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Managed vs. unmanaged *Fagus orientalis* Lipsky forests: Structure and diversity of natural regeneration in northern Iran

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Abstract: The predominant natural disturbance regime within an old-growth Oriental beech (*Fagus orientalis* Lipsky) forest has been imitated in order to continue the forest cover. It is unclear how much the silvicultural characteristics of regeneration in a managed forest differ from those in an unmanaged old-growth forest subject only to natural dynamics. In this study, we compared important quantitative (e.g. height, collar diameter, crown width, length of spring shoot on the main stem and length of the uppermost internodes) and qualitative (e.g. healthy, mode of branching and stem form) silvicultural characteristics of beech saplings within the gaps between an unmanaged old-growth Oriental beech compartment and a managed forest in the northern Iran ten years after a single harvest entry using a single-tree selection. Canopy gaps larger than 100 m^2 with visible remnants of gapmakers (i.e. stumps) were included in this study. The saplings' characteristics of both compartments were within typical ranges for an old-growth beech forest. Small, but important differences were also observed. The value of beech saplings' density in the managed compartment (4.9 ± 0.7 SE) was significantly ($P < 0.05$) higher than the unmanaged one (3.4 ± 0.6 SE). Conversely, the value of the Menhinick Richness index in the unmanaged one (0.96 ± 0.05 SE) was significantly ($P < 0.01$) higher than the managed compartment (0.80 ± 0.04 SE). The sapling spring shoot length in the unmanaged compartment (13.3 ± 1.7 SE) was also significantly ($P < 0.01$) higher than the managed one (7.3 ± 0.7 SE). Relying on beech trees in a managed compartment will hamper the stability of future forest stands. The imitation of the old growth forest must be complete. To increase the resistance of the forest stands to adverse conditions, pay attention to the tree species richness at the time of marking.

Keywords: close-to-nature; forest gap; plagiotropic; richness; silviculture

A disturbance in the canopy of forest stands causes changes in the structure, regeneration, vegetation, composition and species diversity (Promis et al. 2009). Storms, fires and harvesting are among the disturbances that create an open space called a 'canopy gap' in the forest (Kukkonen et al. 2008). Gaps assist the forest succession and, furthermore, affect the nutrition cycle, soil, species biodiversity and micro-environmental conditions (light, moisture and temperature) in a forest (Denslow 1987; Yamamoto 1989; Ritter et al. 2005; Mountford et al. 2006; Torimaru et al. 2012).

The understory vegetation, such as regeneration, is also one of the important components in temperate forests which affect the nutrient cycling, forest biodiversity, animal communities and the future composition of the tree species (Helms 1998; Thomas et al. 1999; Augusto et al. 2003; Kimmins

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2004; Antos 2009). Numerous studies have emphasised the effect of the understory vegetation on the overall structure of the forest (Spies, Franklin 1991; Berger, Puettmann 2000; Sullivan et al. 2001; Anderson, Meikle 2006; Dröβler 2006; Hinsley et al. 2009; Nagel et al. 2013; Feldmann et al. 2018). Vacek et al. (2020) showed that after three and six years of management (rhododendron clearance) in the Black Sea region Oriental beech forest (*Fagus orientalis* Lipsky) of Turkey, the number of natural regenerations increased from 63 981 ha^{-1} to 105 075 ha^{-1}.

Due to the importance of gaps and regeneration in temperate forests, many researchers have studied their characteristics. Some studies have shown that the height of the Oriental beech saplings under the closed canopy was significantly higher than within the gaps (Nasiri et al. 2017) and the abundance of beech saplings had a significant negative correlation with the gap size in both natural and man-made canopy gaps (Mohammadi et al. 2019). In some studies, the gap size has been introduced as an effective factor in the establishment of beech regeneration (Vilhar et al. 2015; Feldmann et al. 2018). Some have concluded that the richness and composition of regenerative groups vary at different levels of disturbance (Gálhidy et al. 2006; Fahey, Puettmann 2007; Raymond et al. 2018). Most of the mentioned studies have focused on the quantitative characteristics of regeneration and the qualitative characteristics of regeneration have been studied to a lesser extent. The frequency of healthy Oriental beech saplings increased by 5% to 15% at a relative light intensity and then decreased (Parhizkar et al. 2011b). Comparison of quantitative and qualitative characteristics of regeneration between managed and unmanaged compartments has been performed less and it is unclear how much the silvicultural characteristics of regeneration in a managed forest differ from those in an unmanaged old-growth forest subject only to natural dynamics.

