

The importance of coarse woody debris in dynamic phases exposure in the beech (*Fagus orientalis* L.) stands of Hyrcanian forests

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Abstract: In a natural forest, phases of different dynamics are gradually replaced to create sustainability in the stands. Coarse woody debris is among the most significant structural elements of natural stands that perform an influential position in the identification of dynamic phases. Therefore, the focus of this study is on dead wood conditioning as one of the major structural components in determining the various dynamic phases in the northern forests of Iran as part of the temperate forests. For this study, compartment 326 of Gorazbon District was considered as one of the control parcels of Kheyroud Forest. In this parcel, 25 one-hectare sample plots were selected as permanent plots for a long-term forest structure and succession studies. The coarse woody debris by 100% sampling method was measured. The results showed that there are 8 main phases in this area (gap formation, understorey initiation, stem exclusion, volume accumulation, volume degradation, multiple, lighting, old-growth). The extensive forest area (52%) is located in the understorey initiation and stem exclusion phases. The results also showed that the total average volume of snags and logs was $41.5 \text{ m}^3 \cdot \text{ha}^{-1}$. Furthermore, the mean dead wood volume in decay classes 1, 2, 3 and 4 was 10.33, 12.22, 9.15 and $83.9 \text{ m}^3 \cdot \text{ha}^{-1}$, respectively. The average frequency of dead trees in the diameter classes smaller than 25 cm, 25–50 cm and in the diameter class more than 50 cm is 25.79, 6.93, and 4.88. The significance analysis results obtained by ANOVA test showed that there is a significant difference between volume, snag and log stock and the shape of dead wood in various dynamic phases. Therefore, in general, dead wood in the forest differs according to habitat, evolutionary stage (dynamic phases), standing volume and species diversity of the tree species.

Keywords: succession; stand structure; Kheyroud forest

The floristic structure and composition of the forests of northern Iran reveal that these forest stands are in the last stage of succession (ZENT, ZENT 2004; GLAESER 2006; MARI et al. 2016). In the last succession stage, the forest stands exist in an equilibrium state (FRELICH 2016). The structure and composition of a dynamic ecosystem are continually developing or they are changing under the influence of environmental conditions (JENTSCH et al. 2002). Dynamics means changes in the structure of forest stands over time and the dynamics of the final stage

of succession means a change in the structure of forest stands across a period (SEIDL et al. 2011).

As time passes, trees in a stand die and fall as growing old and longevity beginning. Besides the drying of old trees, an open space is created in the stand canopy which provides a suitable environment for tree regeneration (KARKI, HALLGREN 2015; VÉZEAU, PAYETTE 2016). The younger generation occupies these gaps and causes the stand restoration (SHOO, CATTERALL 2013; ELGAR et al. 2014). By getting older, this young group gradu-

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ally comes to the higher storey and is responsible for other tasks than mature trees. Lastly, this cycle continues with the aging and end of the longevity (PEIXOTO et al. 2018).

In a natural forest, the diversity of the development stages is noticeable (GLATTHORN et al. 2017) when the initial stage (increasing the sizes), the optimal stage (volume accumulation) and the decay stage have been identified in the Hyrcanian forests (SEFIDI et al. 2010).

Different structure and composition in the dynamic process lead to the formation of relatively stable states that are called phases (BOBIEC 2002). In a natural forest, phases of different dynamics are gradually replaced to create sustainability in the stands (SHOROHOVA et al. 2009). The growing up stage (initial stage) includes gap formation, understorey initiation and regeneration phases. Volume accumulation, lightning and stem exclusion phases were recognized in the stability stage (optimal stage) and finally the decline stage (decay stage) includes old growth and volume degradation (ÓDOR et al. 2002).

The dynamics of forest stands or the process of transformation of forest stands is the conversion of forest stands over time (OLIVER, LARSON 1996). Structural components such as living trees, dead trees, forest gaps perform an influential role in determining the dynamic phases. Dead wood is one of the most important structural basics of natural stands which can have different diameters depending on their species and their ecological nature (CLINTON et al. 1993; YAMAMOTO 2000; FRANKLIN et al. 2007; RICHARDS, HART 2011). The dead tree is also an important structural characteristic of the natural and old-growth forests which encompasses a wide range of ecological and biochemical functions (HARMON et al. 1986). The coarse woody debris can be considered as an adequate and indispensable indicator in the nutrient cycle, long-term carbon storage, forest regeneration, production and sustainability, and forest biodiversity assessment of forest ecosystems (HARMON et al. 1986; HUSTON 1996; HARMON, SEXTON 1996; STEVEN 1997; STURWANT et al. 1997; McCOMB, LINDMAYER 1997; LARSEN 2001; ATICI et al. 2001).

Today it is known that more than a third of European forest tree species for the survival depends on old and dead trees (CHRISTENSEN et al. 2005). In addition, dead trees afford the habitat and needed nutrients for birds, bats, and other mammals and

are important for small forest species such as insects, fungi, nematodes (ALIEN et al. 2000; HILMAN-KLEVESON 2001; NORDEN et al. 2004; XI et al. 2009), lichens and non-vascular plants (PALLETTO et al. 2008) and vascular plants and vertebrates (SITONEN 2001). They additionally perform an influential role in the health and fertility of the forest (ZHOU et al. 2007). Despite the importance of dead trees, nowadays, in many forests there is a small stock that can be due to improper management operations in commercial forests and even protected areas (CRONKLETON et al. 2012). The average number and volume per hectare of dead trees are generally less than 2% in many forests, including forests of Europe and the Caucasus, except for less intact natural and protected forests (CHRISTENSEN et al. 2005). However, their ecological role has been recognized for a long time (ELTON 1966). Reducing the importance of the production function of temperate and boreal forests has led to a change in the attitude to the role of dry trees in ecosystem processes (HARMON et al. 1986).

