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Gap characteristics under oriental beech forest development stages in Kelardasht forests, northern Iran

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Abstract

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This study was carried out to evaluate gap characteristics and gapmakers for different development stages of an oriental beech forest in northern Iran. Development stages of 1 ha square-shaped mosaic patches were identified using 100 × 100 m sampling grid and all gaps within these mosaics were recorded. Gap areas were calculated and classified into four classes and gapmakers were counted and classified into 4 decay and 4 diameter classes as well. Results showed that gaps comprised 13.7, 9.1 and 17.6% of the study area in initial, optimal and decay stages, respectively. There was a significant difference between development stages with respect to gap size and the highest amount was observed in decay stage. Medium-sized gaps were the most frequent in all three stages. Frequency distribution of gapmakers varied among development stages. Our findings revealed that 200–500 m^2 is the most preferable gap size for close-to-nature silvicultural approaches in Hyrcanian beech forests. To achieve this gap size 1–2 trees should be marked for harvesting operations.

Keywords: close-to-nature silviculture; forest stand; stand dynamics; gapmaker; silviculture

Understanding dynamics of natural forest stands in development processes is mandatory to achieve the goal of forest management systems. Death of forest trees after reaching their physiological old growth age leads to gap formation. Within these gaps, seeds enjoying suitable conditions will become seedlings, saplings and young trees. Finally, as the result of competition and different growth stages forest stands will be created. Development stages are a reaction to natural and anthropogenic disturbances, and are formed by diverse rates of mortality, growth and regeneration (Rubin et al. 2006).

Development stages including initial, optimal and decay ones have various phases (Leibundgut 1993; Korpel 1995). The mean patch size of the development mosaic in forest stands has been reported from 570 to 10,000 m^2 in various studies (Drößler, Meyer 2006; Christensen et al. 2007; Parhizkar et al. 2011a; Král et al. 2014). According to Korpel (1995) gaps play an important role for identification of development stages, particularly in decay stage. However, he did not consider any role for gaps to identify optimal stage. Hassani and Amani (2009) described a development stage on the basis of the relative frequency of trees per diameter classes and the stand structure for the Hyrcanian beech forests in Iran. No role for gaps has been considered in their description. Emborg et al. (2000) reported that the gap area in decay stage is larger than in optimal and initial stages. However, most studies about gap disturbance have focused on gap size and its effect on soil (Ritter et al. 2005; Galhidy et al. 2006), light intensity (Hu, Zhu 2009; Parhizkar et al. 2011b) and quantitative and qualitative characteristics of natural regeneration (Galhidy et al. 2006; Mountford et al. 2006). There is not any report about forest gaps with respect to development stages in Hyrcanian forests.

Different factors including storm, snow, drought, soil characteristics, shallow depth to the bedrock and some of tree species characteristics like stem dimensions, crown, rooting depth and its spreading affect gap formation and gap size (Clinton, Baker 2000; Lin et al. 2004; Woods 2004; Scharenbroch, Bockheim 2007). Gap formation changes the light availability to the ground and affects the availability of moisture and nutrients (Ritter et al. 2005; Galhidy et al. 2006). Also, herbivory decreases competition among tree regenerations and therefore is accountable for domination of taller species. Therefore, the species combination is relatively homogeneous and significantly specific to gap area, light availability and herbivory (Naaf, Wulf 2007). Regarding gap characteristics, Sefidi et al. (2011) reported that an average of 3 gaps per hectare existed in the oriental beech forest and the gap area varied from 19 to 1,250 m^2. Most gaps (58%) had less than 200 m^2 area. One tree-fall event was responsible for 41% of gap formations. Petritan et al. (2013) in an old-growth sessile oak (*Quercus petraea* Linnaeus)-European beech (*Fagus sylvatica* Linnaeus) forest in Romania reported 60, 34 and 2% for < 100, 100–300 and > 500 m^2 gap area, respectively. They also reported most of the gaps (84%) were made by more than one tree-fall event.

In this research we tried to determine the role of gaps among development stages based on Hassani and Amani (2009) description. The aims of our study were: (*i*) evaluation of gap characteristics (i.e. gap size, gap fraction: percentage of gap area to study area, gap frequency), (*ii*) evaluation of gapmakers (i.e. uproots, snags, decay classes, frequency), (*iii*) comparison of gap characteristics and gapmakers among development stages.

