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ORIGINAL PAPER

Deadwood assessment in different developmental stages of beech (*Fagus orientalis* Lipsky) stands in Caspian forest ecosystems

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Abstract Deadwood is an indicator that addresses many parameters of naturalness and is becoming a general reference for natural forests. If there are enough of the different kinds of deadwood in a forest, then it is likely to be properly natural. Also, it is a practical indicator, representing the health and biodiversity of forests. The aim of this research was to find out how much deadwood should be present in different developmental stages in a natural forest as a reference. For this purpose, a natural forest ecosystem in Mazandaran province, north of Iran, which is located in Noshahr, was selected. Species, diameter and height of all (living and dead) trees in each area were assessed. Then, developmental stages were determined, and their map was produced. The amount of deadwood was determined in different stages. Results showed that all three stages (initial, optimal and decay stage) could be recognized in the studied beech stands. Deadwood rate varied and greatest volume and number of it occurred in decay and initial stages, respectively. The frequency and volume of deadwood depend on the pattern of natural disturbance, developmental stages and stand structure. The amount of deadwood within managed forests is open to debate and requires detailed knowledge about beech stands in local conditions. So, based on these results in natural forests of beech in north of Iran, deadwood volume between 4.9 and 54.3 m^3 ha^{-1} or 1.1–9.6 % of total volume of wood could be considered as a reasonable amount and each developmental stage must be different.

Keywords Deadwood · Optimal stage · Stand structure · Natural disturbance

Introduction

Deadwood and its biodiversity play an important role for sustaining forest management and environmental services such as stabilizing forest, soil protection and storing carbon (Ritter and Saborowski 2012). Despite its importance, deadwood is now at a critically low level in many temperate forests, mainly due to inappropriate management practices. Recently, deadwood has become more considered as an indicator in the assessment of naturalness of forest ecosystems (Larson et al. 2001; Kristensen 2003; Schuck et al. 2004; Laarmann et al. 2009) a source of nutrients in natural forest (Beets et al. 2008) and an important component in both carbon sequestration and cycling (Teodosiu and Bouriaud 2012). The amounts of deadwood in natural forests depend on many factors such as geographical location and forest management (Stevenson and Jull 2006; Yan et al. 2007; Woodall and Liknes 2008), and its correct estimation must consider forest type (species composition and stand structure), developmental stages, type and frequency of natural disturbance, type of management, but also soil and climatic characteristics, which together contribute to complete the formation and decomposition cycle of deadwood (Christensen et al. 2003). Deadwood quantity and spatial distribution, recent

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mortality rate and cause of mortality together are indicators of forest naturalness (Laarmann et al. 2009). So, managers attempt to emulate natural forest disturbances in their interventions by adopting principles of “ecological forestry” (Franklin et al. 2007). Naturalness is so complex, and deadwood is an indicator of naturalness that addresses many components of it that can be a reference for natural forests. It is important to know how much deadwood should be present in the natural forests and in different developmental stages. Volume of deadwood depends on species composition, stand structure, developmental stages, natural disturbance regime, forest history and management intensity. The hypothesis is that the amount (number and volume) of deadwood differs in various developmental stages, and it must be determined in each stage, because they may become a criterion in determining various developmental stages, and also in managed forests, the amount of deadwood is highly considered.

Presence of deadwood can be related to the intensity of silvicultural management and the way these are carried out (Guby and Dobbertin 1996; Green and Peterken 1997). There are already a number of indicators representing forest structure. Some of these indicators, as for example the amount of deadwood, have been used as a measure for intervention intensity (Müller et al. 2007) and one of the main parameters that used as a silvicultural management intensity indicator (SMI) in European beech forests (Schall and Ammer 2013).

This is why the amount of deadwood in managed forests is significantly lower than that in forests left to evolve naturally: It has been assessed that only 2–30 % of the deadwood found in un-managed forests takes place in managed ones (Lesica et al. 1991; Green and Peterken 1997; Kirby et al. 1998; Jonson 2000). Therefore, the forest management leads to reduction and homogenization of coarse woody debris (CWD), which can trigger degradation processes (Debeljak 2006). Due to less attention to stand structure and developmental stages in forest intervention, managed beech forests contain only small amount of deadwood. Without sufficient amount of deadwood, the stability of these forests will continue to decline.