Dead trees in the forest usually include standing and rooted trees, fallen trunks, rotten and rootstock trees, and perforated trunks. The total number of dead trees between 1 to 342 m³·ha⁻¹, the portion of dead trees between 24% to 73%, standing dead trees between 27% to 41%, and most of them are between 2 to 3 decay degrees, are obtained in pure and mixed beech stands of natural and protected forests (KORPEL 1995; MAYER 1999; SANIGA, SCHÜTZ 2001; FRIEDMANN, WALHEIM 2000; JAVERESKY et al. 2002; MONTFORD et al. 2002; CHRISTENSEN et al. 2005; MOTTA et al. 2006; MAYER, SCHMIT 2011).

Dead standing trees provide habitats for wildlife in the forest. Dead trees provide a new ecological niche for many plants and animals and play an essential role in the nutrient cycle (McCOMB et al. 1993; SANTIAGO, AMANDA 2005).

An outstanding feature of natural forests is that these forests have large amounts of coarse woody debris in different stages of decay, as well as high numbers of live trees and old trees with dry parts (WIRTH et al. 2009). Generally, the affluence and volume of dead wood in the forests depend on the type of forest, volume of production, succession stages, pattern of natural distribution, type and incidence of human activities, records of harvesting, type of management and climatic characteristics and habitat soil (CHRISTENSEN et al. 2003). Dead wood, as an important part of the structure of forest stands, is always considered

in the studies of forest stand dynamics (SEFIDI, MARVIE-MOHADJER 2010).

Therefore, the focus of this study is on coarse woody debris conditioning as one of the principal structural components in determining the dynamics of various phases in the northern forests of Iran as part of the temperate forests. Therefore, this study tries to answer the question about the role of this structural component in the various dynamic phases.

MATERIAL AND METHODS

Study area

The study area is located in Kheyroud Nowshahr Educational and Experimental Forest, seven kilometres east of Noshahr in Mazandaran province, between 51°32'30" to 51°35'25" north latitude and 36°27'30" to 36°40'25" east longitude in the geographical coordinate system. Gorazbon District is the third district of the forests under the management of the Natural Resources Faculty (NRF), which is situated at an altitude of 540–1,350 m a.s.l. The Gorazbon District has 27 compartments and its area is 934.24 hectares. This forest is bounded from the north to the southern edge by the forests of Chalandar (watershed 46) and from the east by the forests of the Chelir district, to the south by the Kheyroud River, and to the west by the forests of the Namkhaneh district. In this study, compartment 326 was considered, which is one of the control sites of Kheyroud forest (Fig. 1). Parcels 326

and 327 are intended to be part of a control unit that will not be harvested in any way and will therefore be suitable for long-term research activities. Based on typology studies (ETEMAD et al. 2013), the pure beech type occupies the majority of these two parcels.

Method of studying

After preliminary studies according to the study objectives, parcel 326 was selected as the studied area, considering that the type is pure beech, and moreover as a control parcel. In this area 25 one-hectare plots were selected as permanent plots for the long-term research studies of forest structure and succession, all of them are separated by blue from each other and all the trees in them are numbered. Since the beginning of forestry activities no management practices on compartment 326 have been done so far.

Dynamics phases

Different structure and composition in a dynamic process result in relatively stable formations that are called dynamic phases. In a natural forest, different phases are gradually replaced to create the stand stability. Eight phases have been identified in the forests of northern Iran (SEFIDI 2012).

The main characteristics of gap formation phases include high stocking of standing live trees and dead trees, large gap frequency and their area, presence of thick-bodied dead trees in early stages



Fig. 1. Location of the study area in Iran (51°32'30" to 51°35'25" north latitude, 36°27'30" to 36°40'25" east longitude)

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of decay, the tree distribution curve is rather descending, and reducing the number of trees more than 100 cm in diameter than equilibrium curve.

The main traits of understory initiation phase consist of standing volume more than average (thick trees of previous generations), high number of seedlings more than 130 cm in height, the tree distribution curve is rather descending, the highest presence of trees in 10–20 diameter classes, and the number per hectare is high and the stand often has two or more storeys.

The main traits of stem exclusion phase include medium standing volume (thick trees of previous generations), low number of seedlings taller than 130 cm, the tree distribution curve is irregular and the highest presence of trees exists in 20–40 cm diameter classes, the number per hectare is low and the stand often has a single storey, canopy cover is completely closed, low gap number and their small area.

The major properties of lightning phase include medium standing volume and median diameter, low seedling frequency, most features similar to the stem exclusion phase, the number per hectare is low and the stand often has a single storey, open canopy cover, high gap number and their small or medium area.

The chief factors of volume accumulation phase consist of high standing volume and median diameter, low height growth and high diameter growth, the tree distribution curve in middle classes more than equilibrium forest, low number of seedlings more than 130 cm in height, close canopy cover and low gap number and their small area, the number per hectare is low and the stand often has one or two storeys.

The principal elements of old-growth phase comprise the tree distribution curve in middle classes more than equilibrium forest, high standing live volume, dead trees and median diameter, low height diameter, the number per hectare is relatively low and the stand has two storeys, and medium number of gaps and canopy cover.

