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Variability of Plant Diversity and Soil Features Following Gap Creation in Caspian Beech Forests of Iran

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ABSTRACT

Due to study the effects of gap size and position on herbal diversity indices and soil features, twelve canopy gaps with an area between < 200 m^2 and 1000 m^2 were selected in a reserve oriental beech (Fagus orientalis Lipsky) stand in the north of Iran. For each canopy gap, one non-gap plot (closed canopy) 4 m^2 square sampling quadrate was considered also. Ground vegetation was assessed within five sample plots (2 × 2 m area) from gap center to the edges. Soil samples were taken (0 – 20 cm depth) from within gap and closed canopy positions. Some of soil characters including pH, organic matter and carbon, total nitrogen, phosphorus, potassium, calcium, magnesium and saturated moisture were measured at the laboratory. Results indicated that diversity and richness indices increased with increasing of gap area whereas, evenness indices were decreased. Furthermore, the highest amount of diversity and richness indices were observed in gap center compared with gap edge and closed canopy. But, closed canopy position had the greatest value of evenness indices. Analysis of data showed that soil pH, organic matter and carbon and also total nitrogen increased with increasing of gap area. Also the highest values of these characters were detected in within gaps. Whereas, saturated moisture amounts decreased with increasing of gap area and the highest value of this character was detected in closed canopy. Compare means of available phosphorus, potassium, calcium and magnesium in the gap size indicated that medium gaps had the greater amounts than in the small and large gaps. These characters were significantly greater in within gaps in comparison to closed canopy. Greater amounts of carbon to nitrogen ratio were found in medium gap and closed canopy position. In general, our research results provide a useful basis for evaluating the implications of forest management practices.

Keywords: gap size, gap position, diversity, richness, evenness, nutrient elements, soil.

INTRODUCTION

Beech (Fagus orientalis *Lipsky*) is the most industrial commercial tree species among more than 80 broad - leaved trees and shrubs in Iran. In the north of Iran, pure and mixed oriental beech forests cover 17.6 per cent of the surface land area and represent 30 percent of the standing biomass. This species is the most valuable wood -

producing species in the Caspian forests [45] and reaches in mature stage to more than 100cm dbh and about 50 meters height. They are found in small groups up to 500 m a.s.l. while individuals have been reported from 110 m up to 2650 m [38]. When trees start to dry alone or collectively, gaps will be created in forest canopy. Such gaps increase the forest biodiversity by settling new species. Since the 1980s, these canopy gaps have therefore been a major focus of forest ecologists. They studied not only environmental conditions [46] and effects on tree regeneration [11], but also herb layer response [2]. Studies on the herb layer species composition generally report that plant species number, herb layer cover and the abundance of many species are higher in gaps than under closed canopy [27]. These differences increase with increasing gap size [23, 41]. Although patterns of herb layer response to canopy gaps have been frequently studied, several questions are still open.

In beech forests of Iran, formation of gaps by wind throw is a characteristic natural disturbance event. Gap size varies greatly from the size of only a single crown to vast open fields with diameters of many tree lengths. However, changes in abiotic and biotic conditions depend both on gap size and within gap position [32, 37]. Consequently, it is not easy to predict how soil properties react to gap formation. Although it is recognized that gaps modify soil resources, few studies have focused on below - ground processes [28]. Most studies of gaps have addressed vegetation dynamics, regeneration through seedling establishment, effects of microclimate variables on the regeneration and, in general have concentrated on aboveground processes [46, 40]. Relatively few studies have addressed belowground effects of canopy gaps on soil chemical and biochemical properties. Thus, the objectives of this study were to examine the impacts of small, medium, large gaps on herbal diversity indices and soil properties, a "sink" and "source" of plant nutrients in beech stands in northern Iran. The present paper assesses experimentally the effects of gap creation on soil nutrient supply. Also this study is helpful to understand mechanism of the development of vegetation influenced by different gap size, and to derive some rules for nature - based management of Iran beech forests with gap dynamics.

