

Article

Influence of Forest Management and Sylvicultural Treatments on Abundance of Snags and Tree Cavities in Mountain Mixed Beech Forests

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Abstract: In this study the influence of forest management on the characteristics of snags and tree cavities in the Hyrcanian forests of Iran was investigated. In particular, the effect of two sylvicultural treatments (shelter wood and single-tree selection) was assessed in comparison to protected stands. The abundance, diameter, height, and degree of decay of snag species, and the characteristics of birds excavated and natural cavities (number and height from the ground level) were measured by systematic plots in each stand. The results showed that the abundance, species diversity, and size of snags in both of the sylvicultural treatments were significantly lower than the protected stands. The number of birds excavated and natural cavities on thicker snags with moderate decay was significantly higher than other decay classes. Abundance, species diversity, size of snags, and number of tree cavities in the single-tree selection stands were significantly higher than sheltered-wood stands.

Keywords: cavity-nesting birds; shelter wood system; single-tree selection; snags; biodiversity

1. Introduction

Those trees which are standing dead or dying are called snag, and are part of forest deadwood [1,2]. At the end of the biological age of trees, although the physiological life of them ends, their ecological role continues in the forest ecosystems [3,4]. Snags are indeed important components of forest ecosystems and play an effective role in preserving forest biodiversity. Snags provide habitats for different forest animals in different forms depending on the quality of the wood and the degree of decay [5].

Over time, snags gradually lose their leaves, twigs, branches, bark, and parts of their trunk. Therefore, it is possible to classify snags by observing the severity of their decay [6,7]. Snags may occur naturally for many reasons such as the end of the lifespan of the tree, genetic defects, or damage caused by logging operations, competition, lightning, storms, fires, decay, drought, flooding, pests, diseases, and insect infestations before the end of tree longevity [8].

Snags have long been considered in forest management as a factor that increases the risk of fires, as well as the accumulation and prevalence of forest pests and diseases. However, since 1970 many studies have been conducted on the positive role of deadwood within forest ecosystems [9,10]. Many species use tree cavities for nesting, roosting, or as a shelter, and the microclimate is important for their life cycle [11].

In particular, many organisms at different trophic levels are associated with snags as food sources and nests [12,13]. For instance, several species of birds use snag trunks as nesting and breeding sites [14].

Due to the association of snags with wildlife and other living organisms, the presence of snags is essential for the stability and succession of forest ecosystems. Qualitative characteristics of snags are very important in forest ecology studies considering that snags characterized by different degrees of decay are used by different animal species [9].

Extensive studies have been conducted in the last years on the impact of different forest management practices on the quantity and quality of snags in different forests of the world [15]. Oder et al., in a recent study carried out on Romanian *Fagus sylvatica* L., *Quercus petraea* (Matt.) Liebl., *Quercus frainetto* Ten., *Quercus cerris* L., and *Tilia tomentosa* Moench stands, revealed an average overall deadwood amount of $47 \text{ m}^3 \text{ ha}^{-1}$, with snags constituting less than 30% in managed stands, that is two or three times lower than unmanaged forests [6]. Another study regarding the deadwood amount in Polish forests highlighted that the deadwood amount in stands located within protected areas was substantially higher than the deadwood in managed forests ($32.9 \text{ m}^3 \text{ ha}^{-1}$ vs. $7.5 \text{ m}^3 \text{ ha}^{-1}$), while there were no significant differences between forests in Natura 2000 sites and forests outside of it [16].

Focusing on south-western European forests, Alberdi et al. [17] found that the species composition of the stand has a strong influence on the amount of deadwood in mixed forests that showed double the volume of deadwood than that of pure conifer and broadleaf stands [17], confirming the findings of a previous study conducted in China [18]. On the other hand, little is known regarding the impact of different forest management systems on deadwood (in particular snags) volume and decay stage in Iranian forests where previous studies focused mostly on natural unmanaged forests [19,20].

In another study conducted in Polish forests, the abundance of tree cavity resources in spruce-pine (*Pinus/Picea* genera) stands with three different management activities (conservation, semi-conservation and managed) was compared. Their results showed that the highest frequency of cavities was in the conserved stand ($12.5 \text{ cavities ha}^{-1}$) and the lowest was in the managed stand ($3 \text{ cavities ha}^{-1}$), also, the frequency of cavities in dead trees was higher than in living trees [21].

Preserving the remaining forest biodiversity is one of the important goals of Forest Landscape Restoration Programs (FLRP) in natural stands such as the Hyrcanian forests in Northern Iran [22]. In order to achieve sustainable forest management information is needed on the number, species, sizes, and dynamic of snags to perform a proper planning of the forest interventions. The aims of this research were to evaluate the impact of two silvicultural treatments on the abundance of snags and tree cavities (bird excavated cavities, BEC, and natural cavities, NC) in mixed oriental beech mountain forests. In particular, a comparison of the effects on these parameters of the two most common forestry treatments in Iranian beech forests, i.e., the shelter wood system and single-tree selection, was carried out using protected stands as control values.

2. Materials and Methods

2.1. Study Area

This research was conducted in the Hyrcanian forests in northern Iran (latitude $37^{\circ}38'34''$ to $37^{\circ}42'21''$ N, longitude $48^{\circ}48'44''$ to $48^{\circ}52'30''$ E). The study focused on six stands (Table 1). In two stands, the shelter wood method (Sh1 and Sh2) was performed, in two stands, the selection cutting method (Sc1 and Sc2) was applied, and in the other two stands, no harvesting operations have been performed over the last 30 years being protected stands (Pr1 and Pr2). The elevation of the compartments ranges from 1350 to 1550 m a.s.l. The medium rainfall per year is 1050 mm, with the highest rainfall in summer and autumn. The average daily temperature varies between -5°C in December, January, and February up to $+26^{\circ}\text{C}$ during summer months. Such forests are natural uneven-aged mixed broadleaf stands. Within the study area, beech (*Fagus orientalis* Lipsky)

and hornbeam (*Carpinus betulus* L.) are the two main dominant species, and the companion species are Caucasian alder (*Alnus subcordata* C.A.M.), Norway maple (*Acer platanoides* L.), Cappadocian maple (*Acer cappadocicum* Gled.), wych elm (*Ulmus glabra* Hudson), chestnut-leaved oak (*Quercus castaneifolia* C.A. Mey), Caucasian zelkova (*Zelkova carpinifolia* (Pall.) K. Koch), and lime tree (*Tilia rubra* D.C.). Soil type can be classified as forest brown (Alfisols), well drained, and with a texture which varies between sandy clay loam and clay loam.