The chief traits of volume degradation phase include most of the old-growth features associated with severe volume reduction, high standing live volume, dead trees, high tree diameter, the ratio of dead tree volume than live trees (more than 20%), the presence of thick-bodied dead trees in early decay stages, reduction in the tree distribution curve in more than 100 cm diameter class than balance

curve, the number per hectare is relatively low and the stand has two storeys and medium number of gaps and their size.

The basic properties of mixed or complex phase consist of complexity in forest structure, having multiple phase attributes, variety in disturbance with irregular repetition, reducing the tree dispersion curve and close to equilibrium curve, the presence of trees on most diameter classes, variety in size, quality and type of dead trees.

Measurement method for standing and fallen dead wood

In practice, the coarse woody debris is divided into standing and fallen categories (VON OHEIMB et al. 2005). In this study, standing dead trees with a diameter of more than 7.5 cm, which were standing or trunks with a height of more than 1.3 m, were measured. Moreover, the fallen trees including trees (diameter greater than 7.5 cm) and fallen parts of large trunks or big branches with ≤ 7.5 cm diameter in the bigger trunk and minimum length of 1.3 meters were measured and recorded. For determining the volume, height, and diameter of all dead trees, the length and diameter of fallen trunks were measured. In trunk and branch fallen parts, their length, thin head diameter, middle diameter, and thick head diameter were measured. Furthermore, due to the importance of decomposition and decay of dead trees and their role in the forest environment, decay degree of standing and fallen dead trees was studied separately.

The coarse woody debris is classified into four classes according to the degree of decay. The tree freshly dried, the crown is healthy, often thin branches still exist, the bark of the tree remains healthy and wood stays quite hard (first-level decay). The dead tree crown is not broken yet. Most branches are dry and fallen, the bark of the tree decreases at the onset of separation from the trunk and the wood stays still hard (second-level decay). The dead tree crown is crushed. The tree continues without bark and branches, and the wood is hard (third-level decay). The top of the dead trees is broken regularly. There is neither bark nor huge branches. Hardwood is turning into soft wood. More than 70% of the wood has become soft wood (fourth-level decay) (THOMAS et al. 1979; SOLLINS 1982; ATICIE et al. 2008).

SMALIAN'S (Eq. 1) and HUBER'S (Eq. 2) equation were used to calculate the volume of dead wood because the longitudinal shape of the trunk was like an incomplete paraboloid.

$$V = \frac{g_1 + g_2}{2} \times h \quad (1)$$

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

where:

g_1, g_2, g_m – lower, upper and middle cross-sections, respectively

h – incomplete parabolic height.

The longitudinal shape of the tree trunk from the tree collar is an initially incomplete neiloid form. The formula for calculating the volume for incomplete neiloid from the Newton equation is derived (Eq. 3).

$$v = h/6 \times (g_1 + 4g_m + g_2) \quad (3)$$

where:

h – incomplete neiloid height,

g_1 – under cross-sectional,

g_2 – includes a high cross-section,

g_m – middle cross-sectional.

It is not possible to use any of the prescribed formulas to calculate standing dead trees that have been broken. Therefore, the following relationships were used (TRAVAGLINI, CHIRICI 2006) considering that the diameter at breast height was measured and the target species was determined. Therefore, using the forest height curve, the total height was extracted and then the diameter reduction coefficient for each meter of the trunk was calculated from the following equation. Diameter reduction coefficient calculation from Eq. (4):

$$d_{fg} = d_{1.3}/(h - 1.3) \quad (4)$$

where:

d_{fg} – diameter reduction coefficient,

$d_{1.3}$ – diameter at breast height,

h – total height.

Middle diameter calculation equation (Eq. 5):

$$d_m = d_{1.3} - (d_{fg} \times l/2) \quad (5)$$

where:

d_m – diameter at the middle height of the tree

d_{fg} – diameter reduction coefficient,

$d_{1.3}$ – diameter at breast height,

l – length of the trunk that is broken.

Then, using the middle diameter obtained from the previous equation, Huber's formula was used to calculate the volume (Eq. 6).

$$V = g_m \times h \quad (6)$$

where:

g_m – middle cross-section

h – incomplete paraboloid height.

The significance analysis was performed through ANOVA test after data normalization by employing the Kolmogorov-Smirnov (K-S) test via SPSS (Version 23, IBM).

RESULTS

Identified phases

Table 1. documents the occupancy of beech stands in different phases and the distribution of each of them than each other. In this region eight

Table. 1. The distribution of the development phases in a sample plot (dotted borders represent the continuity of the evolutionary phases in the natural forest stands)

Sub-plot 1 Stem exclusion	Sub-plot 2 Gap formation	Sub-plot 3 Stem exclusion	Sub-plot 4 Stem exclusion	Sub-plot 5 Understorey initiate
Sub-plot 6 Understorey initiate	Sub-plot 7 Stem exclusion	Sub-plot 8 Multi phases	Sub-plot 9 Volume degradation	Sub-plot 10 Stem exclusion
Sub-plot 11 Lighting	Sub-plot 12 Old-growth	Sub-plot 13 Old-growth	Sub-plot 14 Stem exclusion	Sub-plot 15 Understorey initiate
Sub-plot 16 Old-growth	Sub-plot 17 Volume accumulation	Sub-plot 18 Lighting	Sub-plot 19 Understorey initiate	Sub-plot 20 Understorey initiate
Sub-plot 21 Stem exclusion	Sub-plot 22 Understorey initiate	Sub-plot 23 Volume accumulation	Sub-plot 24 Volume degradation	Sub-plot 25 Old- growth