The Oriental beech is a shade tolerant species that is dominant in the middle and upper altitudes of Hyrcanian forests with high air moisture which are covered with fog in the growing season (Sagheb-Talebi et al. 2014). In Iran, natural Oriental beech forests were created on the southern part of the Caspian Sea at elevations above 750 m a.s.l. These forests created on the acidic and calcic parent rock with hydromorphous brown, acidic brown, podzolic brown and pseudogley soils where the C/ N ratio does not go higher than 20 (Sagheb-Talebi et al. 2014). In these forests, the single-tree selection system was chosen as the preferred silvicultural system because it was thought to emulate the predominant natural disturbance regime that characterises Oriental beech forests, ensuring the presence of a continuous forest cover (Amiri et al. 2015). In February 2017, the forest ban law that prohibits any logging in these forests (Müller et al. 2017) was approved by the Iranian Parliament. Different methods of forest management have different effects on the regeneration, species diversity and structure of forest stands (Nagaike et al. 2005). If the single-tree selection system induces significant differences in the quantitative and qualitative characteristics of the regeneration, this could jeopardise the structure and dynamism of these beech forests and support the decision of a no-management approach in the existing beech forests. A previous study showed that management based on emulating natural disturbances preserves, sustains, and promotes species diversity (Harvey et al. 2002). Some studies have shown that man-made gaps can create better conditions for seedling growth (Wang, Liu 2011).

In this study, we compared the quantitative and qualitative characteristics of the regeneration in an Oriental beech forest, which was partially harvested in 2009, with an unmanaged Oriental beech forest to examine the possible differences. The specific goals were to (*i*) identify the effects of the gap size on the silvicultural characteristics of beech saplings in the managed and unmanaged forests; (*ii*) identify the differences in the beech saplings' silvicultural characteristics in managed and unmanaged compartments and (*iii*) identify the differences in the Menhinick Richness index in managed and unmanaged compartments. We hypothesised that the saplings' characteristics had increased with an increasing gap size and that they have had more favourable conditions in the unmanaged compartment.

MATERIAL AND METHODS

Study sites. The study was conducted in a managed (compartment No. 136) and an adjacent unmanaged (compartment No. 139) uneven-aged Oriental beech forest of the Langa region forest district, Watershed No. 36 (Kazemrood) on the southern part of the Caspian Sea (36°32'15''N–36°35'10''N

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and 51°02'25''E–51°05'05''E), northern Iran (Figure 1). The forest type is irregular Oriental beech. The bedrock is acidic (igneous and metamorphic) and the soil of this region is of forest brown [Cambisol (FAO classification) or Ochrept from Inceptisols (USDA classification)] (Zarrinkafsh 2002) and its pH varies from 5.6 to 6.1. The mean annual precipitation and mean annual temperature are 1 300 mm and 8 °C, respectively. The maximum precipitation occurs in the early spring (Apr) and the fall (Oct–Dec) and the maximum temperature occurs May to July. There is no biological dry season (Anonymous 2010).

The two compartments studied have similar canopy densities (75%–80%) and slope gradients (range: 0%–80%, predominance: 31%–60%) in addition to the tree species composition [Oriental beech: 80%–83%, European hornbeam (*Carpinus betulus* L.): 10%–12% and other species: 5%–7%], a north–northeast slope direction and two-layered forest canopies. Compartment No. 139 is a protected reserve stand that covers an area of 43 ha. No silvicultural intervention has occurred in it and it is located at an altitude between 1 350 m a.s.l. and 1 650 m a.s.l. Compartment No. 136 is located at an altitude between 1 220 m a.s.l. and 1470 m a.s.l. and covers an area of ~30 ha. This compartment had a single harvest entry in 2009 and there was no previous history of management. The harvesting intensity was 13 $m^3 \cdot ha^{-1}$ (~3% of the stand volume). The mean diameter at breast height (*DBH*) of the trees in compartment No. 139 (36.5 cm) was about 10 cm more than compartment No. 136 (26.3 cm). The tree density in compartment No. 139 (203 $stems \cdot ha^{-1}$) was twice that of compartment No. 136 (422 $stems \cdot ha^{-1}$), while the standing volume in compartment No. 139 (467 $m^3 \cdot ha^{-1}$) was slightly higher than compartment No. 136 (448 $m^3 \cdot ha^{-1}$) (Parhizkar et al. 2021) (Table 1).