Table 1. Description of studied parcels (Sh: shelter wood silviculture; Sc: selection cutting silviculture; Pr: protected; numbers indicate repetition; FO: *F. orientalis*; CB: *C. betulus*; AV: *A. velutinum*; AC: *A. cappadocicum*; AS: *A. subcordata*; QC: *Q. castaneifolia*; TB: *T. begonifolia*; UG: *U. galbra*; ZC: *Z. carpinifolia*).

Management Method	Area of Compartment (ha)	Average Elevation (a.s.l. m)	No. of Sample Plot	Forest Type (% of Number); DBH \geq 7.5 cm
Sh1	45	1550	42	FO (56.1), CB (23.0), AV (7.3), AC (4.6), AS (3.0), QC (2.1), TB (2.0), UG (1.0), ZC (0.9)
Sh2	42	1450	40	FO (53.4), CB (26.2), AV (7.3), AC (5.2), AS (3.5), QC (2.1), TB (0.9), UG (0.9), ZC (0.5)
Sc1	45	1450	43	FO (48.3), CB (17.6), AV (11.2), AC (9.3), AS (6.2), QC (2.4), TB (2.3), UG (1.6), ZC (1.1)
Sc2	49	1350	46	FO (49.5), CB (14.0), AV (6.0), AC (10.3), AS (13.2), QC (0.9), TB (1.8), UG (2.8), ZC (1.5)
Pr1	52	1400	49	FO (37.6), CB (19.7), AV (11.6), AC (9.9), AS (8.6), QC (6.9), TB (2.8), UG (2.1), ZC (0.8)
Pr2	51	1450	49	FO (45.7), CB (15.6), AV (8.9), AC (7.3), AS (6.5), QC (5.2), TB (4.6), UG (3.4), ZC (2.8)

The stand Sc1 was harvested twice (in 2000 and 2010) by single-tree selection silviculture method; the harvested timber volume in the first and second rounds was 18.7 and 10.5 m³ ha⁻¹, respectively. In addition, the stand Sc2 was harvested twice (in 1995 and 2005) by single-tree selection silvicultural method; the harvested timber volume in the first and second rounds was 15.6 and 8.5 m³ ha⁻¹, respectively. Three cuttings of preparatory cut, seed cut, and removal cut were performed in 1985, 1990, and 1995 in the Sh1 and Sh2 stands. In each of the above cuttings about 20–25% of the standing volume was harvested. These stands (Sh1 and Sh2) have not been harvested since 1995 because the silvicultural method changed from shelter wood to selection cutting. Tree felling was completed by chainsaw and logs were extracted by cable skidder in all studied stands. No tree felling operations have been carried out in the protected stands (Pr1 and Pr2) since 1970.

2.2. Data Collection

Abundance and characteristics of live trees and snags were determined by systematic plot sampling with random starting points. The dimensions of the sampling network were 100 m by 100 m, the shape of sample plots was circular, and the area of each was equal to 1000 m². The total number of plots established in each stand was from 40 to 49 plots. Diameters at breast height (DBH) of all living trees and snags that were equal or greater than 7.5 cm were measured using a DBH tape (Jackson, MS, Germany) with an accuracy of 1 mm in the sample plots. The height of trees and snags taller than 4 m was measured using a clinometer with an accuracy of 0.1 m. The stem volume of each tree was estimated using the local volume tables for each tree species. The snag species were identified according to their bark design. The stem volume of each snag was calculated using Huber's formula $V = AmH$ where V is the stem volume (m³), Am is the mid-point cross-sectional area (m²), and H is the height (m). The percentage of bark present on snag stems was estimated by observation to nearest 5% to determine their decay intensity. The decay intensity of each snag was determined based on the presence of leaves, bark and branches, color, and structure of wood, and classified in 5 classes (DC) [3,23]. DC1, trees

that have recently died, leaves and bark remains, tops are intact and the majority of fine branching present, cambium is still fresh, solid wood and its color is original; DC2, trees that have been dead for some time, do not have leaves but the bark remains, tops are intact and most of fine branching present, cambium decayed, larger twigs present, trunk shape is round, wood solid, wood color is original; DC3, trees that have lost more than 50% of their branches and less than 50% of their bark remains, tops are intact, leaves absent, sapwood missing, heartwood mostly sound; DC4: trees with broken tops, leaves absent, bark often absent, few or no coarse branches, wood color is original to faded, heartwood decayed soft; DC5, trees with broken tops and no leaves and branches, bark absent, trunk shape is round to oval, wood is fragmented and powdery, and heavily faded.

The time required for a snag to change from DC1 to DC5 depends on several factors, the most important of which are climatic conditions, topography and tree species. This period is reported to be 27 years for beech species and 21 years for hornbeam species in the Hyrcanian forests [24].

Tree cavities (TC) were counted on each snag and their height from ground level was measured. In this study we measured the cavities excavated by birds (BEC), especially by woodpeckers, and the cavities created naturally (by decay, limb breakage, or other injuries of trees) that could be used by birds on snags (NC) [25–27]. Cavities excavated by birds (BEC) and natural cavities (NC) were distinguished based on the entrance shape of the cavities. The entrances of the cavities excavated by birds were circular or oval, while the entrances of the natural cavities were irregular. However, not all natural cavities on snags have the potential to be used by birds and depend on cavity characteristics [25,28,29]. In this study all BEC and NC were considered, recorded, and measured. First, each side of the snags was searched using a binocular to find the cavity. Then, the height from ground level and the entrance diameters (width or length) of the detected cavities were measured. A 9 m ladder was used to reach the cavities at heights less than 13 m, and a fishing rod and a camera (SONY HDR XR 550, Sony Corporation, Tokyo, Japan) were used to reach the cavities at higher heights on snags.