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Table 2. Varieties of dead tree species, degree of decay, diameter class and shape in different dynamic phases

Species	Ave.	Degree of decay	Mean	Diameter class	Ave	Type	Ave.	Type	Mean
Hornbeam	1.25	1	10.33	< 25	25.79	Stump	8.67	Standing (snag);(m)	4.11
Lime tree	0.14	2	12.22	25–50	6.93	Snag	6.57	Fallen (log); (m)	10.38
Beech tree	42.23	3	9.15	> 50	4.88	Log			27.00
Maple tree	0.66	4	9.83						
Alder tree	1.00								
Oak tree	1.75								

Ave. – average

major phases were identified, each of which could have smaller cycles. For example, the volume accumulation phase may additionally have initial volume accumulation and last volume accumulation cycles. The highest area of the forest (52%) occurs in the understorey formation and stem exclusion phases. It can be an indication of the continuity and long presence of stands in these phases or because of forest stand dynamics.

Types of species

Fig. 2 and Table 2 illustrate the diversity of dead wood species in various dynamic phases. As Table 1 shows, the average number of dead hornbeam, lime, beech, maple, alder, and oak trees in different phases is 1.25, 0.14, 42.23, 0.66, 1 and, 1.75, respectively.

Furthermore, the results show that it's remarkable the distribution of individual dead trees per hectare

of various species in the dynamic phases despite the beech dominance (Fig. 1). The mean number of coarse woody debris species in the stem exclusion, gap formation, understorey initiation, mixing (complex), volume degradation, lightning, old-growth and volume accumulation phases is 4.95, 24.5, 9.66, 5.6, 5.9, 5.75, and 33.9 per hectare, respectively.

Total volume of dead wood (coarse woody debris)

In general, the total average volume of standing and fallen dead trees includes $41.5 \text{ m}^3 \cdot \text{ha}^{-1}$. Further, the mean coarse woody debris volume in decay classes 1, 2, 3 and 4 was 10.33, 12.22, 9.15 and $9.83 \text{ m}^3 \cdot \text{ha}^{-1}$, respectively (Table 1).

Fig. 4 illustrates the distribution of whole dead trees in different degrees of decay in the types of dynamic phases. The mean coarse woody debris

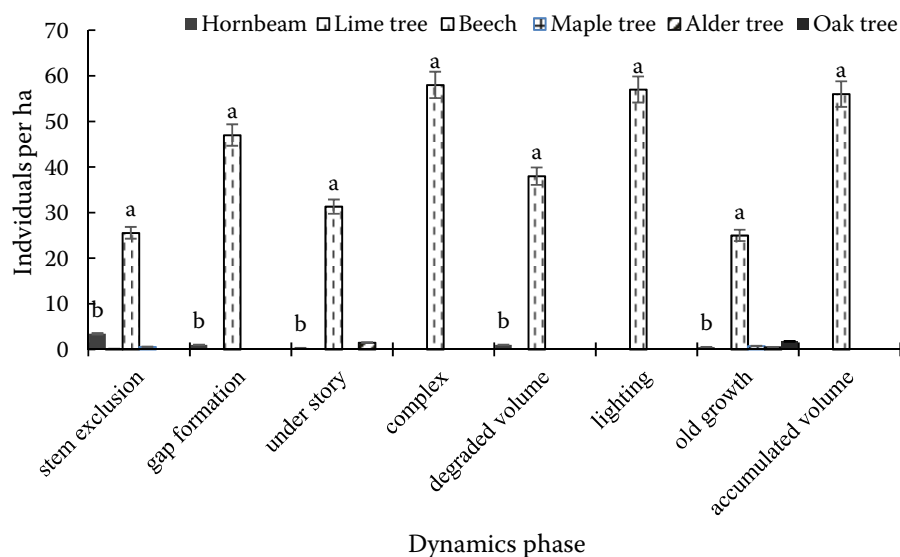


Fig. 2. Frequency of species diversity of dead trees in various dynamic phases

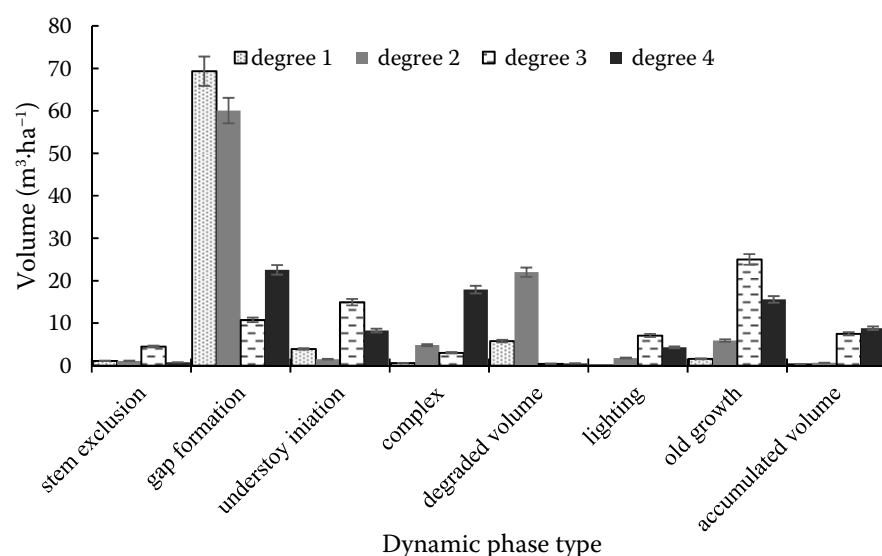


Fig. 3. Total of dead tree volume distribution at decay degrees in dynamic phases

volume in the stem exclusion, gap formation, understory initiation, complex, volume reduction, lighting (light increasing), old-growth and volume increasing phases was 1.86 ± 1.76 , 40.68 ± 28.4 , 7.09 ± 5.7 , 6.59 ± 7.7 , 7.18 ± 10.18 , 3.29 ± 3.08 , 12.02 ± 10.44 and $4.3 \pm 4.46 \text{ m}^3 \cdot \text{ha}^{-1}$, respectively (Fig. 2).