MATERIAL AND METHODS

Study site

The study was carried out in an unmanaged compartment of district one in Langa region, watershed No. 36 (Kazemrood) of the Hyrcanian beech forest (36°32'15"N–36°35'00"N and 51°02'25"E to 51°05'05"E), northern Iran (Fig. 1). This is an irregular uneven-aged oriental beech forest in addition to other tree species like *Carpinus betulus* Linnaeus, *Acer cappadocicum* Gleditsch, *Acer velutinum* Boissier, *Prunus avium* Linnaeus, *Tilia begonifolia* Steven, *Alnus subcordata* C. A. Meyer and *Quercus castaneifolia* C. A. Meyer (tree density: 265 stems per hectare, volume: 381 m^3·ha^{-1}). Oriental beech (*Fagus orientalis* Lipsky) is the most dominant tree species with 84.9% of tree frequency and 82.2% of wood volume per hectare. History of forestry activities in the Caspian region is relatively short and the first forest management plan for the study forest was prepared just 46 years ago. Within this management plan, compartment No. 139 has been kept as a virgin natural reserve area and no silvicultural intervention has been implemented in this compartment. The compartment covers 43 ha with an altitudinal range between 1,350 to 1,650 m a.s.l. Forest soil is a forest brown soil (Cambisol according to FAO classification and Ochrept from Inceptisols according to USA classification) (Habibi Kasseb 1992; Zarrinkafsh 2002) with pH between 5.2 and 6.1. The annual precipitation and mean annual temperature are 1,300 mm and 8°C, respectively (Anonymous 1998).

Field method

Development stages. All studies were carried out in spring and summer 2016. Field sampling was performed, based on systematic sampling with a 100 × 100 m grid (Fig. 2, No. 1–31). Sample plots had 1,000 m^2 areas and circular shape. DBH of trees larger than 7.5 cm were measured for all species in 31 sample plots (accessing all plots was not pos-

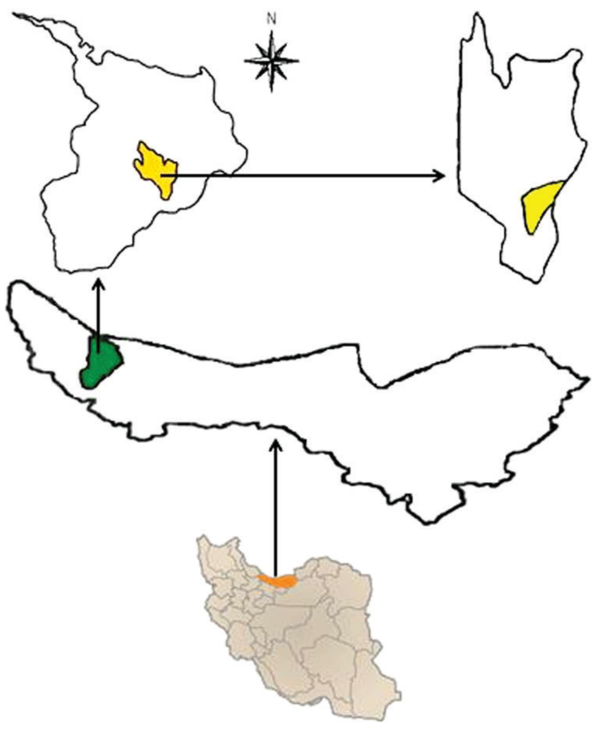

Fig. 1. Geographical location of the study area

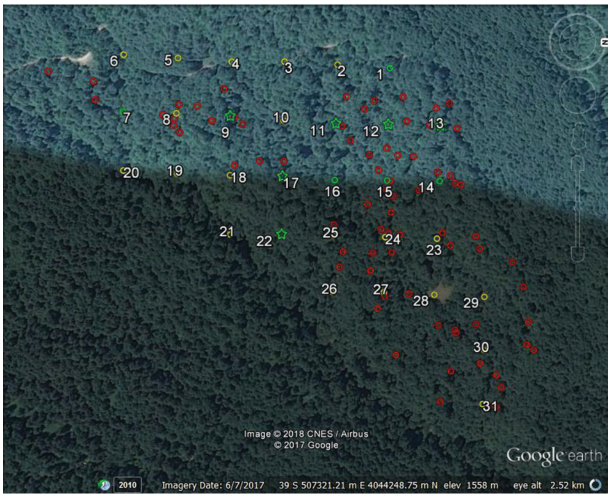

Fig. 2. Distribution map of sampling plots (numbers), gaps (red circle) and development stages (initial: yellow circle, optimal: green circle and decay: green star) in the study area