2.3. Data Analysis

After checking data for normality (Kolmogorov–Smirnov test, $\alpha = 0.05$) and homogeneity of variance (Levene test, $\alpha = 0.05$), the means of dendrometric characteristics of live trees and snags were compared using one-way ANOVA in the stands (Sh, Sc, and Pr). Multiple comparisons among means were made using Duncan's test ($\alpha = 0.05$). The abundance and volume of snags in dbh classes, and in the different snag species, were compared by ANOVA and Duncan's test ($\alpha = 0.05$). The frequencies of tree cavities in different decay, dbh, and species of snags were compared using non-parametric Chi-Square test. Statistical analyses were performed using SPSS version 17 (Chicago, IL, USA) software.

3. Results

The results showed that all the dendrometric characteristics of live trees and snags (except height of live trees) were significantly affected by silvicultural treatments (Table 2). Density, dbh, basal area, and standing volume of live trees were significantly higher in the protected stands (Pr) than in the selection cutting stands (Sc), and shelter wood stands (Sh). Density of snags in the Pr stands was significantly higher than their density in the Sc stands and Sh stands. The mean dbh of snags in the Pr stands was significantly higher than their mean dbh value in the Sc stands and Sh stands. The mean height of snags in the Pr stands was significantly higher than Sc stands, while there was no significant difference between the means of the height of snags in the Sc and Sh stands. The mean basal area of snags in the Pr stands was significantly higher than Sc stands, and in the Sc stands it was significantly higher than in the Sh stands. The mean standing volume of snags in the Pr stands was significantly higher than their means in the Sc stands, and in the Sc stands it was significantly higher than in the Sh stands (Table 2).

Table 2. Dendrometric characteristics (mean ± SD) of live trees and snags in the studied parcels and results of ANOVA and *t* tests. Sh: Shelter wood managed stand; Sc; selection cutting managed stand; Pr: protected stand. Different letters among columns indicate statistically significant differences according to Duncan’s test.

Stand Characteristics	Tree Condition	Sh1	Sh2	Sc1	Sc2	Pr1	Pr2	F-Value	p-Value
Density (stem ha ⁻¹)	Live	205.7 ± 22.1 b	210.1 ± 25.1 b	183.5 ± 21.3 c	189.0 ± 22.0 c	273.4 ± 28.3 a	270.5 ± 27.6 a	235.9	0.000
	Snag	6.1 ± 0.9 c	5.3 ± 0.8 c	11.0 ± 2.2 b	10.3 ± 2.1 b	35.8 ± 3.3 a	36.6 ± 3.6 a	152.7	0.000
	<i>t</i> -test	<i>t</i> = 1305.5 **	<i>t</i> = 1245 **	<i>t</i> = 850.2 **	<i>t</i> = 837.4 **	<i>t</i> = 450.8 **	<i>t</i> = 372.2 **	-	-
DBH (cm)	Live	21.5 ± 2.0 c	22.0 ± 2.1 c	26.6 ± 2.4 b	27.3 ± 2.0 b	32.8 ± 4.1 a	31.7 ± 3.7 a	139.1	0.000
	Snag	15.5 ± 2.2 c	15.7 ± 2.2 c	24.7 ± 3.4 b	23.2 ± 3.5 b	45.4 ± 4.1 a	47.5 ± 4.5 a	126.4	0.000
	<i>t</i> -test	<i>t</i> = 17.4 **	<i>t</i> = 19.6 **	<i>t</i> = 3.8 N.S.	<i>t</i> = 4.9 N.S.	<i>t</i> = 32.2 **	<i>t</i> = 44.6 **	-	-
Height (m)	Live	19.8 ± 1.9 a	19.5 ± 1.9 a	18.7 ± 2.0 b	17.8 ± 2.1 c	19.3 ± 2.5 a	17.6 ± 2.3 b	11.2	0.071
	Snag	8.0 ± 2.1 b	8.4 ± 2.0 b	8.2 ± 1.5 b	7.8 ± 1.4 b	14.2 ± 2.6 a	14.0 ± 2.7 a	140.3	0.000
	<i>t</i> -test	<i>t</i> = 32.5 **	<i>t</i> = 31.7 **	<i>t</i> = 29.6 **	<i>t</i> = 28.4 **	<i>t</i> = 13.4 **	<i>t</i> = 10.2 **	-	-
Basal area (m ² ha ⁻¹)	Live	7.7 ± 0.6 c	7.8 ± 0.8 c	11.8 ± 1.5 b	12.2 ± 1.5 c	19.6 ± 2.0 a	19.4 ± 1.9 a	101.6	0.000
	Snag	0.12 ± 0.02 c	0.10 ± 0.01 c	0.54 ± 0.05 b	0.45 ± 0.05 b	4.17 ± 0.8 a	4.76 ± 2.1 a	95.7	0.000
	<i>t</i> -test	<i>t</i> = 438.3 **	<i>t</i> = 496.1 **	<i>t</i> = 344.4 **	<i>t</i> = 350.9 **	<i>t</i> = 107.6 **	<i>t</i> = 98.2 **	-	-
Standing volume (m ³ ha ⁻¹)	Live	91.5 ± 10.1 c	92.7 ± 10.1 c	133.7 ± 15.0 b	131.5 ± 13.8 b	210.5 ± 15.1 a	205.8 ± 14.5 a	186.5	0.000
	Snag	0.72 ± 0.07 c	0.70 ± 0.06 c	4.48 ± 0.86 b	4.27 ± 0.72 b	28.94 ± 3.75 a	39.21 ± 4.40 a	99.6	0.000
	<i>t</i> -test	<i>t</i> = 1450.8 **	<i>t</i> = 1394.0 **	<i>t</i> = 170.3 **	<i>t</i> = 195.6 **	<i>t</i> = 119.7 **	<i>t</i> = 100.4 **	-	-

Note: **: significant at α = 0.01. N.S.: not significant.

Results indicated that the density, height, basal area, and standing volume of live trees were significantly higher than their values for snags in all studied stands, while dbh of live trees was significantly higher than dbh of snags in the Sh stands (Table 2).

Results showed that the proportions of snag volume in the Pr stands were 8.6% and 9% from total standing volume, while the proportions in the Sc stands were 5.3% and 5.7%, and in the Sh stands they were 2.5% and 2.9% (Figure 1).