MATERIALS AND METHODS

Study area: This research performed in the reserve oriental Beech (Fagus orientalis *Lipsky*) stand at Langa - Kelardasht, water catchment 36 in Mazandaran province, north of Iran with the area of 43 ha. (Between 36° 32´ 15˝, 36° 35´ 10˝ northern latitude, 51° 2´ 25˝, 51° 05´ 20˝eastern longitude). The maximum elevation is 1650 m and minimum is 1350 m. Minimum temperature in February (7°C) and the highest temperature in August (26°C) are recorded, respectively. Mean annual precipitation of the study area were from 289 to 32 mm at the Tonekabon city metrological station, which is 30 Km far from the study area. The soils are semi - deep, moderately well drained. They have textures of clay loam with pH of 4.2 to 6. Bedrock is sandstone with silting and argillite stone. Presence of logged and bare roots of trees is indicating rooting restrictions and soil heavy texture [3].

Gap selection: For this study, twelve canopy gaps with an area between < 200 m^2 and 1000 m^2 were selected in a reserve oriental beech stand. Moreover, for each canopy gap, one non - gap plot (closed canopy) 4 m^2 square sampling quadrate was considered. Canopy gaps areas were measured in the field according to common method [50]. The sampling protocol was built up by locating and measuring two perpendicular lines in each gap: one along the longest line visible and one perpendicular to it at the widest section of the gap. The gaps were classified in three classes: four gaps in 80 - 200 m^2 area class (small gap with area mean of 168.55 m^2), five gaps in 200 - 500 m^2 area class (medium class with area mean of 313.46 m^2), and three gaps in 500 - 1000 m^2 area class (large class with area mean of 719.82 m^2). Ground vegetation was assessed within five 2 × 2 m sample plots from center to the gap edges (Fig 1).

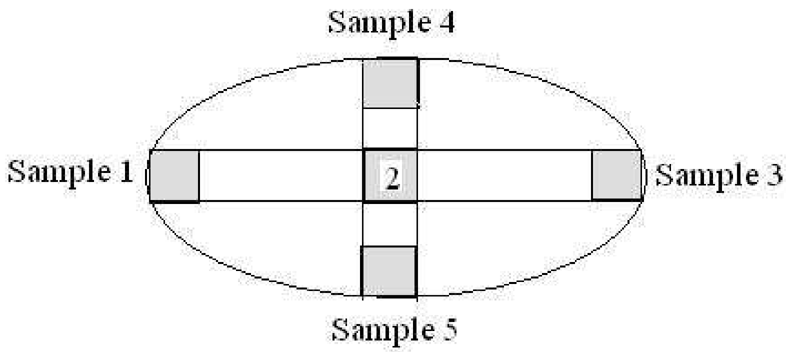

Fig.1. Gap display and collected samples

Then, different indices of biodiversity (diversity, richness and evenness of the herb layer) such as Shannon and Simpson diversity, Menhinick and Margalef richness and Sheldon and Pielou evenness indices were calculated by past software.

Soil sampling and analysis: For this purpose, two positions were distinguished including within gap and closed canopy. Soil samples were taken at 0 - 20 cm depths from all positions using core soil sampler with 81cm^2 cross section [44]. Roots, shoots and pebbles in each sample were separated by hand and discarded. The air - dried soil samples were sieved (aggregates were crushed to pass through a 2 mm sieve) to remove roots prior to chemical analysis. Soil pH was determined using an Orion Ionalyzer Model 901 pH meter in a 1:2.5, soil: water solution. Saturated moisture was measured using of weighting method [26, 52]. Soil organic carbon was determined using the Walkey - Black technique [1]. The total nitrogen was measured using a semi Micro - Kjeldhal technique [9]. The available P was determined with spectrophotometer by using Olsen method [33]. The available K and Ca (by ammonium acetate extraction at pH 9) were determined with Atomic absorption spectrophotometer (AAS) [8]. The values of Mg were measured by ICP – AES (Spectroflame) [26] at the Laboratory.

Statistical analysis: Normality of the variables was checked by Kolmogrov - Smirnov test and Levene test was used to examine the equality of the variances. Differences between gap different areas and gap positions in diversity indices and soil characteristics were tested with two - way analysis (ANOVA) using the GLM procedure. Interactions between independent factors were tested also. Duncan test and Independent sample t-test were used to separate the averages of the dependent variables which were significantly affected by treatment. Significant differences among treatment averages for different parameters were tested at $P \leq 0.05$. SPSS v.11.5 software was used for all the statistical analysis.