The volume of standing coarse woody debris (snags)

Fig. 3 documents the standing dead tree distribution in various degrees of decay in the types of dynamic phases. The average stock of standing dead trees in the stem exclusion (individual reduction), gap formation, understory initiation, multiphase (complex), volume degradation, lightning, old-growth, and increasing (accumulated) volume

phases amounted to 0.63 ± 0.58 , 18.68 ± 8.47 , 4.3 ± 3.94 , 3.5 ± 4.25 , 3.86 ± 5.03 , 2.78 ± 2.66 , 6.18 ± 6.35 and $3.1 \pm 3.27 \text{ m}^3 \cdot \text{ha}^{-1}$, respectively (Fig. 4).

Figure 5 illustrates the occurrence of logs in separate degrees of decay in the types of dynamic phases. The mean log volume in the stem exclusion, gap formation, understory establishment, multiphase, volume reduction, lightning, old-growth, and increasing volume phases was about 1.23 ± 1.18 , 21.9 ± 21.6 , 2.8 ± 2.03 , 3.07 ± 3.49 , 3.62 ± 4.98 , 0.58 ± 0.52 , 6.8 ± 4.08 and $1.29 \pm 1.28 \text{ m}^3 \cdot \text{ha}^{-1}$, respectively (Fig. 5).

Frequency in diameter classes

Table 2 shows the mean frequency of dead trees in the diameter classes smaller than 25, 25–50 cen-

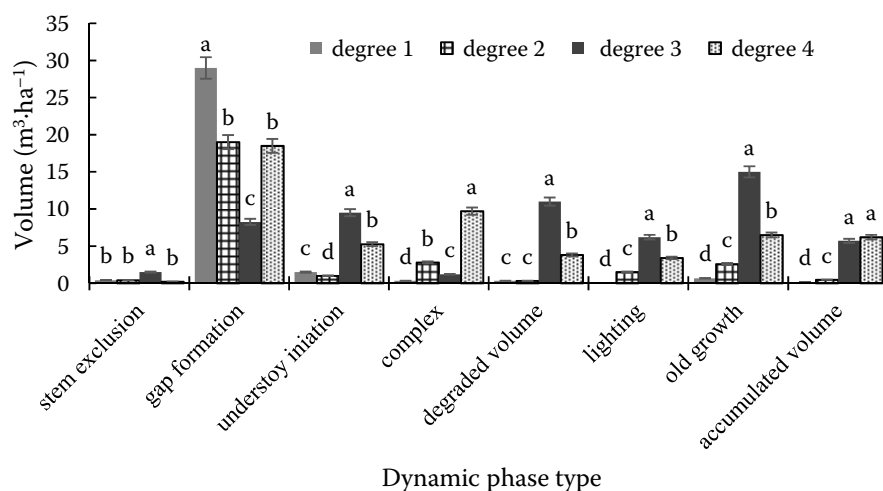


Fig. 4. Snag volume distribution at decay degrees in each dynamic phase

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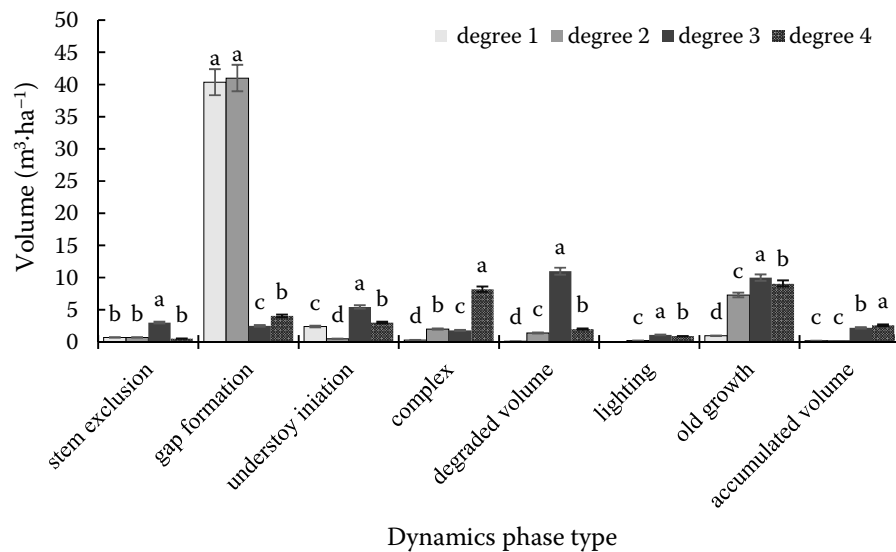


Fig. 5. Log volume distribution at decay degrees in dynamic phases

timetres and more than 50 centimetres. The average number of coarse woody debris individuals in the diameter classes smaller than 25 cm, 25–50 cm, and more than 50 cm equalled to 25.79, 6.93 and 4.88, respectively.