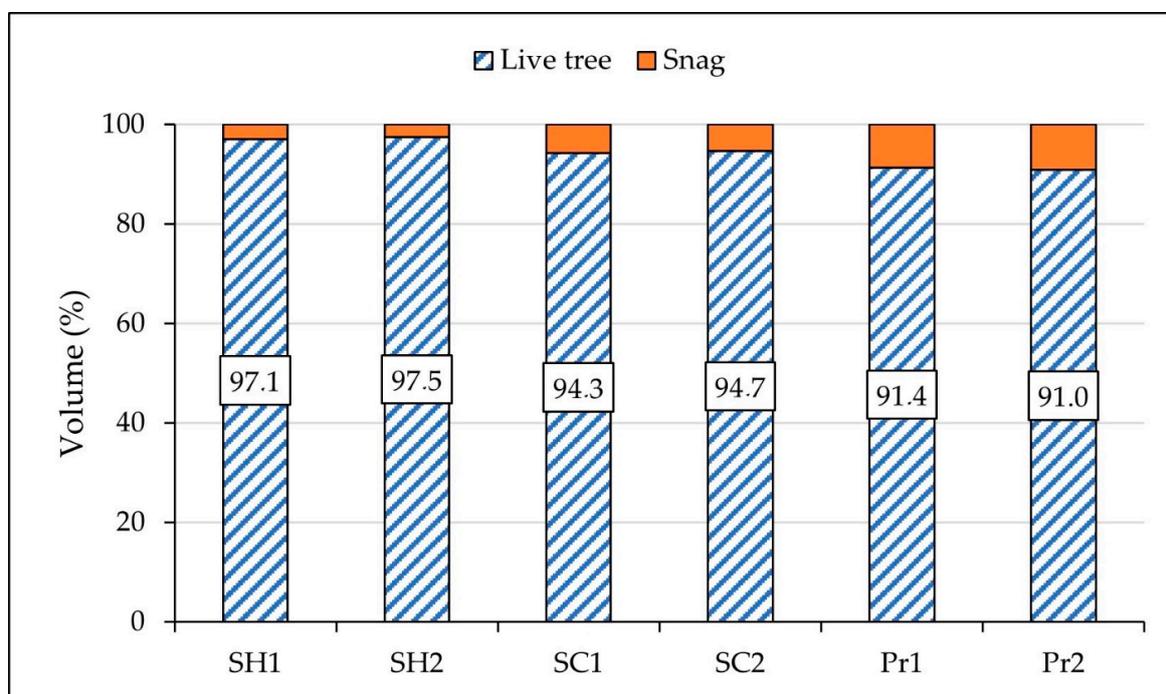


Figure 1. Volume proportion of live trees and snags in the studied stands (Sh: shelter wood silviculture, Sc: selection cutting silviculture, and Pr: protected). DC1 is a tree that died very recently and DC5 a tree with the most advanced decay.

Results indicated that DC1 had the highest volume proportion of snags in the Sh and Sc stands, while DC5 had the highest volume proportion of snags in the Pr stands (Figure 2). The volume proportion of snags decreased by increasing their decay intensity in the Sh and Sc stands, while the volume proportion of snags increased by increasing their decay intensity in the Pr stands.

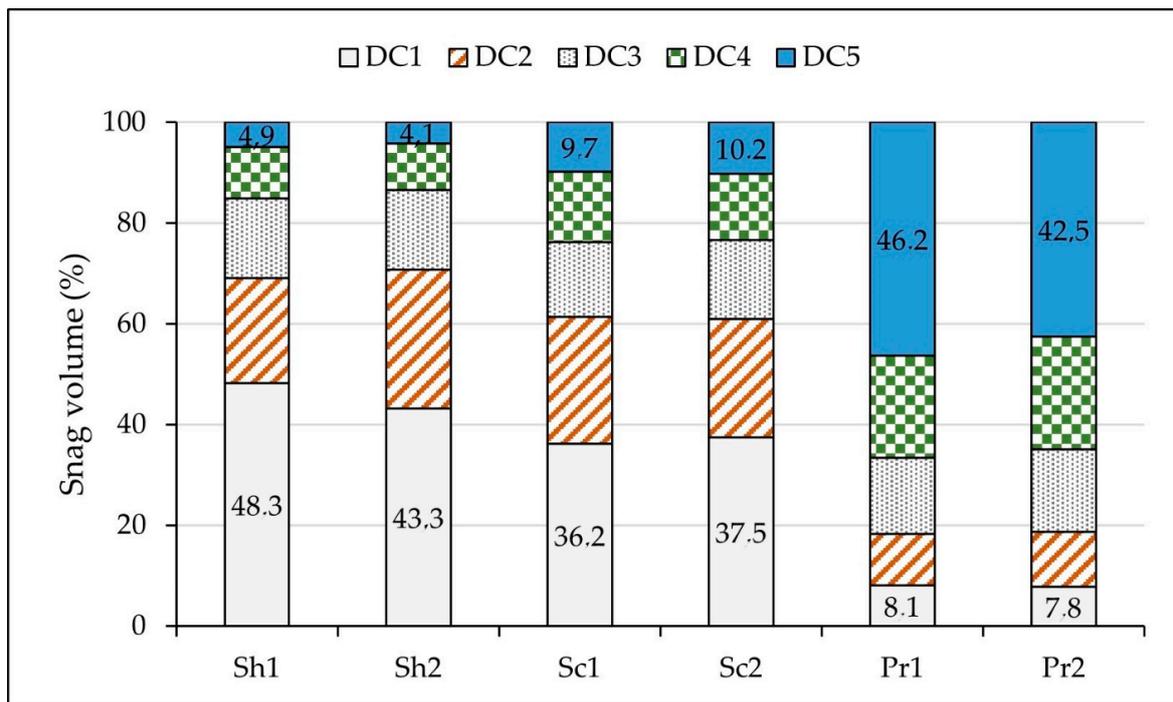


Figure 2. Volume proportion of decay classes (DC) of snags in the studied stands (Sh: shelter wood silviculture, Sc: selection cutting silviculture, and Pr: protected).

Snag density decreased by increasing their dbh class in the studied stands (Figure 3). Snag density in the Pr stands was significantly higher than in the Sc and Sh stands in all of the dbh classes. Snag density in the Sc stands was higher than in Sh stands in all of the dbh classes, but the difference was significant only in the 7.5–25 cm class. Snags with a dbh > 75 cm were not observed in the Sh stands, and snags with a dbh > 100 cm were not observed in the Sc stand, while snags with a dbh of 100–125 cm had a density of 2.4 stem ha⁻¹ in the Pr stands.