Previous studies within the same forest complex showed a total of 102 gaps and 3.5 $gaps \cdot ha^{-1}$,

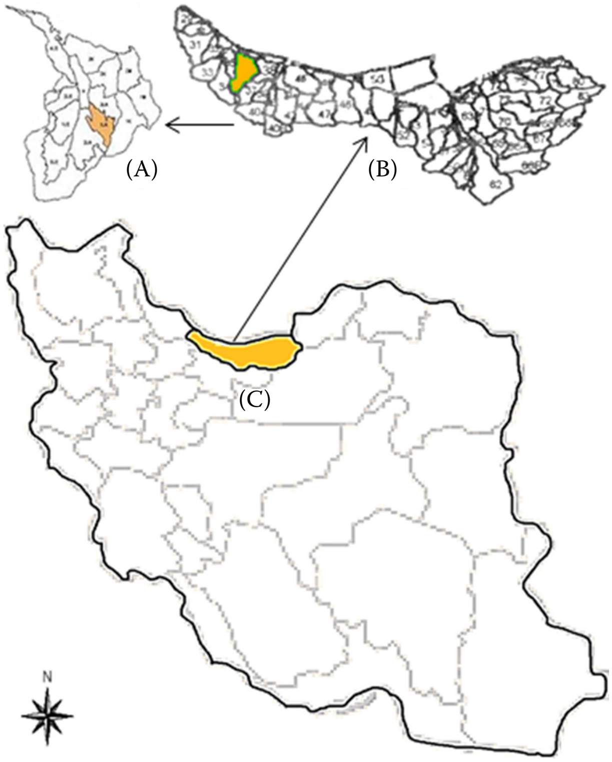

Figure 1. Illustration of (A) District one in Langa region (brown color), (B) watershed number 36 (yellow color) of the Hyrcanian uneven-aged Oriental beech forests, (C) northern Iran (yellow color)

within the managed compartment and 59 gaps and 2.6 $gaps \cdot ha^{-1}$ in the unmanaged compartment. The mean expanded gap areas were 282.4 m^2 ± 17.9 SE (range: 103.1–1 557.8 m^2) in the managed compartment that covered 9.8% of the total area and 501.7 m^2 ± 28.5 SE (range: 116.9–1 334.9 m^2) that covered 13.7% of the unmanaged compartment (Parhizkar et al. 2021).

Field methods. All forest expanded gaps with an area > 100 m^2 were identified in the two compartments and recorded by the Global Positioning System (GPS). Expanded canopy gaps were defined as an opening in the upper canopy layer due to the mortality or harvesting of one or more trees with

Table 1. Characteristics of stand trees in the managed (No. 136) and unmanaged (No. 139) compartments (after Parhizkar et al. 2021); values are always expressed as ± standard error

Compartments	Stems per ha	Mean *DBH* (cm)	Basal area ($m^2 \cdot ha^{-1}$)	Standing volume ($m^3 \cdot ha^{-1}$)	Altitude (m a.s.l.)
Managed	422 ± 13	26.3 ± 0.5	35.17 ± 1.8	448 ± 25.8	1 220–1 470
Unmanaged	203 ± 6	36.5 ± 0.9	34.45 ± 2.0	467.15 ± 30.4	1 350–1 650

DBH – diameter at breast height

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remnants of the gapmaker or parts of it still visible and limited in area by the trunks of the surrounding trees (Runkle 1992). The length of the longest and shortest axes of each gap was measured with a Vertex III (Haglöf Sweden AB, Sweden) (Luoma et al. 2017). Then, the area of each gap was computed using the function for an ellipse (Runkle 1981; Weber et al. 2014) and were classified into four size classes according to Parhizkar et al. (2021) (small: gap area ≤ 200 m^2; medium: 200 m^2 < gap area ≤ 500 m^2; large: 500 m^2 < gap area ≤ 1 000 m^2; very large: gap area > 1 000 m^2).

In each compartment, the gaps were numbered and then by using a lottery system, we randomly selected (if any) at least 3 replicates of each gap size class with the longest gap axis in a north-south direction and examined the characteristics of the regeneration in them.

The qualitative and quantitative characteristics of the saplings were assessed in five sample plots (extent of 2 m × 2 m) that were established at the centre and the four sides (north, east, south and west) of each gap. The plots were aligned in a north-south (longer axis) and east-west direction (shorter axis) and located at the ends of each axis at a distance of 1 m from the trunks of the gap edge trees.

All of the seedlings (regeneration shorter than 15 cm tall) and saplings (taller than 15 cm, but with a *DBH* less than 7.5 cm) within the plots were counted (Parhizkar et al. 2011b) and the Menhinick Richness index (the ratio of the total number of observed species in the community to the square root of the total number of observed individuals), the number of tree species·$plot^{-1}$ and plant abundance (number of individuals·$plot^{-1}$) were computed by the species group and for all the species combined. We measured the height, collar diameter, crown width (largest distance between the two largest branches, length of the spring shoot on the main stem and length of the uppermost internodes (distance between the uppermost lateral bud and terminal bud on the main stem) of the beech saplings.