Yan et al. (2010) proposed that the increase in deadwood in old-growth forest was due to the natural disturbances and mortality rate. In European beech forests, fine scale disturbance is the main kind of natural disturbance, providing a constant presence of deadwood of diverse sizes overtime (Korpel 1995; Peterken 1996; Emborg et al. 2000; Standovar and Kenderes 2003). Debeljak (2006) found that there is a significant difference in deadwood quantity between managed and virgin forests in European temperate forests. Böhl and Brändli (2007) demonstrated that up to 30 m^3 ha^{-1} of deadwood was found in Swiss forests that vary with the region. In addition, there was little proof of correlations between deadwood volume and forest parameters such as management, site or stand attributes. The suggested target values for the volume of deadwood (20 m^3 ha^{-1}) have been attained, whereas the number of snags per hectare has not been achieved.

Based on a European literature review, Bütler et al. (2005) found that the European agreement was that there should be at least 20–40 m^3 ha^{-1} deadwoods for European forest communities. They suggest a target value of 20 m^3 ha^{-1} deadwood for Switzerland. The volume of deadwood in Swiss forests is, nevertheless, still much less compared to that in virgin beech forests in the Ukrainian Carpathians, which have an average of 111 m^3 ha^{-1} deadwood (Commarmot et al. 2005). Similar quantities of deadwood have been recorded in other European virgin and natural forests (Brändli 2005). Therefore, the aim of this research as a case study was to investigate how much deadwood should be present in different developmental stages in a natural forest as a reference. Because the importance of deadwood is unfortunately just formally observed in forestry plans of the north of Iran, whereas this importance has not been suitably considered in practice. Then, through the various developmental stages, there is no report of the number of volume of deadwood. This will cause problems in future conditions of beech stands.

Materials and methods

Materials

The study site is located in Kheiroudkenar forest, a natural temperate deciduous forest in west of Mazandaran province, north of Iran (Caspian region) at 51°35′N and 36°35′E (Fig. 1). The study area is extended between 750 and 1,450 m.a.s.l. The climate is temperate with annual mean temperature of 15.8 °C while the annual mean precipitation is 1360 mm with maximum rain occurring in late summer and fall. The soils belong to *Inseptisols* and *Alfisols*. The most important forest associations of the region are *Rusco-Fagetum* and *Carpineto-Fagetum*. Tree species include beech (*Fagus orientalis* Lipsky), hornbeam (*Carpinus betulus* L.), maple (*Acer velutinum* Boiss.), alder (*Alnus subcordata* C.A.M.) and other broad leaved species. In the study area, all stands were dominated by beech, but in some sites, other tree species such as hornbeam and maple are also important.

Methods

Regarding the methodology of this research, we first identified and determined developmental stages. Many studies have been done in relation to determining stand