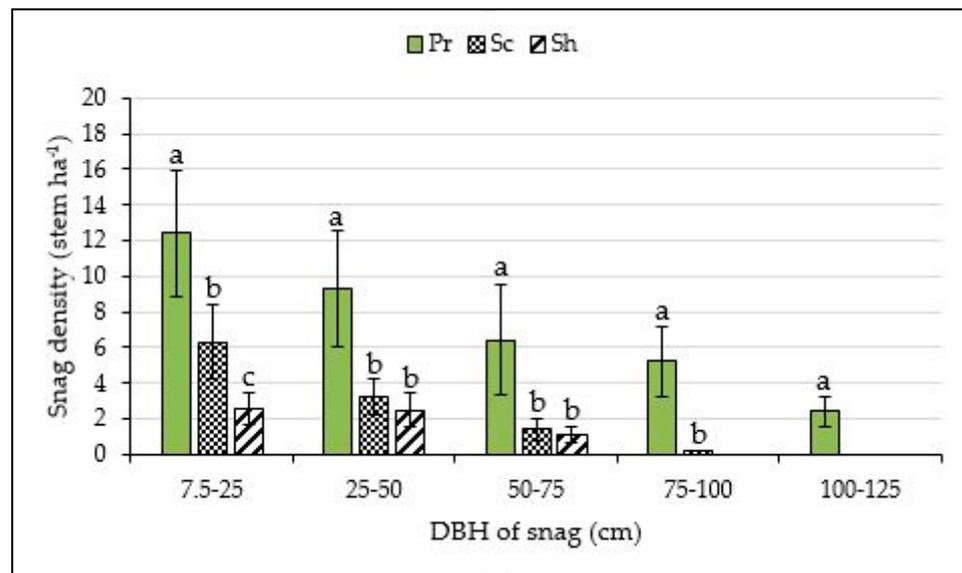


Figure 3. Mean snag density in dbh classes in the studied stands (Sh: shelter wood silviculture, Sc: selection cutting silviculture, and Pr: protected). ANOVA results (dbh of 7.5–25 cm: $F = 50.4$, $p < 0.001$; dbh of 25–50 cm: $F = 44.5$, $p < 0.001$; dbh of 50–75 cm: $F = 42.6$, $p < 0.001$; dbh of 75–100 cm: $F = 51.7$, $p < 0.001$).

Results showed that snag volume increased by increasing their dbh class (Figure 4). Snag volume in the Pr stands was significantly higher than their volume in the Sc and Sh stands. The mean volume of snags with a dbh > 100 cm in the Pr stands was 12.2 m³ ha⁻¹.

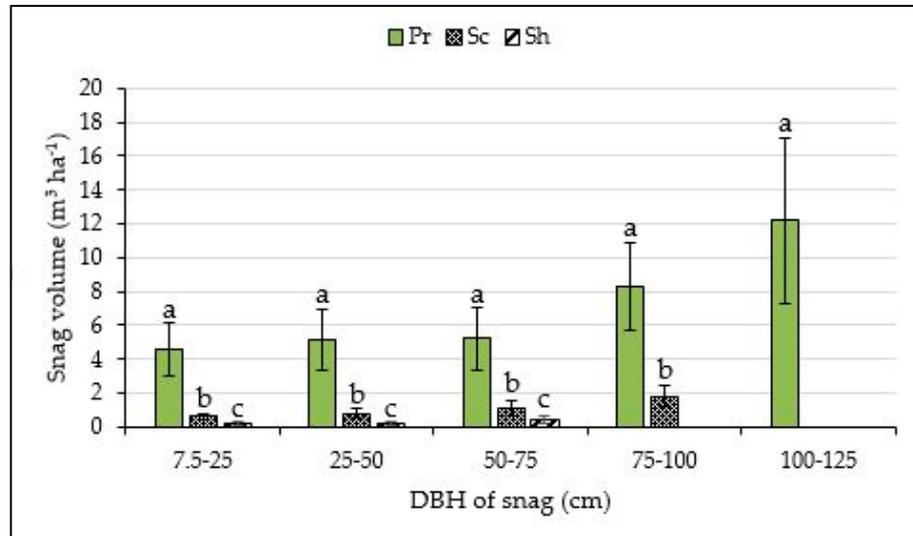


Figure 4. Snag volume in dbh classes in the studied stands (Sh: shelter wood silviculture, Sc: selection cutting silviculture, and Pr: protected). ANOVA results (dbh of 7.5–25 cm: $F = 80.2, p < 0.001$; dbh of 25–50 cm: $F = 76.8, p < 0.001$; dbh of 50–75 cm: $F = 68.5, p < 0.001$; dbh of 75–100 cm: $F = 39.3, p < 0.001$).

Results showed that the snag volume consisted of more species in the Pr stands than in the Sc and Sh stands (Figure 5). The snags of *F. orientalis* had the highest values among species in all studied stands. The volume of all snag species in the Pr stands was significantly higher than the Sc stands, and in the Sc stands the volume was significantly higher than the Sh stands.