sible due to harsh topographical conditions). All measured trees were classified into four diameter classes: small (DBH < 30 cm), medium (30 cm < DBH < 50 cm), large (50 cm < DBH < 70 cm) and very large (DBH > 70 cm) (Sagheb-Talebi et al. 2005). Development stages for plots were identified (Table 1) (Hassani, Amani 2009) and were used to determine surrounding 1 ha square-shaped mosaic patches of development stages. Based on our experience and knowledge, inappropriate plots for this generalization were abandoned.

Gaps. All gaps within the study site (43 ha) were located and their central coordinates were recorded using a handheld GPS receiver (GPSMAP 60CSx; Garmin, Taiwan). More than 100 m^2 gaps which still contain remnants of their gapmakers and are located in 1 ha mosaic patches were selected (Fig. 2). As such, 21 plots and 54 gaps were considered for further analysis. Length and width of these gaps were measured using a tapeline and the gap area was calculated using an ellipse formula (Runkle 1981; Weber et al. 2014). Gap sizes were classified into small (< 200 m^2), medium (200–500 m^2), large (500–1,000 m^2), and very large (> 1,000 m^2) area (Schütz 1990).

The gapmakers were counted and classified into four decay classes (Müller-Using, Bartsch 2004): (*i*) recently dead, cambium still green, crown intact, (*ii*) bark sloughing, usually fine longitudinal shakes in the wood, twig sloping, (*iii*) spreading of longitudinal shakes to furrows, diameter of present branches > 5 cm, (*iv*) log collapsing, wood friable, crown completely decomposed. The same diameter classification as for living trees was implemented for gapmakers.

Comparison between development stages for all variables was carried out using the Kruskal-Wallis test due to non-normality and the Mann-Whitney *U* test was used for pairwise comparisons in SPSS (Version 16.0, 2007) environment.

RESULTS

Based on forest structure (distribution of four diameter classes) the study area was classified into three development stages (initial, optimal and decay) (Figs 3a–c).

Gap characteristics

54 gaps were recorded in 21 mosaic patches. Maximum (3.2) and minimum (2.4) mean of gap frequency per hectare varied from 2.4 to 3.2 for decay and optimal stage, respectively. Gaps comprised 13.7, 9.1 and 17.6% of the study area in initial, optimal and decay stages, respectively. Both the largest (1,334.9 m^2) and the smallest size (115.9 m^2) of gaps was calculated for initial stage (Table 2). More than 50% of gaps had an area between 200 and 500 m^2.

Table 1. Identification key for different development stages (Hassani, Amani 2009)

Development stage	Identification key
	ST > 70%
Initial	50% < ST < 70%, MT < 30%, LT + VLT < 30%
	30% < ST < 50%, MT < 30%
	MT + ST > 60%
	ST > 30%, MT > 30%, LT & VLT < 50%
Optimal	ST < 30%
	ST < 20%, MT + LT > 60%
	ST < 20%, MT < 30%, LT + VLT < 50%
Decay	20% < ST < 60%, MT < 20%, 20% < VLT + LT < 60%