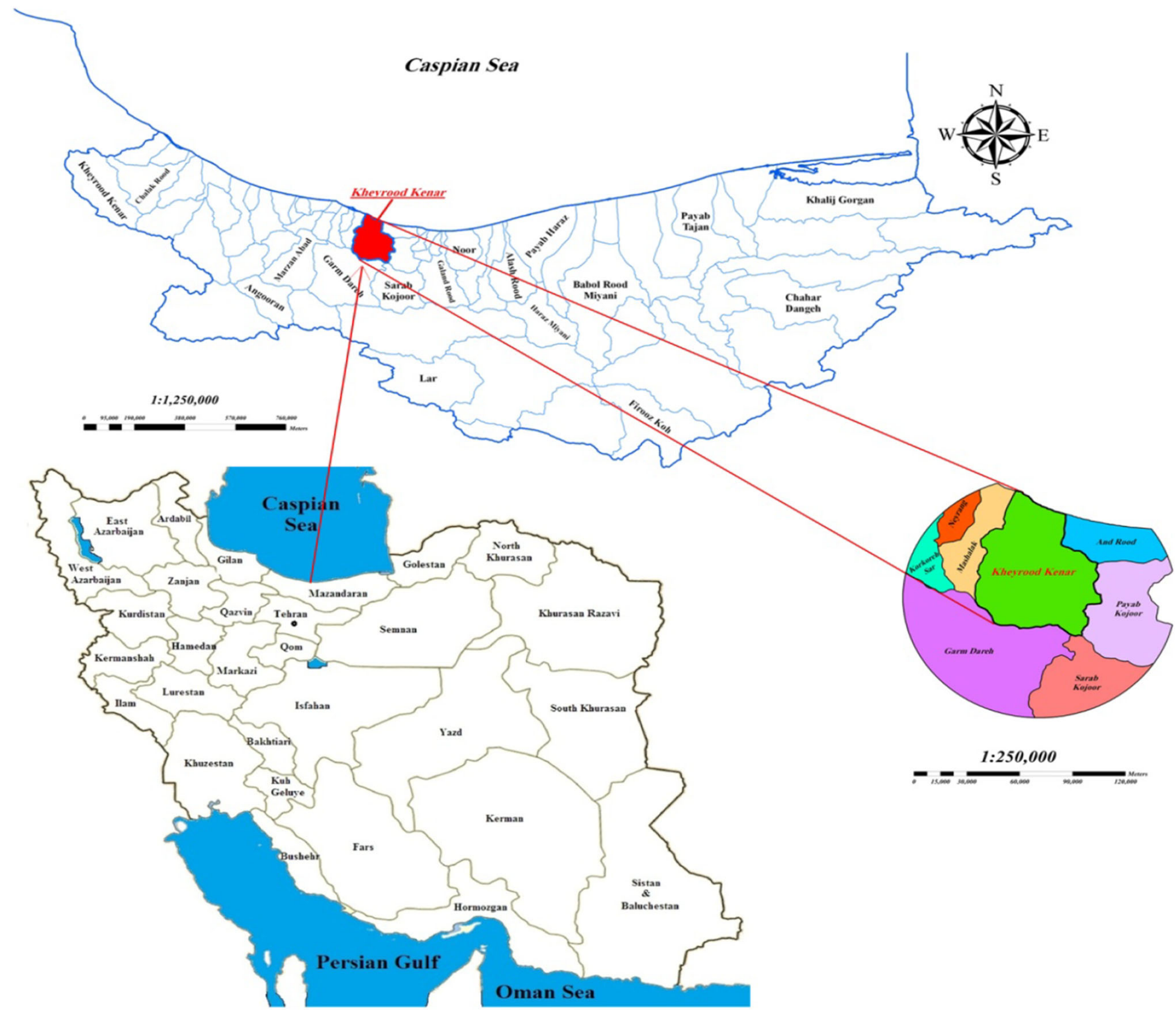

Fig. 1 Geographic map of the study area

developmental stages in different forest type in Europe (Leibundgut 1993; Korpel 1995; Emborg et al. 2000) and oriental beech forests in north of Iran (Mataji 1999; Sagheb-Talebi et al. 2003). In previous studies, the developmental stages and phases were often separately paid attention to, and all of them just tried to determine the developmental stages (three main stages including initial, optimal and decay stages) and do not clarify the amount of deadwood and process of decomposition in each stage, but in this research, there is a merge of both (Fig. 2).

As in every stage, different phases exist. The criteria for distinguishing the developmental stages and phases from each other were defined before the field surface was taken, based on ecological consideration, arguments and using results of other researchers like Leibundgut 1993; Korpel 1995; Emborg et al. 2000; Mataji 1999; Sagheb-Talebi et al. 2003. As shown in Fig. 2, there are three phases in the initial stage. In initial stage, trees are willing to go to upper diameter and height class. Their volume increases, and tree found in all strata (upper, middle and lower). The percentage of canopy and tree density per area is high, and the small gaps caused mainly by breaking small branches are filled with canopy of other trees. In optimal stage, there are two phases of aging and mature, namely early biostatic and late biostatic. This stage begins when the dominant trees have reached completely the upper canopy layer. The number of trees decreases to compare with previous stage, but the volume increases. At the end of optimal stage, we have decay stage which consists of four phases as following: building, pioneer, regeneration and degradation phases. In this stage, old trees begin to degenerate and many gaps occur in the canopy as a result of many reasons,