Fig. 5 reveals the coarse woody debris distribution in diameter classes in different phases. The average coarse woody debris amount in the stem exclusion, gap formation, understory initiation, complex, volume degradation, lighting, old-growth and accumulated volume phases was 12.33 ± 6.2 , $2 \pm 11.15 \pm 15.00$, 19.33 ± 22.59 , 15.9 ± 13.74 , 9.5 ± 13.79 , 9.4 ± 5.5 and 9.72 ± 7.7 $\text{m}^3 \cdot \text{ha}^{-1}$, respectively.

Dead tree forms

Table 2 represents the apparent shape distribution of coarse woody debris (CWD). The mean total stock volume of the stumps, snags, and logs is $4.11 \text{ m}^3 \cdot \text{ha}^{-1}$, $10.38 \text{ m}^3 \cdot \text{ha}^{-1}$ and $27 \text{ m}^3 \cdot \text{ha}^{-1}$, respectively.

Fig. 6 indicates the coarse woody habitat (CWH) distribution in different phases in terms of the form. The mean frequency of coarse woody debris (CWD) forms in the stem exclusion, gap formation, understory development, multiphase, volume degradation, lightning, old-growth, and volume accumulation phases was 48.2 ± 2.11 , 42.4 ± 42.5 ,

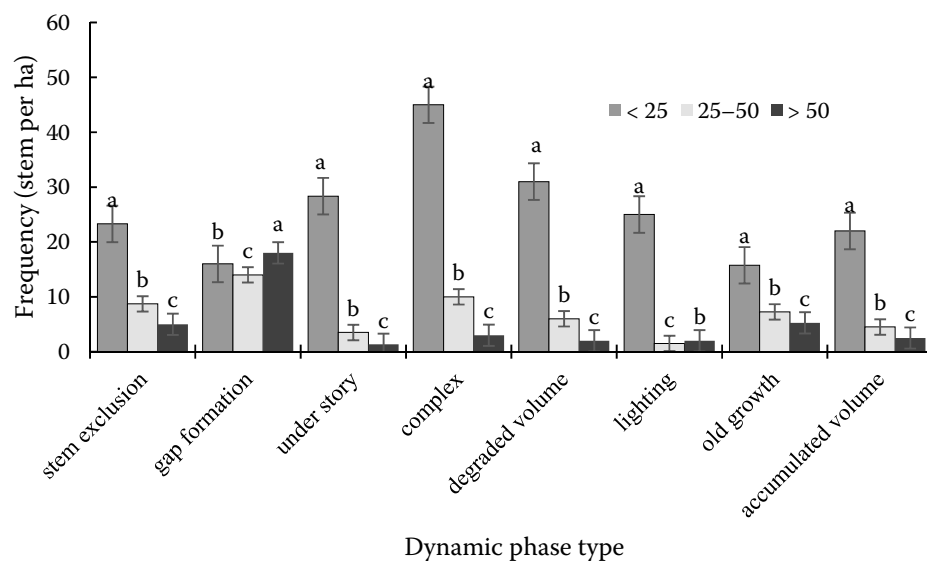


Fig. 6. Dead wood occurrence in diameter classes in dynamic phases

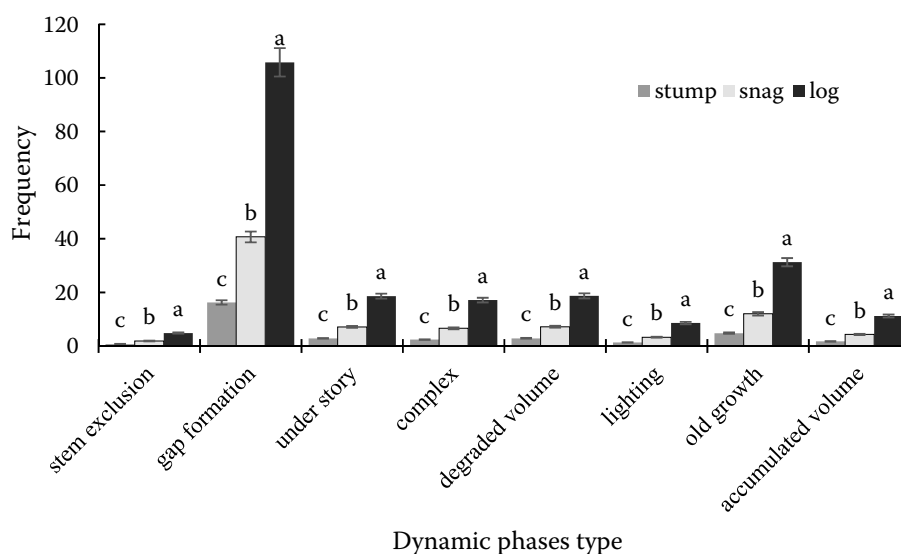


Fig. 7. The coarse woody debris (CWD) morphological frequency in dynamic phases

89.52 ± 8.8, 13.78 ± 13.8, 9.77 ± 8.7, 4.39 ± 3.75, 16.03 ± 13.66 and 74.5 ± 4.9, respectively.

Dead tree (DT) height

Table 2 shows the frequency of snag heights and log lengths in the dynamic phases. The mean height of standing dead trees (snags) and the average length of fallen dead trees (logs) were 8.67 m and 6.57 m, respectively.

Fig. 7. presents the height distribution of snags and the length distribution of logs in several phases. The average height of snags and the length of logs in the stem exclusion, gap formation, understorey initiation, complex, volume degradation, lighting, old-growth and volume accumulation phases

were 5.46 ± 1.18, 13.77 ± 0.42, 13.7 ± 20.7, 5.95 ± 1.34, 9.88 ± 5.9, 6.85 ± 0.49 and 6.10 ± 0.14 m, respectively.