In addition, we also investigated the health status (healthy = with green foliage and in good condition with no browsing on the stem and terminal buds, unhealthy = with no green foliage and not in good condition affected by environmental factors or by browsing on the stem and terminal buds), mode of branching (unforked, forked, or broom shaped) (Marvie Mohadjer 1975, 1976; Roloff 1986; Sagheb-Talebi 1995) and stem form (orthotropic = erect from of the main stem, plagiotropic = horizontal from of the main stem, Barnes et al. 1998) of the beech saplings (Parhizkar et al. 2011b).

Statistical analysis. The mean of the variables measured in the beech saplings was calculated at the plot level and was the basis of the statistical analysis. Regarding the qualitative characteristics, the arithmetic mean of the sapling scores was calculated at the plot level and was used as the plot quality score for each of the variables. Also, the beech sapling density, whole regeneration density and species richness were calculated at the plot level.

All the variables were analysed in terms of the normal distribution and homogeneity of the variance for the parcel, gap sizes and plot location comparisons. Due to the severe violation from the normal distribution and homogeneity of variance, statistical analyses were performed using the non-parametric Kruskal-Wallis (for more than two groups) and Mann-Whitney U (for two groups) tests. Follow up multiple comparisons for the Kruskal-Wallis analysis were performed using the Man-Whitney based Step-Down method (Bihamta, Zare Chahouki 2008). All the statistical analyses were performed using SPSS software (Version 21, 2020).

RESULTS

In the managed compartment, there was no gap > 1 000 m^2 and the gap sizes ranged from 100.2 m^2 to 768.5 m^2, with a mean gap size of 143.1 m^2 (small gaps), 263.1 m^2 (medium gaps) and 659.6 m^2 (large gaps). In the unmanaged compartment, the gap sizes ranged from 115.8 m^2 to 1 174.2 m^2, with a mean gap size of 155.9 m^2 (small gaps), 381.5 m^2 (medium gaps), 883.4 m^2 (large gaps) and 1 175.8 m^2 (very large gaps).

Effect of the gap size on the beech sapling characteristics in the unmanaged compartment. Altogether, 895 saplings and seedlings of the tree species included 204 saplings and 45 seedlings of beech, as well as 124 saplings and 522 seedlings of other species (European hornbeam: *Carpinus betulus* L., coliseum maple: *Acer cappadocicum* Gled., velvet maple: *Acer velutinum* Boiss., wild cherry: *Prunus avium* L., broad-leaved lime tree: *Tilia platyphyllos* Scop., scotch elm: *Ulmus glabra* Huds. and English yew: *Taxus baccata* L.) were counted and measured within 60 sample plots of 12 gaps in the unmanaged compartments. The highest number of beech saplings (66) and seed-

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lings (21) were counted in the medium and small gaps, respectively. The number of seedlings of other species (273) also had the highest value in the small gaps, but the highest number of saplings of other species (49) occurred in the large gaps (Table 2).

The highest mean of the studied characteristics occurred in the different gap sizes of the unmanaged compartment. We did not find any significant differences between the quantitative characteristics by the gap sizes, except for the density of all the saplings (Table 3). The highest mean of all the sapling density occurred in the small gaps (df = 3, chi-squared statictic: $H = 8.667$, $P < 0.05$). Although the values of the species richness and beech sapling density did not show any significant differences in the different gap sizes, they also had the highest values in the small gaps (Table 3). There was no significant differences between the qualitative characteristics of the beech trees by the gap size in the unmanaged compartment, except for the stem form class (df = 3, H = 15.514, P < 0.01) and the mean frequency of the orthotropic beech saplings in very large gaps was higher than the other gaps (Table 3).

The evaluation of the qualitative characteristics of all the beech saplings showed that the relative frequency of the healthy saplings in all the gap sizes was higher than the unhealthy ones, except for the very large gaps (Figure 2A). The relative frequency of the unforked saplings in allthe gap sizes was higher than the forked and broom-shaped ones and also, as the gap size increases, the frequency of the unforked saplings increases. Broom shaped saplings were present only in the small and medium-sized gaps (Figure 2B). The number of plagiotropic saplings in all the gap sizes was higher than the orthotropic ones, and the relative frequency of the orthotropic beech saplings increased with the increasing gap size (Figure 2C).