RESULTS

Canopy gap characteristics. Twelve canopy gaps with different areas were detected in study site (Table 1). Gaps classified in three classes: four gaps in 80 - 200 m^2 area class (small gap with area mean of 168.55 m^2), five gaps in 200 - 500 m^2 area class (medium class with area mean of 313.46 m^2), and three gaps in 500 - 1000 m^2 area class (large class with area mean of 719.82 m^2). Result is indicating the most present gaps in study area have 190 - 300 m^2 area.

Table 1. Characteristics of canopy gaps in study area

Gap class (m^2)	Gap number	Gap area mean (m^2)	Minimum and maximum of gap area (m^2)
80- 200	4	168.55	88.1 - 198.2
200-500	5	313.46	245.8 - 470.8
500-1000	3	719.82	530.5 - 1000.2

Biodiversity indices: Results indicated that the Shannon and weaver and Simpson diversity indices, Menhinick and Margalef richness indices for herb layer increased with increasing of gap area (Fig. 2 and 3). Whereas, Pielou and Sheldon evenness decreased with increasing of gap area (Fig. 4). Shannon and weaver and Menhinick indices were significantly (P < 0.05) higher in large gaps compared with small gaps (Table 2 and Figs. 2 and 3). But, the highest amount of Sheldon evenness index (P <0.05) was detected in small gaps in comparison to large gaps (Table 2 and Fig. 4).

About the effects of gap positions on biodiversity, the results showed that the highest amount of diversity and richness indices were observed in gap center in comparison to gap edge and closed canopy (Table 2 and Figs 5 and 6). Whereas closed canopy position had the greatest value of evenness indices in comparison to the other positions (Table 2 and Fig. 7). Shannon and weaver and Menhinick indices were significantly (P < 0.05) greater in gap center positions than closed canopy (Table2 and Figs 5 and 6). Closed canopy position devoted in the greatest value (P <0.05) of Sheldon evenness index in comparison to the other positions (Table 2 and Fig. 7).

Table 2. Three - way analysis of herbal diversity indices in gap different areas and positions

Variables Source	Diversity indices	df	SS	F-Value	MS	Sig
Gap area	Shannon and weaver	2	0.96	4.401	0.480	0.022
	Simpson	2	0.042	0.828	0.021	0.448
	Menhinick	2	0.390	6.297	0.195	0.006
	Margalef	2	0.443	2.971	0.222	0.068
	Pielou	2	0.049	1.152	0.024	0.331
	Sheldon	2	0.110	3.552	0.055	0.043
Gap position	Shannon and weaver	2	0.876	4.014	0.438	0.030
	Simpson	2	0.042	0.817	0.021	0.452
	Menhinick	2	0.236	3.806	0.118	0.035
	Margalef	2	0.375	2.516	0.188	0.100
	Pielou	2	0.065	1.535	0.032	0.234
	Sheldon	2	0.346	11.149	0.173	0.000
Gap area × Gap position	Shannon and weaver	4	1.295	2.967	0.324	0.037
	Simpson	4	0.133	1.306	0.033	0.293
	Menhinick	4	0.421	3.392	0.105	0.023
	Margalef	4	0.692	2.319	0.173	0.083
	Pielou	4	0.098	1.164	0.025	0.348
	Sheldon	4	0.084	1.355	0.021	0.276