The significance analysis using ANOVA test results confirmed that there was a significant difference (95%) between the averages of total logs and snags (Table 3).

The significance analysis results showed that there was a significant difference (95%) between the occurrence forms of dead trees in various dynamic phases. However, there was no significant difference in the coarse woody debris (CWD) distribution in the diameter classes (Table 3).

The results of significance analysis were obtained by ANOVA test after data normalization by employing the Kolmogorov-Smirnov (K-S) test. The results revealed that there was no significant differ-

Table 3. The results of ANOVA with probability ($P = 0.05$) for all dead wood, standing and fallen dead wood

		Sum of Squares	df	Mean Square	<i>F</i>	Sig.
Dead wood	between groups	33.842	7	4.835	2.007	0.026
	within groups	57.818	24	2.409		
	total	91.660	31			
Snags	between groups	32.534	7	4.648	1.916	0.0111
	within groups	58.218	24	2.426		
	total	90.752	31			
Logs	between groups	27.415	7	3.916	2.245	0.048
	within groups	40.126	23	1.745		
	total	67.541	30			

df – degrees of freedom, *F* – *F* value, significant differences at $\alpha = 0.05$

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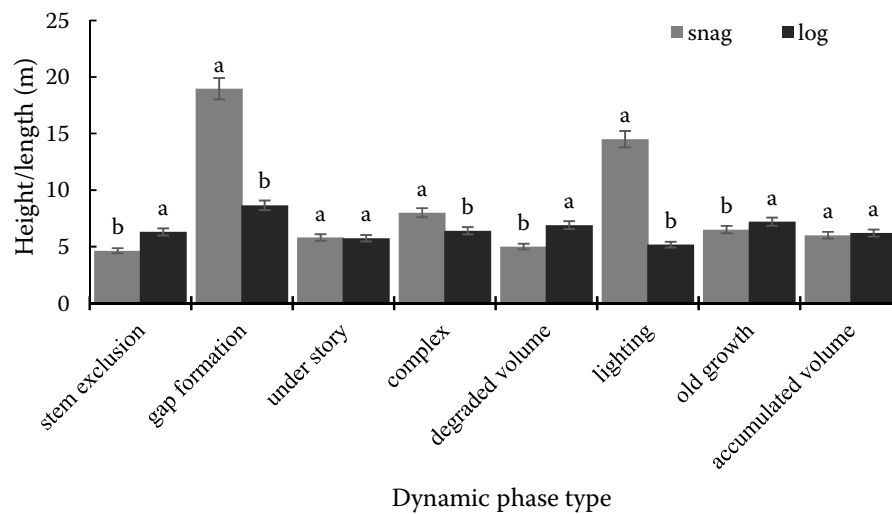


Fig. 8. Height/length status of dead trees (logs and snags) in various types of phases

ence between the mean standing dead tree height and the fallen dead tree length in different dynamic phases with probability of 95% (Table 5).

DISCUSSION

In the natural forests, the forest stands are not in a permanent circumstance even in the climax succession stage and are continually developing. These situations are referred to as developmental stages. However, the succession stages, in turn, can be divided into what is called dynamic phases. The concept of the phase is the difference of structural features such as live trees, dead trees, forest gaps and natural regeneration in each state from other states. The dead wood as one of the most notable structural components of forest stands performs an effective part in the separation of dynamic phases simultaneously with other features.

The Oriental beech (*Fagus orientalis*), which is also commercially valuable, is a species associated with the succession climax step in the Hyrcanian forests of Iran. So far, much research on it has been done (SAGHEB-TALEBI et al. 2003; SEFIDI et al. 2010; AMIRI et al. 2013; SEFIDI et al. 2016; JAVANMIRI POUR et al. 2017). In general, the results of the present study determined that beech (96.74%) was the most frequent species of coarse woody debris. Other species such as hornbeam, oak, maple and alder accounted for only 3.26 % of dead wood abundance. It seems that the main reasons for the prevalence of beech species in the studied area are the lack of commercial harvesting because of the scrutinized area (control site) and also the lower rate of beech degradation in comparison with other species (SARIYILDIZ et al. 2005; LIZINIEWICZ 2009). Among the logs, the frequency of beech species is higher than that of other species. In the MARAVI MOHADJER et al. (2008) study, the most prevalent

Table 4. ANOVA test results with probability ($P = 0.05$) for dead trees in terms of the number in diameter classes and apparent form

		Sum of Squares	df	Mean Square	<i>F</i>	Sig.
Diameter class	between groups	263.499	7	37.643	0.215	0.977
	within groups	2804.365	16	175.273		
	total	3067.865	23			
Shape	between groups	17.901	7	2.557	2.867	0.038
	within groups	14.270	16	0.892		
	total	32.171	23			

df – degrees of freedom, *F* – *F* value, significant differences at $\alpha = 0.05$

Table 5. ANOVA test results with probability ($P = 0.05$) for comparing the dead wood height

Height	Sum of Squares	df	Mean Square	<i>F</i>	Sig.
Between Groups	114.213	7	16.316	1.288	0.363
Within Groups	101.372	8	12.672		
Total	215.585	15			

df – degrees of freedom, *F* – *F* value, significant differences at $\alpha = 0.05$

species were hornbeam, rye, and other species. The main causes for the higher abundance of hornbeam snags compared to beech snags are known as shorter hornbeam longevity than in beech, damage resulting from felling by the villagers, the high number of hornbeam individuals per unit area, lack of utilization of hornbeam dead trees and the outbreak of the leaf pest of the family Geometridae.