ST – small trees, MT – medium trees, LT – large trees, VLT – very large trees

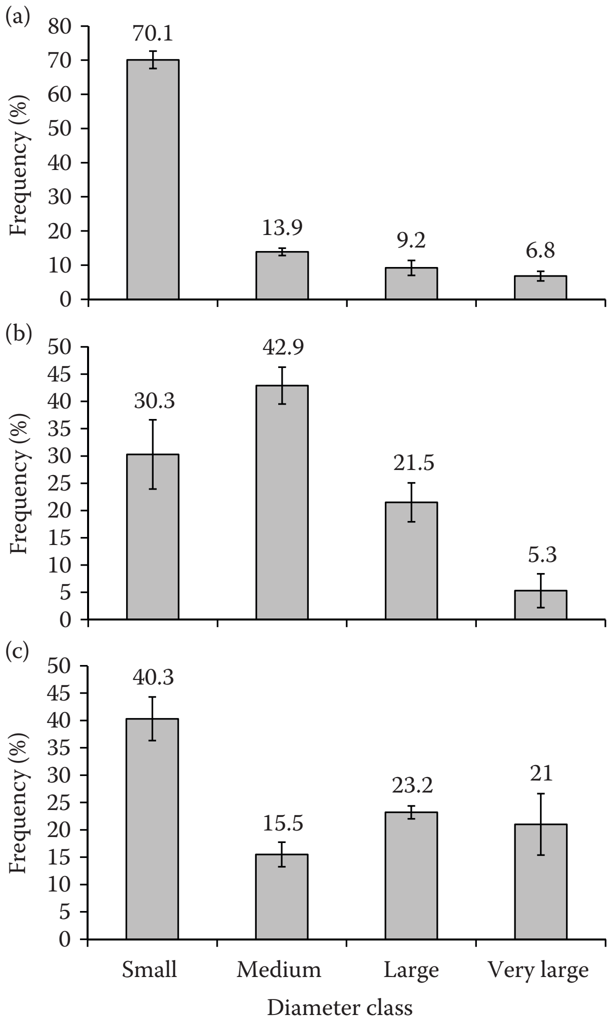

Fig. 3. Mean frequency of diameter classes for initial (a), optimal (b) and decay (c) stage

Gaps with smaller size than 200 m^2 were noticed only in initial stage. More than 1,000 m^2 gaps were not noticed in optimal stage (Fig. 4a).

Gapmakers

There were 52, 30 and 54 gapmakers with different diameter and decay classes in initial, optimal and decay stages, respectively. Oriental beech was the most frequent gapmaker (90%). The range of gapmaker frequency per gap varied among development stages. Decay stage had 1–8 gapmakers per gap while 1–7 and 1–5 gapmakers per gap were counted for initial and optimal stages, respectively. More than 70% of gaps had been created by the death of 1–3 trees and approximately 20% of gaps had been created by five gapmakers (Fig. 4b). The proportion of uprooted trees (> 55%) was higher than that of snags (Table 3).

The frequency of gapmakers in small and medium tree classes was higher than in large and very large tree classes. Maximum frequency of medium tree classes was noticed in initial and optimal stages. In decay stage, small tree class was the most frequent gapmaker and its frequency decreased with the increase of diameter class (Fig. 4c).

Gapmakers showed various characteristics with respect to decay classes. Some gaps had only one class and some gaps contained all the four classes. Two mortality types were identified for most gaps (2nd and 3rd classes). The first class comprised 13% of gapmakers (Fig. 4d).

The Kruskal-Wallis test showed a significant difference between development stages with respect to gap size, number of all gapmakers per gap and number of uprooted trees. Using pairwise comparisons, the highest number of these variables was noticed for decay stage. Optimal stage had the lowest means of gap size and uprooted trees and the lowest mean of gapmaker frequency per gap was noticed for the initial stage. There was no significant difference between development stages with respect to the number of snags (Table 4).

DISCUSSION

Gaps comprised 13.7, 9.1 and 17.6% of the study area in initial, optimal and decay stages, respectively. Other studies showed different values, such as 37.8% in a European beech-fir forest (Nagel, Svoboda 2008), 41.4% in a European beech-fir-spruce forest (Bottero et al. 2011) or 28.5% in an old-growth sessile oak-European beech forest (Petritan et al. 2013). Different heights and crown size of surrounding trees are the probable reason for this different result. There is a significant difference between development stages with respect to the gap

Table 2. Characteristics of gaps in the study area

	Site area (ha)	Frequency of gaps	No. of gaps per hectare	Gap fraction (%)	Gap area (m^2)	
					minimum	maximum
Initial	10	26	2.6	13.7	115.9	1,334.9
Optimal	5	12	2.4	9.1	227.0	532.2
Decay	5	16	3.2	17.6	344.7	1,177.5