Effect of the gap size on the beech sapling characteristics in the managed compartment. In the managed compartment, 551 saplings and seedlings included 224 saplings and 18 seedlings of beech, as well as 129 saplings and 180 seedlings of other species (European hornbeam: *Carpinus betulus* L., coliseum maple: *Acer cappadocicum* Gled., velvet maple: *Acer velutinum* Boiss., wild cherry: *Prunus avium* L., broad-leaved lime tree: *Tilia platyphyllos* Scop., scotch elm: *Ulmus glabra* Huds. and chestnut-leaved oak: *Quercus castaneifolia* C. A. Mey) were counted and measured within 45 sample plots of 9 gaps. The highest number of beech saplings (94)

Table 2. Number of seedlings and saplings within different size classes of gaps in the managed and unmanaged compartments

Gap size	Unmanaged								Managed							
	No. of plots	No. of beech seedlings	other species[b] seedlings	sum of seedlings	No. of beech saplings	other species[b] saplings	sum of saplings	total	No. of plots	No. of beech seedlings	other species[b] seedlings	sum of seedlings	No. of beech saplings	other species[b] saplings	sum of saplings	total
Small	15	21	273	294	63	13	76	370	15	6	36	42	72	15	87	129
Medium	20	17	132	149	66	41	107	256	15	1	87	88	58	51	109	197
Large	15	1	73	74	38	49	87	161	15	11	57	68	94	63	157	225
Very large	10	6	44	50	37	21	58	108	–	–	–	–	–	–	–	–
Total	60	45	522	567	204	124	328	895	45	18	180	198	224	129	353	551

[b]includes European hornbeam: *Carpinus betulus* L., coliseum maple: *Acer cappadocicum* Gled., velvet maple: *Acer velutinum* Boiss., wild cherry: *Prunus avium* L., broad-leaved lime tree: *Tilia platyphyllos* Scop., scotch elm: *Ulmus glabra* Huds., English yew: *Taxus baccata* L. and chestnut-leaved oak: *Quercus castaneifolia* C.A.Mey.

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Table 3. Comparison of beech saplings parameters by gap size in the managed and unmanaged compartment (mean ± standard error)

Parameters	Unmanaged gap size				Managed gap size		
	small	medium	large	very large	small	medium	large
Age (year)	8.3 ± 1.3	9.9 ± 1.4	6.9 ± 0.6	10.1 ± 1.8	8.4 ± 1.3	9.8 ± 1.4	10.9 ± 1.2
Collar diameter (mm)	14.1 ± 2.9	22.6 ± 5.6	10.4 ± 1.5	14.3 ± 4.1	11.1 ± 2.5	11.5 ± 1.6	17.2 ± 3.1
Sapling height (cm)	107.8 ± 23.2	158.2 ± 40.7	81.3 ± 13.9	135.0 ± 42.1	86.5 ± 19.5	93.0 ± 16.4	148.1 ± 33.1
Length of spring shoot (cm)	8.9 ± 1.8	14.9 ± 3.5	12.3 ± 2.1	19.5 ± 6.3	8.8 ± 2.2	5.2 ± 0.9	8.1 ± 1.1
Length of uppermost internode (cm)	2.7 ± 0.4	2.9 ± 0.4	2.4 ± 0.4	3.2 ± 0.7	2.1 ± 0.2	2.1 ± 0.3	2.4 ± 0.3
Crown width (cm)	66.7 ± 14.2	107.9 ± 27.2	65.4 ± 10.9	88.0 ± 27.2	62.5 ± 19.4	69.0 ± 12.6	92.1 ± 17.9
Beech saplings density (individuals·plot^{-1})	4.2 ± 1.1	3.3 ± 0.9	2.5 ± 1.0	3.7 ± 2.1	4.8 ± 1.1	3.8 ± 1.0	6.3 ± 1.5
Richness (tree species·plot^{-1})	3.8 ± 0.2	2.8 ± 0.4	3.2 ± 0.3	2.2 ± 0.5	1.8 ± 0.1b	2.4 ± 0.2[a]	2.7 ± 0.2a
All saplings density (individuals·plot^{-1})	24.6 ± 7.6[a]	12.8 ± 2.6[ab]	10.8 ± 2.1[ab]	9.9 ± 6.2[b]	8.6 ± 1.6	13.1 ± 2.2	15.0 ± 2.8
Healthiness	0.7 ± 0.08	0.5 ± 0.08	0.7 ± 0.07	0.6 ± 0.1	0.5 ± 0.09	0.4 ± 0.09	0.5 ± 0.09
Stem form	0.09 ± 0.06[b]	0.3 ± 0.08[b]	0.1 ± 0.04[b]	0.7 ± 0.1[a]	0.2 ± 0.08	0.2 ± 0.08	0.2 ± 0.06
Mode of branching	1.6 ± 0.2	1.6 ± 0.1	1.3 ± 0.1	1.2 ± 0.06	1.3 ± 0.07	1.5 ± 0.1	1.4 ± 0.08