The reason is the higher percentage of fallen beech trees relative to hornbeam, the faster decomposition of hornbeam wood than in beech. The high rate of decay in hornbeam can be attributed to the high-grade conditions for deposition by decomposers and its chemical properties (ALIDADI et al. 2014). Unquestionably, the type of dead wood species is discovered in the examined phases and has no effective function in determining any of them. Therefore, only their abundance is different. For example, the highest average of their frequencies in the gap formation phase was 24 trees per hectare while the lowest mean regularity is at 4.95, which is relevant to the stem exclusion phase.

One of the most essential traits of dead trees is a structural component of their stock in forest stands. In the present study, the dead tree mean volume was $41.5 \text{ m}^3\cdot\text{ha}^{-1}$, which is more than in other studies in northern Iran (Figs 2–4). The main reason is related to the lack of traditional and commercial harvesting from the studied area as the control compartment.

Although there are compelling details in relation to the coarse woody debris volume in the dynamic phases, the results of this study explained that the highest dead wood stock was related to the gap formation phase (68.40 m^3) because in the mentioned phase dry-tree species are observed, especially in the early stages of decay, namely grades 1 and 2 (69.35 and 60.08 m^3 , respectively) while the stock of dead trees in the last stages of decay is lower. In this phase, the presence of coarse woody debris in order to initiate the beech stand dynamics is necessary in view of the nature and regeneration mechanism of beech species.

Obviously, with the continuation of the dynamic process, thick dead trees are decomposed and provide the required nutrition to deploy natural regeneration (YANG et al. 2014; DIACI 2017). The amount of dead trees in the early stages of decay is higher in the volume degradation phase (decay phase) than in the other phases. The main difference is low volume per hectare ($7.18 \text{ m}^3\cdot\text{ha}^{-1}$) and their dimensions are not comparable with the dead tree sizes in the gap formation phase.

Furthermore, the results of this study showed that the lowest stock of coarse woody debris was observed in the stem exclusion phase ($1.86 \text{ m}^3\cdot\text{ha}^{-1}$). Because of the apparent features of this phase, there is an enormous number of low-diameter dead trees that are rapidly decomposed and eliminated consequently, they do not have much volume (WALENTOWSKI et al. 2013; LOGUERCIO et al. 2018). Similarly, the highest crown competition occurs in this phase (OLIVER, LARSON 1996). Therefore, there is regularly a single-storey stand that often includes the completely closed canopy cover. Once the trees are excluded (becoming fine woody debris), near trees quickly fill the empty space depending on the size of the trees and the small dimension of the crown in the stem exclusion phase.

In other phases, the dead wood volume was different and its amount in the ultimate decay stages stays greater than in the initial stages such as understory initiation, lighting, old-growth and increasing volume (optimum) phases. As an example, the volume and number of dead woods are low and often in more advanced stages of decay in the increasing volume phase. Further, some live trees become dead trees when they reach longevity time in the old-growth phase. For this reason, the coarse woody debris volume in this phase is higher than in the other phases ($12.02 \text{ m}^3\cdot\text{ha}^{-1}$), except for the gap formation phase (Figs 2–4; Table 4).

Other significant traits of dead wood are distribution of its diameter classes (Table 1; Fig. 5). The results of this study show that the highest frequency of dead wood in the diameter classes is similar to

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the distribution pattern of live trees in the diameter classes. In other words, the dead wood frequency in lower diameter classes is high while their number in the higher diameter classes is small but it has a large size. Therefore, this pattern returned in most of the dynamic phases, with some difference, with the exception of the gap formation phase. The most significant causes for this pattern not occurring in the gap formation phase are related to the high stock of dead wood in terms of abundance and volume, especially large-sized dead trees.

Generally, the highest percentage of dead trees in terms of standing or fallen ones are fallen dead trees (logs) (Tables 2 and 4; Fig. 6). The results showed that the standing dead tree ratio is about of the total dead tree stock. In the study of HABASHI (1997), this ratio was equal to 23% in Mazandaran Vaz forest, in the study of ZOLFAGHARI (2004) to 26% in the Chelir district of Kheyroud Forest and in SEFIDI'S research (2007) it was about 37% and 40% for the Patom and Namkhaneh districts of Kheyroud Forest. The higher amount of logs is due to the falling of standing dead trees because of their drying and gravity (OBERLE et al. 2018). In first-degree dead trees due to the presence of branches, wind can be one of the effective factors in dead tree falling.

In relation to the height of dead trees, the results of this study showed that the most frequent were the dead trees in the gap formation phase. In other phases, although the differences are unobjectionable, they are not comparable with the coarse woody debris height in the gap formation phase (Fig. 7; Tables 3 and 5). The most important reason for this condition in dead wood is the impossibility of a static state due to the progress of decay rates. Because the components of dead wood are heavy during rain and rain absorption, they fell due to weight loss, become fragmented and logs. The logs decompose in a shorter period of time because of the warmer climate in the northern part of Iran compared to Europe. Therefore, a lower volume of logs exists on the early decay stages and they have a shorter length.

Considering the discussed issues, in general, the coarse woody debris amount in the forest varies according to habitat, evolutionary stage, volume and diversity of tree species. Therefore, the use of coarse woody debris is a particularly valuable tool in determining and distinguishing the dynamic phases. Dynamic phases can also be used to study the dynamics of northern forests of Iran in the long-term. It is also to be used to improve manage-

ment interventions in the management of valuable forests of northern Iran (Hyrcanian forests).

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