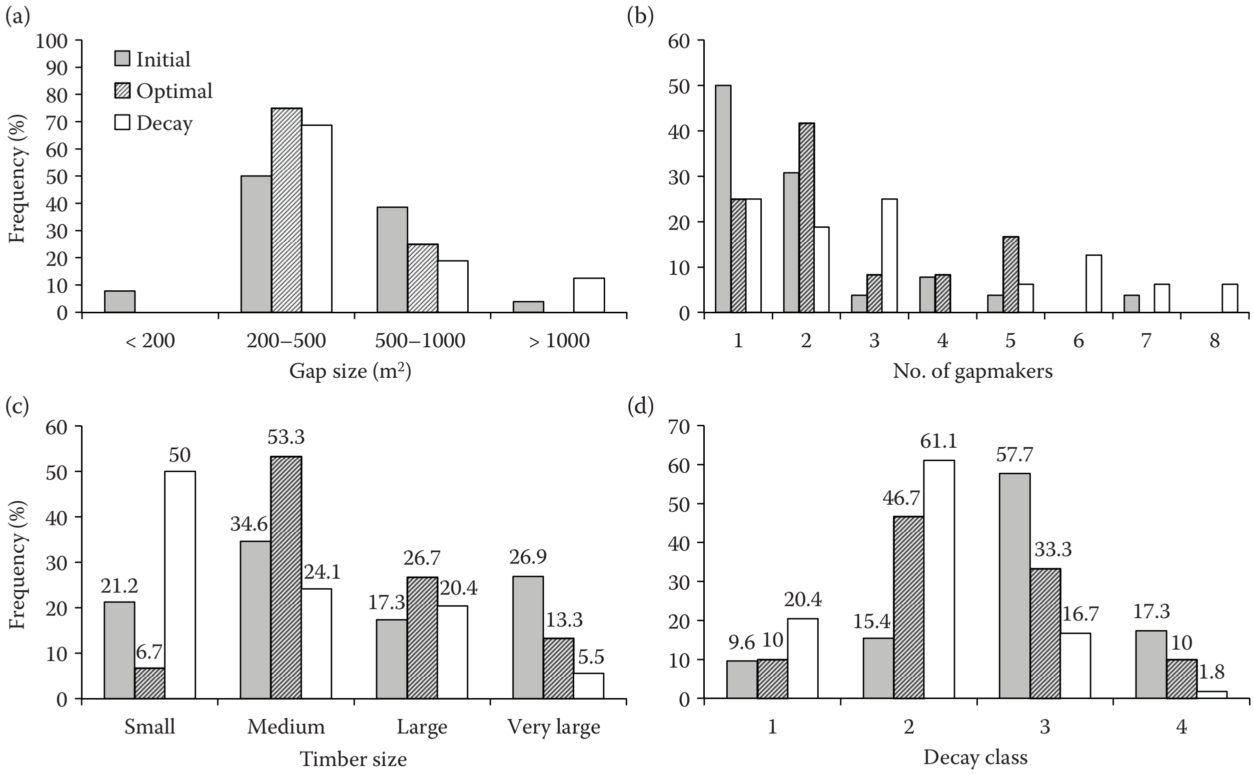

Fig. 4. Frequency distribution of gaps in different size classes (a), gapmakers per gap (b), gapmakers in different diameter classes (c), gapmakers in different decay classes (d) in different development stages

size and the highest number of these variables was calculated for decay stage. This result is supported by Korpel (1995) and Emborg et al. (2000).

Medium-sized gaps (200–500 m^2) were the most frequent area class in all three stages. Kucbel et al. (2010) and Petritan et al. (2013) reported the same results from their studies on two different European beech forests. There was not any gap with 200 m^2 and more than 1,000 m^2 in optimal stage. According to Korpel (1995) the optimal stage is expected to exhibit more homogeneous conditions and the structure of forest stands tends to regular, even-aged and single-storey forests. Height of tree is one of the important factors in gap size as the death of trees with similar dimensions will create gaps of similar size. Therefore, less diverse gap sizes are noticeable in the optimal stage.

