deadwood should be forbidden.

5. Conclusions

In this study, the effect of accessibility of a forest based on the number, volume, and degree of decay of deadwood was evaluated and compared between recreational and natural forests. The results showed that forest accessibility indicators have a significant effect on the number and volume of different deadwood groups. The share of deadwood among the decay classes was also influenced by the accessibility of a forest. In particular, lower amounts of deadwood in the first class were detected in the recreational forest with easy accessibility. This confirms that the deadwood in early stages of decay is the type most often collected by local inhabitants, considering its higher energetic and technical characteristics. The results obtained imply that management techniques must be established in order to maintain an appropriate level of deadwood in the forest stands. These tactics should be weighed against the demands of the local population and their right to gather deadwood for household purposes. Such policies ought to begin with careful oversight of local residents' deadwood gathering. In particular, collection for energetic purposes should still be permitted, however, it should be regulated to prevent the collection from mostly or exclusively including deadwood in the D1 class. There should be legal restrictions on the amount that a single-family group is permitted to collect. Finally, deadwood of large dimensions should be prohibited from collection due to its significance to the preservation of biodiversity.

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