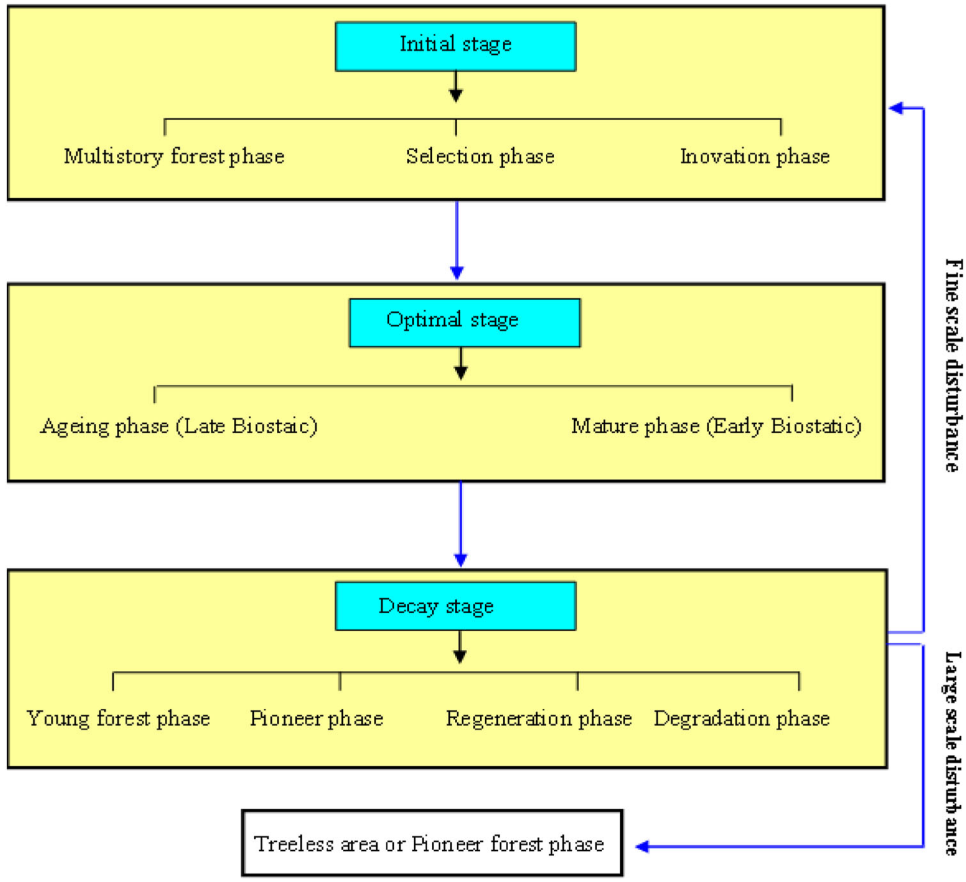

Fig. 2 Developmental stages in natural forests (Mataji and Sagheb- Talebi 2007; slightly altered after Korpel 1995 and Emborg et al. 2000)

mainly breaking big branches, dying trees and windthrow. Volume is distributed unequally in forest stand. If disturbance happens in small scale, decay stage shifts into initial stage. If it happens in large scale, we will have treeless areas, which will be substituted by pioneer phase in the passage of time.

In this study, all living trees and all standing and fallen deadwood of diameter of over 7.5 cm were measured in full callipering method. Measuring parameters include diameter, height, basal area, volume and spatial distribution of all trees in the natural beech stands in an area of about 10 ha. For volume estimation, the height and dbh of all standing dead tree and the dbh of logs were measured. The volume of standing and fallen entire deadwoods was estimated by using Huber's (Ritter and Saborowski 2012), and the volume of living trees measured by using regional tariffs based on dbh and height measurements. Then, developmental stages were determined based on ecological consideration and using results of other researchers (e.g., Mataji 1999; Sagheb-Talebi et al. 2003), and then, map of stages of the mosaic cycle was created.

To determine the stand structure in each stage, relative abundance of trees in timber classes (small, medium and large) was measured, and the situation of each stage was determined in structural triangle (Anonymus 2000).

Results and discussion

As showed in Table 1, the results show that beech has the highest number, basal area and volume. So, we can claim that in this study area, beech is dominant. Of course, there are some companion species such as maple, hornbeam, alder and oak. Comparisons between developmental stages show that the initial stage has the highest number (462 n ha^{-1}), while the lowest found in decay stage (194 n ha^{-1}). Table 1 shows also the highest volume and basal area found in optimal stage, while the lowest of them are obtained in initial stage (Table 1).