[a, b] significant ($P < 0.05$) differences between means

and seedlings (11) were counted in the large gaps. The number of seedlings of the other species (87) had the highest value in the medium gaps, but the highest number of saplings of the other species (63) occurred in the large gaps (Table 2).

The highest mean of all the characteristics occurred in large gaps of the managed compartment, except the length of the spring shoot. We did not find any significant difference between the quantitative characteristics by the gap sizes, except the species richness (Table 3). The highest mean of the species richness was occurred in the large and medium gaps ($df = 2$, $H = 8.470$, $P < 0.05$). Although the values of the beech and all of the species saplings density did not show any significant differences in the different gap sizes, they also had the highest values in the large gaps (Table 3). There was no significant difference between the qualitative characteristics of the beech by gap size in the managed compartment (Table 3).

In the managed compartment, the relative frequency of the healthy saplings in all the gap sizes was higher than the unhealthy ones and no significant change occurs with the increasing size of the gaps (Figure 2A). The relative frequency of the unforked saplings in all the gap sizes was higher than the forked and broom shaped ones, except for the medium-sized gap. Also, the broom shaped saplings were not present in the medium-sized gaps (Figure 2B). The number of plagiotropic saplings

Table 4. Comparison of beech saplings parameters between managed and unmanaged compartments (mean values ± standard error)

Parameters	Unmanaged	Managed
Age (year)	8.8 ± 0.7	9.7 ± 0.7
Collar diameter (mm)	16.3 ± 2.3	13.1 ± 1.4
Sapling height (cm)	123.2 ± 17.1	107.8 ± 13.8
Length of spring shoot (cm)	13.3 ± 1.7[a]	7.3 ± 0.7[b]
Length of uppermost internode (cm)	2.8 ± 0.2	2.2 ± 0.1
Crown width (cm)	83.6 ± 11.2	73.9 ± 9.6
Beech saplings density (individuals·plot^{-1})	3.4 ± 0.[6]b	4.9 ± 0.7[a]
Richness (tree species·plot^{-1})	3.0 ± 0.2[a]	2.3 ± 0.1[b]
All saplings density (individuals·plot^{-1})	14.8 ± 2.4	12.2 ± 1.3
Healthiness	0.6 ± 0.04	0.5 ± 0.05
Stem form	0.2 ± 0.05	0.2 ± 0.04
Mode of branching	1.5 ± 0.08	1.4 ± 0.05
Menhinik Richness index	0.96 ± 0.05[a]	0.80 ± 0.04[b]