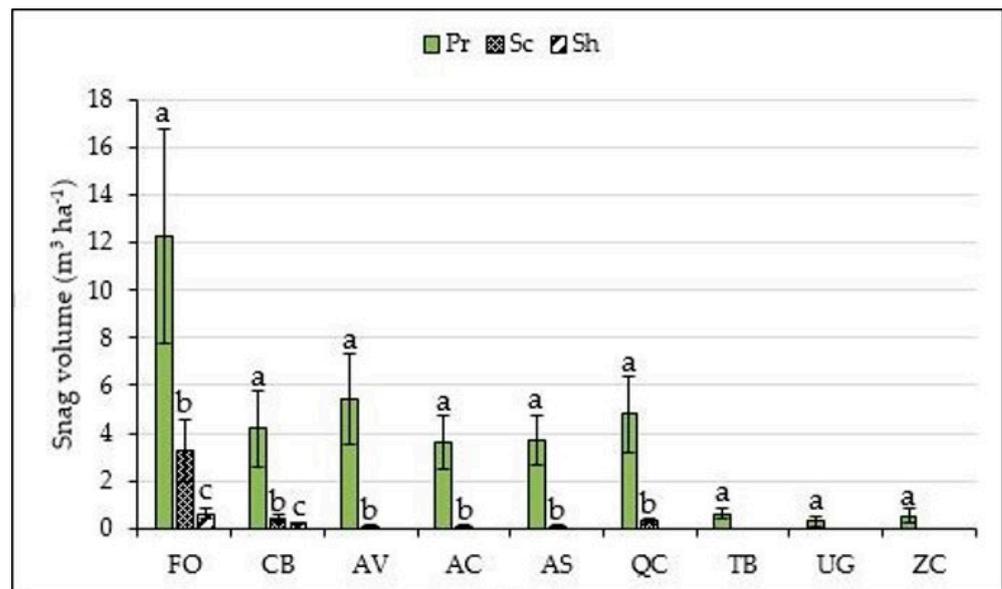


Figure 5. Snag volume in tree species in the studied stands (Sh: shelter wood silviculture, Sc: selection cutting silviculture, and Pr: protected; (FO: *F. orientalis*; CB: *C. betulus*; AV: *A. velutinum*; AC: *A. cappaducicum*; AS: *A. subcordata*; QC: *Q. castaneifolia*; TB: *T. begonifolia*; UG: *U. galbra*; ZC: *Z. carpinifolia*). ANOVA results (FO: $F = 65.8, p < 0.001$; CB: $F = 48.5, p < 0.001$; AV: $F = 71.6, p < 0.001$; AC: $F = 62.0, p < 0.001$; AS: $F = 66.1, p < 0.001$; QC: $F = 59.3, p < 0.001$).

Results indicated that the frequency of snags with tree cavities (TC) in the Pr stands was significantly higher than their frequency in the Sc stands, and in the Sc stands the frequency was significantly higher than in the Sh stands (Table 3). Frequency of TC in the Pr stands was significantly higher than their frequency in the Sc stands, and in the Sc stands their frequency was significantly higher than in the Sh stands. Also, the frequency of both types of cavities (excavated, BEC, and natural, NC) in the Pr stands was significantly higher than in the Sc stands, and in the Sc stands the frequency was significantly higher than in the Sh stands. The mean number of TC on the snags in the Pr stands was significantly higher than their means in the Sc and Sh stands. Results showed that the silvicultural treatments had no significant effect on the height from ground level of TC, BEC, and NC.

Table 3. Tree cavity (TC), bird excavated cavity (BEC), and natural cavity (NC) characteristics (mean ± SD) in the studied stands and results of ANOVA tests (Sh: shelter wood silviculture, Sc: selection cutting silviculture, and Pr: protected). Different letters among columns indicate statistically significant differences according to Duncan’s test.

BCN Characteristics	Sh1	Sh2	Sc1	Sc2	Pr1	Pr2	F-Value	p-Value
Snags with TC (%)	19.3 ± 2.7 c	20.4 ± 2.5 c	33.0 ± 3.1 b	27.1 ± 2.8 b	59.7 ± 3.5 a	63.5 ± 3.9 a	184.4	0.000
Frequency of TC (N ha ⁻¹)	1.2 ± 0.6 c	1.2 ± 0.7 c	5.5 ± 0.8 b	4.7 ± 0.9 b	70.5 ± 3.9 a	81.3 ± 4.1 a	140.3	0.000
Frequency of BEC (N ha ⁻¹)	0.3 ± 0.1 c	0.2 ± 0.1 c	2.2 ± 0.4 b	2.3 ± 0.3 b	25.1 ± 3.6 a	28.9 ± 3.5 a	106.8	0.000
Frequency of NC (N ha ⁻¹)	0.9 ± 0.3 c	1.0 ± 0.3 c	3.3 ± 0.4 b	2.4 ± 0.3 b	45.4 ± 5.8 a	52.4 ± 6.3 a	117.0	0.000
Intensity of TC (N snag ⁻¹)	1.0 ± 0.05 c	1.1 ± 0.05 c	1.5 ± 0.11 b	1.7 ± 0.12 b	3.3 ± 0.62 a	3.5 ± 0.70 a	95.7	0.000
Height of TC from ground (m)	7.1 ± 0.7 a	7.7 ± 1.0 a	9.0 ± 1.1 a	9.0 ± 1.2 a	8.7 ± 1.0 a	8.8 ± 1.1 a	9.68	0.204
Height of BEC from ground (m)	7.7 ± 0.6 a	7.6 ± 0.7 a	9.2 ± 0.8 a	9.3 ± 1.0 a	8.9 ± 1.5 a	8.5 ± 1.5 a	3.24	0.102
Height of NC from ground (m)	6.9 ± 0.5 a	7.0 ± 0.7 a	8.9 ± 1.1 a	8.8 ± 1.0 a	8.5 ± 1.4 a	9.0 ± 1.6 a	1.80	0.110

Results showed that the highest frequency of snags with TC was in DC3 followed by DC2 > DC1 > DC4 > DC5 (Figure 6). More than 60% of DC3 snags and about 42% of DC2 snags had TC, while 11.8% of DC1 snags and 10.3% of DC4 snags had TC, and only 2.7% of DC5 snags had TC. The results showed that in the snags with less decay intensity (DC1 and DC2) the frequency of BEC was higher than the frequency of NC, while in the snags with more decay intensity (DC3 and DC4), the frequency of NC was higher than the frequency of BEC, so that in very decayed snags (DC5) BEC was not found.

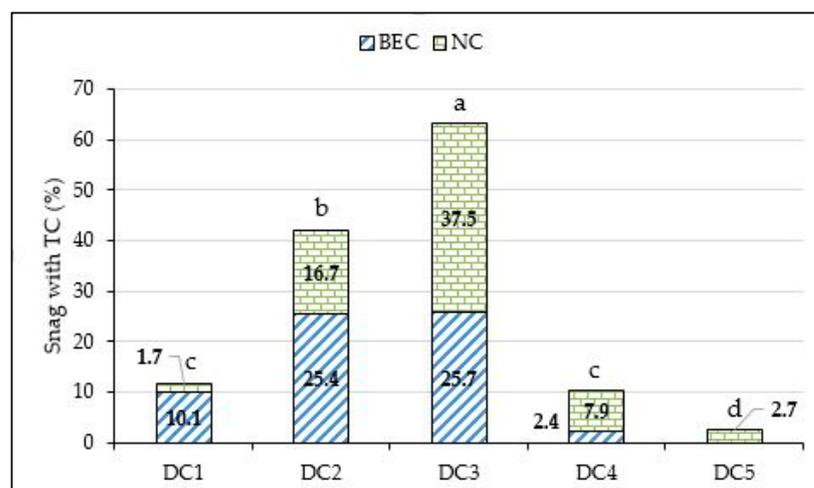


Figure 6. Frequency of snags with tree cavity (TC) in different decay classes ($\chi^2 = 100.2, p < 0.01$). BEC: bird excavated cavity; NC: natural cavity. DC1 is a tree that died very recently and DC5 is a tree with the most advanced decay. Different letters among columns indicate statistically significant differences according to both Duncan’s test and the Chi-square test (TC ratio in pairs).