In Fig. 3, the frequency distribution of stems is illustrated. The maximum frequency belongs to small timber size in the initial stage. In subsequent, frequency decreases, so that in decay stage there is the lowest frequency in hectare. Figure 4 shows the frequency distribution of stems in height classes in different developmental stages. The initial stage has the highest frequency in low classes. The

Table 1 The stem number, basal area and volume of species in different developmental stages

Tree species	Number						Basal area						Volume					
	Initial		Optimal		Decay		Initial		Optimal		Decay		Initial		Optimal		Decay	
	N/ha	%	N/ha	%	N/ha	%	m^2/ha	%	m^2/ha	%	m^2/ha	%	m^2/ha	%	m^2/ha	%	m^2/ha	%
Beech (*Fagus orientalis*)	311	67.3	289	90.6	81.5	42.0	17.9	58.6	34.9	89.9	19.1	54.4	252.3	61.4	481.5	89.3	289.6	56.7
Hornbeam (*Carpinus betulus*)	61	13.2	7	2.2	80.5	41.5	4.7	7.2	0.6	1.5	8.8	25.2	71.7	7.8	7.0	1.3	120.8	23.6
Maple (*Acer velutinum*)	14	3	11	3.4	10	5.2	2.2	15.4	2.26	5.8	3.0	8.6	31.9	17.4	38.4	7.1	46.0	9.0
Other species	76	16.5	12	3.7	22	11.3	5.7	18.8	1.04	2.7	4.1	11.8	55.1	13.4	12.1	2.3	55.1	10.8
Total	462	100	319	100	194	100	30.5	100	38.8	100	35.06	100	411.3	100	539	100	511.0	100

optimal stage seems to have normal distribution, and decay stage has a higher frequency in higher height classes.

Regarding the amount and percentage of stems based on diameter classes in different developmental stages (Table 2), large timber is more frequent in decay stage than other stages (20 % higher than in initial stage). This is obvious in the structure triangle, because the position of stages isdifferent, and it shows that stand structure is different among development stages. The biggest difference in developmental stages is visible in both large and small timber (Fig. 5). With shifting mosaic from initial stage toward decay stage, relative abundance of large and medium timbers increases 20 and 10 %, respectively. And that of small timber decreases by 30 percent. In initial stage, the highest number of trees is distributed between dbh classes of 10 and 30 cm (almost 80 % of trees counted in small size). On the contrary, in decay stage the number of trees in large size (>55 cm) is higher than that other stages, and the amount of volume is more than initial stage. The maximum value of volume was observed in the optimal stage (Table 2).

In the studied forest in which beech is dominant, all three developmental stages (initial, optimal and decay) could be recognized. Table 3 shows some characteristics such as stem number, volume and deadwood value for each stage. The stem number in initial, optimal and decay stages is 462, 319 and 194 ha^{-1} hectare, respectively. The range of volume is 411–539 m^3 ha^{-1} where the highest and lowest volumes belong to optimal and initial stages, respectively. So, the highest number of deadwood is in initial stage, and the lowest number happens in decay stage. But based on volume comparison, the opposite state is observed.

Distribution of deadwood by volume and number of stems in different developmental stages is given in table 3. The greatest volume (54.3 m^3 ha^{-1}) and large number (73 n ha^{-1}) were observed in the decay and initial stages, respectively. The results demonstrated that volume per hectare for living trees increases from initial stage to decay stage. But stem number per hectare decreases. The amount and proportion of deadwood volume in beech forests increase from initial stage to decay stage, and it includes a range from 1.1 to 9.6 %.

Comparing the amount of deadwood in different developmental stages, it can be seen that the proportion of deadwood to the total volume increased in the decay stage, which can be considered as a characteristic of old stand in beech forests (Leibundgut, 1993). Deadwood amount in optimal stage is similar to decay stage in terms of number, but in terms of volume it is similar to initial stage.