[a, b] significant ($P < 0.05$) differences between means

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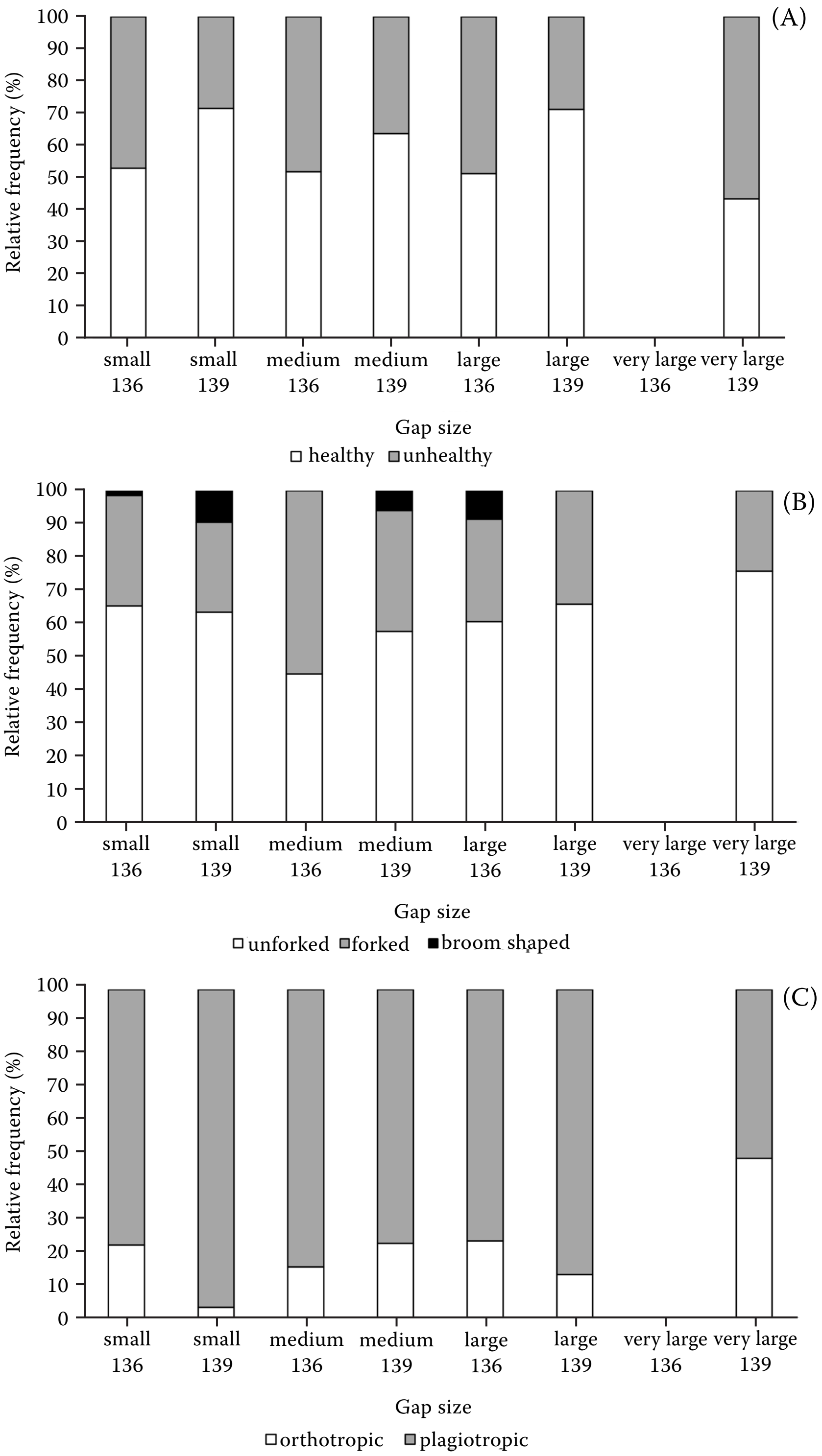

Figure 2. Qualitative characteristics proportion of all beech saplings by gap size in the managed (No. 136) and unmanaged (No. 139) compartments: (A) healthiness class, (B) mode of branching class, (C) stem form class

in all the gap sizes is higher than the orthotropic ones, and there were fewer orthotropic saplings in the medium-sized gaps than in the small and large ones (Figure 2C).

Comparison of the beech sapling characteristics between the two studied compartments. The comparison of the quantitative and qualitative characteristics of the beech saplings between the two studied compartments showed that the highest mean of the beech sapling density occurred in the managed compartment (Mann-Whitney U test: $MWU = 16\ 965$, $P < 0.05$), while the highest mean

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of the species richness occurred in the unmanaged compartment (*MWU* = 935.00, $P < 0.01$). The length of the spring shoot also had the highest mean in the unmanaged compartment (*MWU* = 379.00, $P < 0.01$). There were no significant differences in the mean of the other quantitative and qualitative characteristics between the two compartments (Table 4).

DISCUSSION

There was no significant mean difference ($P < 0.05$) between the age of the beech seedlings in the different gap sizes and also between the two compartments. Therefore, this characteristic did not affect the size of the other characteristics of the beech saplings.

Our findings showed that the highest density of the beech saplings in the unmanaged compartment (4.2 ± 1.1 SE) was in the small gaps, which is consistent with the results of other studies (Tabari et al. 2005; Amiri et al. 2015) in intact beech forests. However, the gap size had no significant effect ($P < 0.05$) on this characteristic in the managed compartment, which is consistent with the results of Mohammadi et al. (2019) and Sefidi et al. (2011) who showed the size of the gap in natural and man-made gaps did not have a significant effect on the abundance and diversity of the seedlings in a northern Iran Khairudkenar forest. Previous studies have shown that the presence of advanced regeneration explains the lack of a significant relationship between the regeneration density and the gap size (Nagel et al. 2010). Advanced regeneration may dominate regardless of the gap size or light availability (Madsen, Hahn 2008; Forrester et al. 2014). Increases in the density may be temporary (Schnitzer, Carson 2001) and may pass over time. For example, tree regeneration may be inhibited over time by disturbing plant layers or invasive species (Kern et al. 2012; Vacek et al. 2020). From our findings, it seems that man-made gaps have been created where advanced regeneration was present. In unmanaged forests, the development stages and the severity and type of disturbances affect the creation of different size gaps (Nagel et al. 2010; Sefidi et al. 2011) and the presence or absence of advanced regeneration does not matter in the creation of natural gaps.