The frequency distribution of gapmakers was similar to the inverse J-shaped curve in initial stage. Nagel and Svoboda (2008) in an old-growth *Fagus-Abies* forest of Bosnia-Herzegovina and Kucbel et al. (2010) in an old-growth fir-beech forest in Slovakia reported similar results. The frequency distribution of gapmakers in optimal and decay stages followed normal and sinusoid curves respectively. Petritan et al. (2013) by studying an old-growth sessile oak-European beech forest in Romania reported that the frequency distribution of gapmakers follows a normal curve. The sinusoid frequency distribution of gapmakers has not been reported in any study yet. According to Korpel (1995), different age between trees in decay stage was more obvious than in the other two stages. This stage has a lower tree frequency than the other two

Table 3. Proportion (%) of uprooted and snag trees

	Initial	Optimal	Decay
Uprooted	71.2	56.7	85.2
Snag	28.8	43.3	14.8

Table 4. Comparisons of development stages with respect to gap characteristics

	Area	Gapmakers	Uprooted tree	Snag
Optimal	377.74 ± 32.6^{b}	2.5 ± 0.4^{ab}	1.4167 ± 0.4^{b}	1.1 ± 0.2^{a}
Initial	526.56 ± 55.4^{ab}	2 ± 0.3^{b}	1.4231 ± 0.3^{b}	0.6 ± 0.1^{a}
Decay	551.14 ± 57.1^{a}	3.4 ± 0.6^{a}	2.8750 ± 0.6^{a}	0.5 ± 0.2^{a}

Similar letters indicate no significant differences between means. Letters a and b indicate significant differences between means (P < 0.05). Mean values are always expressed ± standard error stages. Therefore, young trees would fall as the result of a falling old tree if the distance between old and young trees is short while long distances lead to lesser damage to unaffected younger trees. Also, the spatial pattern of trees in decay stage is not regular (Akhavan et al. 2012), trees are closer to each other in a place and in another place far from each other. That is why the frequency distribution of gapmakers in decay stage followed a sinusoid curve. The existence of trees with similar dimensions and intermediate diameter class in optimal stage causes a less destructive impact of fallen trees on their neighbours. Therefore, trees have higher resistance to uprooting and the frequency distribution of gapmakers in optimal stage follows a normal curve.

Four decay classes are recognized in three development stages. More than 70% of gapmakers were classified into decay stage and 2nd and 3rd decay classes. Kucbel et al. (2010) reported that most of the gapmakers (86%) were at the 3rd (advanced decay) and 4th (strongly decomposed) decay classes, while the 1st (freshly dead trees) and 2nd (moderate decay) decay classes comprised only 3 and 11% and of gapmakers, respectively. A decomposition process varies among tree species. Müller-Using and Bartsch (2003) and Christensen et al. (2005) reported that the decomposition time for European beech does not exceed 25 to 50 years depending on the site conditions. According to Sefidi and Marvie Mohadjer (2016) results, the completion of decomposition time for the 1st, 2nd, 3rd and 4th decay classes approximately requires 37 years and 2, 17, 12 and 6 years' time lapse in the Hyrcanian forests of Iran, respectively. Most of the gapmakers went under the rubric of the third decay class. Therefore, most of the gaps were 20 to 31 years old.

The frequency of uprooted trees was higher than that of snags in all three development stages. There was a significant difference between decay stage and the other two stages for uprooted trees ($P < 0.05$) which confirms that oriental beech is prone to falling damage caused by wind and snowfall particularly in decay stage.

CONCLUSIONS

Natural forest remnants can be used as reference objects for maintaining or restoring old-growth characteristics in managed forests (Bauhus et al. 2009; Keeton et al. 2010). The introduction of the "close-to-nature" silvicultural concept is the result of implementation characteristics in forestry activities (Commarmot et al. 2005). The study area is a natural reserve old-growth forest and most of the gaps have been created by the fall of one or two gapmakers and had a medium size (200–500 m^2) per development stage. Therefore, in order to realize close-to-nature management in similar forests, one or two trees should be marked so that 200–500 m^2 gaps are created by tree harvesting. Two or three gaps per hectare are suitable for similar forests so that the gap fraction comprises about 13.5% of the forest area.

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