How much deadwood should be present in natural forests? Volume of deadwood depends on productivity, natural disturbance regime and management intensity. So,

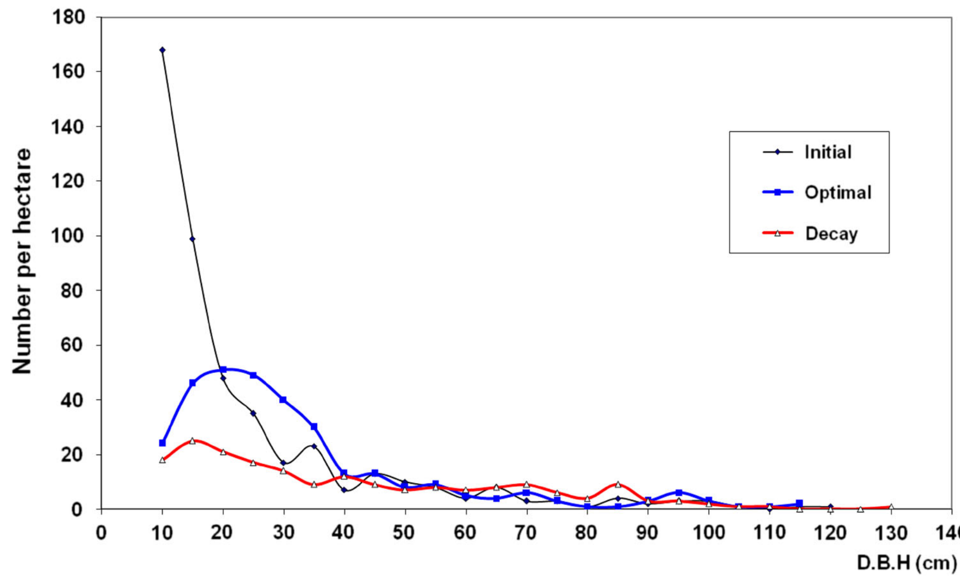

Fig. 3 Distribution of stem in diameter classes in different developmental stages

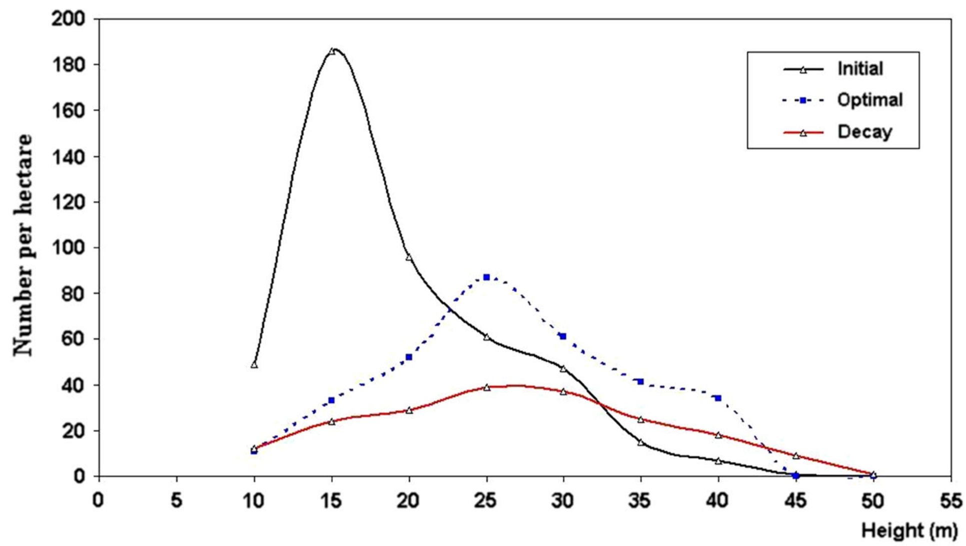

Fig. 4 Distribution of stem in height classes in different developmental stages

Table 2 Quantitative characteristics of the developmental stages of the studied stands

Timber size (cm)	Developmental stages					
	Initial		Optimal		Decay	
	N	%	*N*	%	*N*	%
small (<30)	367	79.4	210	65.8	95	49.0
Medium (35–50)	61	13.2	73	22.9	45	23.2
Large (>50)	34	7.4	11.3	11.3	54	27.8

deadwood volume varies between different forest types and management systems. In unmanaged European forest, deadwood ultimately increases to anything from 5 to 30 % of the total timber, with volume generally from 40 to 200 m^3 ha^{-1} (Mort 2004). Besides, in beech forests in Europe, a normal volume of deadwood of 50–200 m^3 ha^{-1}, accounted to 10–35 % of total volume, can be supposed (Müller-Using and Bartsch 2004). Therefore, the result of our study in relation to deadwood volume in unmanaged forests is similar to other studies done (e.g., Debeljak 2006) in beech stands in Europe.