Results indicated that the frequency of snags with TC increased with the increasing dbh of snags (Figure 7). About 61% of snags with a dbh class of 100–125 cm had TC, while

only 3.6% of snags with a dbh of 7.5–25% had TC. The results showed that the frequency of BEC increased with increasing snag diameter. BEC were not observed in snags with dbh < 25 cm.

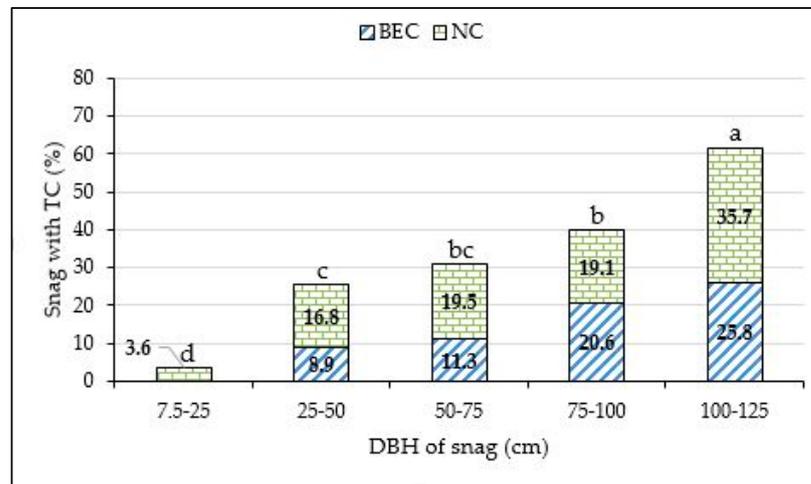


Figure 7. Frequency of snags with tree cavity (TC) in different dbh classes ($\chi^2 = 54.7, p < 0.01$). BEC: bird excavated cavity; NC: natural cavity. Different letters among columns indicate statistically significant differences according to both Duncan’s test and the Chi-square test (TC ratio in pairs).

Results revealed that the frequency of snags with TC was correlated with snag species (Figure 8). The highest frequency of snags with TC was observed in the snag species of *Z. carpinifolia* (67.3%), *Q. castaneifolia* (57.8%), *F. orientalis* (53.1%), and *T. begonifolia* (44.6%). The frequency of snags with BCN in the species of *A. velutinum*, *C. betulus*, *A. cappaducicum*, and *U. galbra* was 15.7%, 13.2%, 10.2%, and 10.2%, respectively. The lowest frequency of snags with TC was observed in *A. subcordata* (5.3%). The results showed that the frequency of NC was higher than the frequency of BEC in the snag species of *F. orientalis*, *A. subcordata*, *Q. castaneifolia*, *T. begonifolia*, and *Z. carpinifolia*, while in the snag species of *C. betulus*, *A. velutinum*, *A. cappaducicum*, and *U. galbra* the frequency of BEC was higher than the frequency of NC.

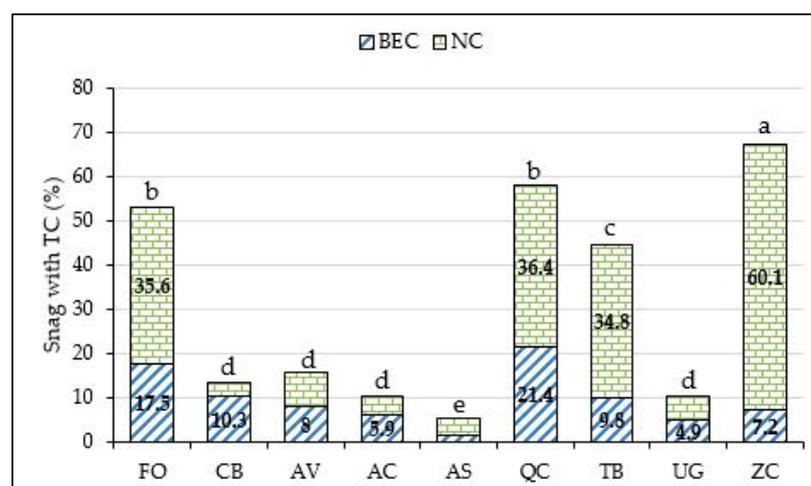


Figure 8. Frequency of snags with tree cavity (TC) in different snag species ($\chi^2 = 113.9, p < 0.01$). (FO: *F. orientalis*; CB: *C. betulus*; AV: *A. velutinum*; AC: *A. cappaducicum*; AS: *A. subcordata*; QC: *Q. castaneifolia*; TB: *T. begonifolia*; UG: *U. galbra*; ZC: *Z. carpinifolia*). BEC: bird excavated cavity; NC: natural cavity. Different letters among columns indicate statistically significant differences according to both Duncan’s test and the Chi-square test (TC ratio in pairs).

4. Discussion

Focusing on the characteristics of the snags in the different sections (Pr, Sc and Sh), a clear trend is evident. Specifically, both Sc and Sh showed values of snag dendrometric characteristics that are substantially lower than the values reported for unharvested natural stands. Such results are in concordance with current literature, which highlighted how natural stands not affected by harvesting presented higher values of deadwood [16]. An important aspect to be highlighted is the fact that snags with a very high dbh (>75 cm) were mostly found only in the unharvested stands. This is particularly relevant, considering that larger snags have higher ecological value, being able to create micro-habitats and shelter for a higher number of animal species [30–32].

Previous research showed that the amount of deadwood and its components depended significantly on forest type, age from the reserve establishment, and volume of living wood [4,33,34].