The value of beech saplings density in managed compartment (4.9 ± 0.7 SE) was significantly ($P < 0.05$) higher than the unmanaged one (3.4 ± 0.6 SE). Conversely, the value of the Menhinick Richness index in the unmanaged one (0.96 ± 0.05 SE) was significantly ($P < 0.01$) higher than the managed compartment (0.80 ± 0.04 SE). This shows that although that although someone marked the trees has, in many cases, correctly imitated nature, most markings are made to strengthen the beech saplings and but they have not considered the richness of the tree species. In the unmanaged forests, in addition to the gaps caused by the accidental falling of trees, the ecological nature of different tree species also affects the presence and abundance of the saplings.

The saplings showed a mean spring shoot length of 13.3 cm in the unmanaged gaps, which is in the range of growth rates recorded for European beech (*Fagus sylvatica* L.) saplings (Petritan et al. 2007; Feldman et al. 2020). The sapling spring shoot length in the unmanaged compartment (13.3 ± 1.7 SE) was also significantly ($P < 0.01$) higher than the managed one (7.3 ± 0.7 SE). A study conducted at a virgin forest reserve of Slovakia showed that the sapling shoot length growth rates in the medium gap was higher than in the small gaps and the sapling survival profit from a larger gap size (Feldman et al. 2020). Vacek et al. (2015) showed that the abundance and size of the natural regeneration is affected by the trees' overstory canopy closure. In our study, the average gap size in the unmanaged compartment was larger than the managed gaps, so the unmanaged compartment receives more light. Previous studies have shown that the maximum assimilation, maximal quantum yield (Čater and Levanič 2019), higher relative humidity, higher water use efficiency and also photosynthetic nitrogen use efficiency in an unmanaged forest were significantly higher than a neighbouring managed forest (Čater, Levanič 2013). The significant difference in the mean beech sapling spring shoot length in the managed and unmanaged compartments that we studied may also be due to the microclimate. The length of the spring shoot is an indicator of the competitive advantage for saplings that were established prior to the gap formation (Feldman et al. 2020).

The mean frequency of the orthotropic beech saplings in the very large gaps within the unmanaged compartment (0.7 ± 0.1 SE) was higher than the other gap sizes, which is consistent with the results of Parhizkar et al. (2011a) in Hyrcanian beech forests. In general, larger gaps receive more light and smaller gaps are the most affected by the tree crowns around the gap (Schliemann, Bockheim 2011). A horizontal light-foraging strategy in the shade leads to plagiotropic growth in beech

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saplings (Petritan et al. 2009). Previous studies indicated that the beech had the most plagiotropic in low light levels (Schmitt et al. 1995; Wagner 1999; Stancioiu, O'Hara 2006) and plagiotropic growth is evident at relative light intensities of less than 15% (Zang, Biondi 2015; Čater, Levanič 2019), which occurs in smaller gaps (Schliemann, Bockheim 2011). Due to the presence of more light in larger gaps, orthotropic growth is evident. Our results showed that there was no significant difference in the frequency of the orthotropic beech saplings between the managed and unmanaged compartments. Previous studies have shown that plagiotropic growth in European beech saplings began in an old-growth forest by less light intensity than in managed forests (Čater, Levanič 2019). Bulušek et al. (2016) also reported that plagiotropic growth and the plasticity of beech crowns is closely positively correlated with the terrain slope.

CONCLUSION

The preponderance of small, large and medium-sized gaps will be sufficient to maintain the main tree species of the shade-tolerant Oriental beech in the managed stand, while more shade-intolerant species may not be successfully maintained in the long run. Insufficient very large gap sizes would, thus, be expected to pose serious challenges for maintaining a high tree species richness and a mixture of shade-tolerant and shade-intolerant species and, thus, to a fundamental objective of a 'close-to-nature' silviculture. We do not know how the characteristics of the regeneration in the two compartments was prior to the intervention. Although there may have been some differences between the two compartments prior to the intervention, the increase of some characteristics, such as the sapling spring shoot length, is consistent with the average gap size in the unmanaged compartment compared to the managed compartment. Monitoring the characteristics of the saplings in the studied areas can show the effects of the intervention more accurately.

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