In spite of deadwood's enormous importance, it is now at a critically low level in many forests due to miss management practices. So, it is required to manage deadwood effectively and increase deadwood volume in managed forests. The amount of deadwood within managed forests is controversial and needs detailed knowledge about beech stands in local conditions. Bütler (2003) suggested 14 standing snags per hectare with a dbh of more than 20 cm

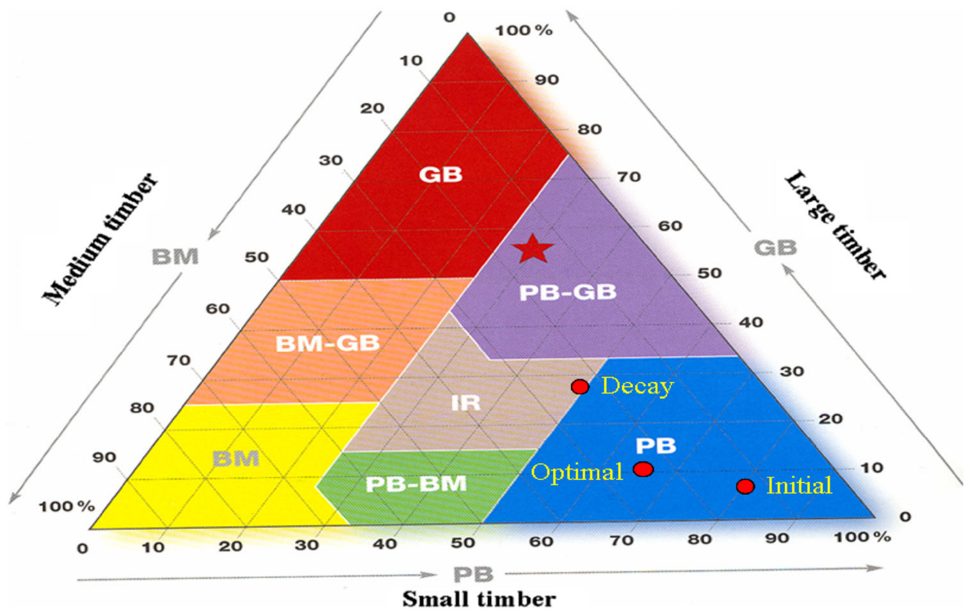

Fig. 5 The structure triangle and developmental stages position

Table 3 The stem number and volume of living trees and deadwood in different developmental stages

Developmental Stages	Number of stems				Volume			
	Living trees		Deadwood		Living trees		Deadwood	
	n ha^{-1}	%	*n* ha^{-1}	%	m^3 ha^{-1}	%	m^3 ha^{-1}	%
Initial	462	86.5	72	13.5	411.3	98.9	4.9	1.1
Optimal	319	92.5	26	7.5	539.0	98.7	7.04	1.3
Decay	194	94.7	11	5.3	511.0	90.4	54.3	9.6

in subalpine forest. For the managed forests of Jura and Plateau in Swiss, the target of environmental policy is five snags per hectare with a dbh at least 40 cm (Hahn et al. 2005).

The actual amount is only 1.3 snags per hectare in the Jura and 1.8 snags per hectare in the plateau. This indicates that there is a significant lack of ecologically high value deadwood in Switzerland forests. In contrary, in this study number of deadwood varied between 11 and 72 ha^{-1} and the maximum frequency of deadwood belongs to initial stage. The volume of deadwood in European forests, especially in Swiss, is, nevertheless, still much less compared to virgin forests, which have 27–255 m^3 ha^{-1}of deadwood, with an average of 111 m^3 ha^{-1} deadwood (Commarmot et al. 2005).

Conclusion

Three stages (initial, optimal and decay stage) with different structure could be recognized in the studied beech stands. Deadwood rate varied and greatest volume and number of it occurred in decay and initial stages, respectively. The frequency and volume of deadwood depend on the pattern of natural disturbance, developmental stages and stand structure. In managed forests of beech in north of Iran, deadwood between 4.9 and 54.3 m^3 ha^{-1} or 1.1–9.6 % of total volume of wood could be considered as a reasonable amount. On average, the amount of deadwood in oriental beech forests in north of Iran can be more than that in European temperate forests where deadwood volume between 20 and 30 m^3 ha^{-1} or 3–8 % of total volume is suggested as a reference (Mort 2004).

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