In both the shelter wood silviculture and tree-selection cutting silviculture, defects and indicators of wood decay are considered when trees are selected for cutting due to the creation of suitable conditions for the tree regeneration, seed establishment, rapid growth of seedlings and remaining trees, and the maximization of the future value of the forest [35]. The results of a study conducted in Estonian forests showed that the bird community was strongly affected by the abundance of deadwood [36].

Another important aspect to highlight consists of the different subdivisions of decay classes among the different stands. In particular, the natural stand showed a higher percentage of D5 class, while class D1 was predominant in Sc and Sh. The subdivision into different decay classes of deadwood is a parameter that is strongly influenced by several variables and it is difficult to identify the best practices of forest management to improve this parameter [4,37]. However, in both Sc and Sh there was a strong prevalence of D1 class, which in time will evolve up to the higher classes. Therefore, in the following interventions, it is recommended to leave some standing snags in order to increase the share in the other decay classes. Research has shown that the survival of a number of endangered bird species depends on the presence of sufficient different forms and decay degrees of forest deadwood, including snags [38–40].

Another difference among harvested and unharvested stands was found regarding the species composition of standing dead trees. Indeed, the amount of snags in Pr stands consisted of multiple species, while in Sc and Sh only the main species (beech and hornbeam) were found as snags.

A similar trend to snags' characteristics and their amount was found regarding TC, with Pr stands showing better values than harvested stands in both the number of snags with TC and number of TC per hectare. Instead, no difference was found regarding the average height of TC from the ground. Comparing the average number of TC with previous similar studies performed in other parts of the world, it is possible to notice that in the Hyrcanian forest the TC number was substantially higher in unharvested stands (about 75 stems ha^{-1} vs. about 15 stems ha^{-1}) when compared with harvested forests (around 5 stems ha^{-1}) [30]. Remm et al. (2006) assessed abundance, characteristics, and affective factors on occurrence of tree cavities, and the role of woodpeckers as keystone species in riverine aspen and birch stands in central Estonia [25]. Their results showed that the abundance of tree cavities was 6.9 cavities ha^{-1} , 68% of which were suitable for secondary cavity nesters. They concluded that riverine areas may be important centers of cavity supply in forested regions; the occurrence of tree cavities is mostly determined by tree species, condition (snags) and size as well as stand type while the occupancy of tree cavities by secondary cavity nesters is determined by tree condition (live trees) and the type and entrance diameter of cavities, and the value of woodpeckers as keystone species depends on the occurrence of natural cavities. The abundance of tree cavities was reported as 40 cavities ha^{-1} [41] in a managed mixed forest and 60.8 cavities ha^{-1} in an unmanaged *Quercus robur* dominated forest [42] in central Sweden; 28.5 cavities ha^{-1} in an *Acer saccharum* dominated forest in NY, USA [43]; 23.2 cavities ha^{-1} in a *Quercus* spp.

dominated forest in KY, USA [44]; 11.2 cavities ha⁻¹ in a forest dominated by *Acer* spp., *Quercus* spp., *Populus* spp., *Tilia* spp. in Ont. Canada [45]. Of course, it should also be noted that, in many cases, woodpeckers start excavation and create an entrance and a corridor but not a nest chamber [21], so to determine the suitability of cavities, dimensions of cavity chambers should be carefully measured and well examined.

A very interesting finding is that there was a very high percentage of snags with TC in both *Zelkova carpinifolia* and *Quercus castaneifolia*, therefore on a secondary species. This highlights the importance of preserving tree species biodiversity during felling choices [46].

Despite the substantial difference found between harvested and unharvested stands regarding snag characteristics, which has already been highlighted by previous studies even if in different stands in different zones of the world, the major finding of the present study consists of revealing the differences between the different forestry treatments, i.e., Sc and Sh. Indeed, selection cutting showed better values regarding both snags and TC. Therefore, the findings of the present study have highlighted how a single-tree selection system has less impact on deadwood, as compared to the shelter wood system. This has already been stated by current literature for other indicators of sustainable forest management [47].

One of the important goals of the implementation of forest ecosystem-based management is to prevent the simplification of the stands structure and the loss of snags [27]. Previous literature suggested that maintaining and creating pine snags in commercial coniferous forests would help in maintaining the biodiversity of tree-dwelling animals [48]. To manage habitats for cavity nesters, it is crucial to know their main requirements as well as where and why the suitable cavities occur [25]. In even-aged oak-dominated stands in Hungary, Aszalós et al. (2020) investigated the foraging activity of woodpeckers on five forms of artificially created deadwood (damaged, girdled, felled trees, and low and tall stumps) over one, two, and three years [49]. Their results illustrated that the woodpeckers used the five deadwood types in very different ways and foraging activity was found to vary greatly in terms of depth of foraging and between years. They concluded that the permanent creation and maintenance of various forms of deadwood as foraging sites play an important role in conserving woodpecker species, which should be considered as a conservation criteria in woodpecker species conservation management programs [50]. Snags are particularly important for primary cavity nesters (woodpeckers) and in forests where holes in live trees are rare (due to tree species or age), whereas old live trees with natural cavities provide a long-term and preferred nest supply for hole-nesting passerines [25].

According to what has been written above and considering the importance of having a comprehensive approach to forest ecosystems to properly plan forest management, taking into consideration the requirements of the various species nesting in forest trees is a crucial issue and should be implemented in forest management plans as a parameter to be thought about when planning harvesting operations.

5. Conclusions

Snags, and deadwood in general, are one of the main components of forest ecosystems and play an important role in their sustainability. It is obvious that forest harvesting has an influence on snags and their characteristics. Therefore, sustainable forest management should accurately assess the effect of harvesting so as to determine effective measures to minimize the impact.

This study focused on an evaluation of the influence of two different forestry treatments (shelter wood and single-tree selection) on the abundance and characteristics of snags and tree cavities (i.e., bird excavated cavities, BEC, and natural cavities, NC) in comparison with an unmanaged stand as a control. This is the first study to carry out this type of evaluation in the Hyrcanian forest in Iran, and one of the first to analyze two specific forestry treatments.

The results obtained showed that both the shelter wood system and the single-tree selection caused a decrease in the amount of snags and tree cavities (both BEC and NC),

confirming how forest harvesting has a substantial impact on these indicators. It is worth stating that the shelter wood system showed the highest impact, providing evidence that single-tree selection is the system that gives the best performance in sustainable forest management.

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