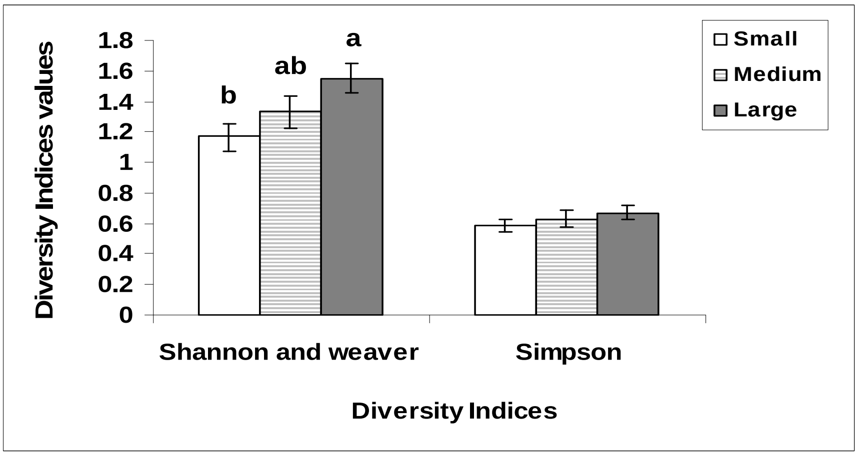

Fig. 2. Mean of diversity indices in gap different areas

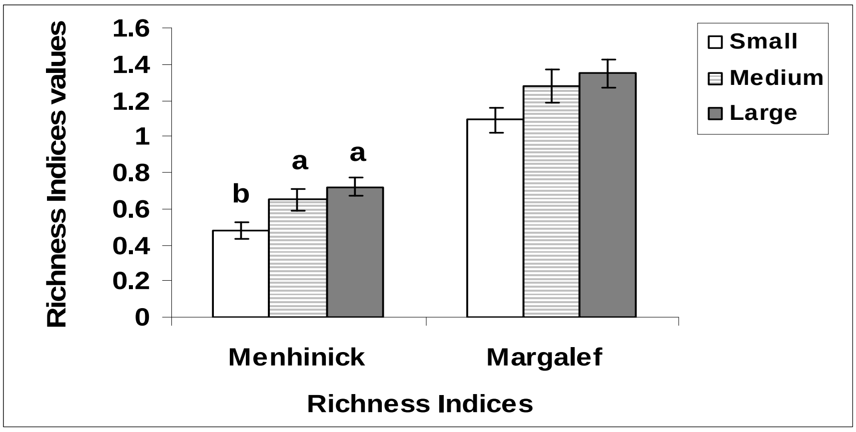

Fig. 3. Mean of richness indices in gap different areas

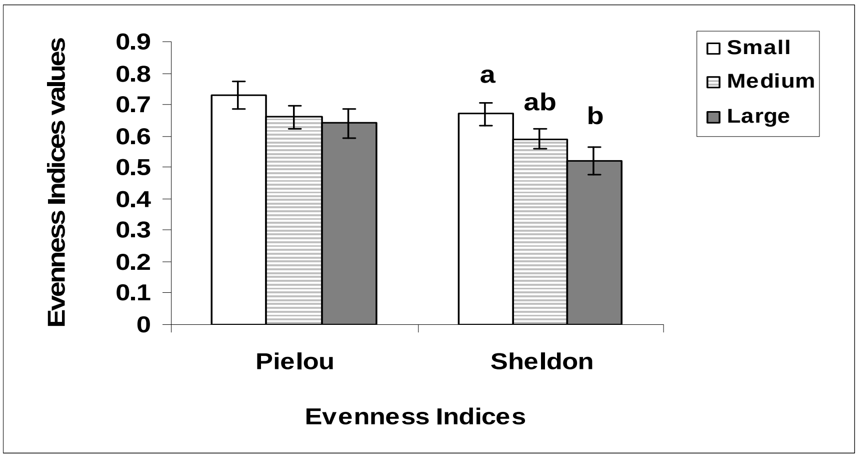

Fig. 4. Mean of evenness indices in gap different areas

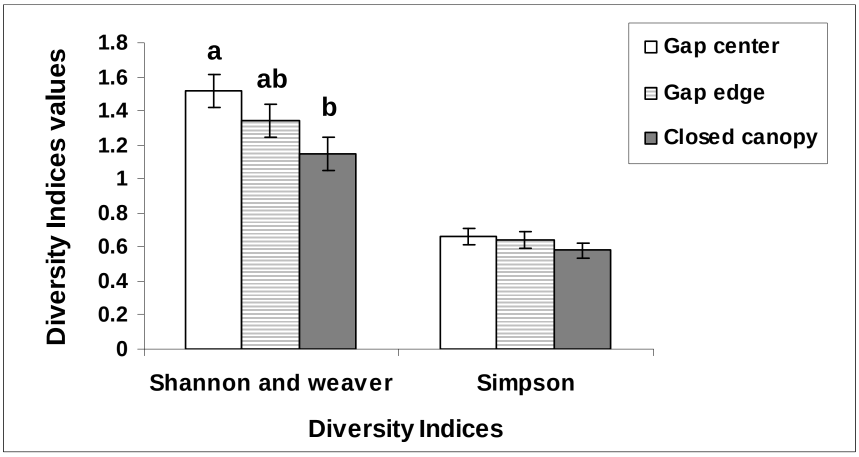

Fig. 5. Mean of diversity indices in gap different positions

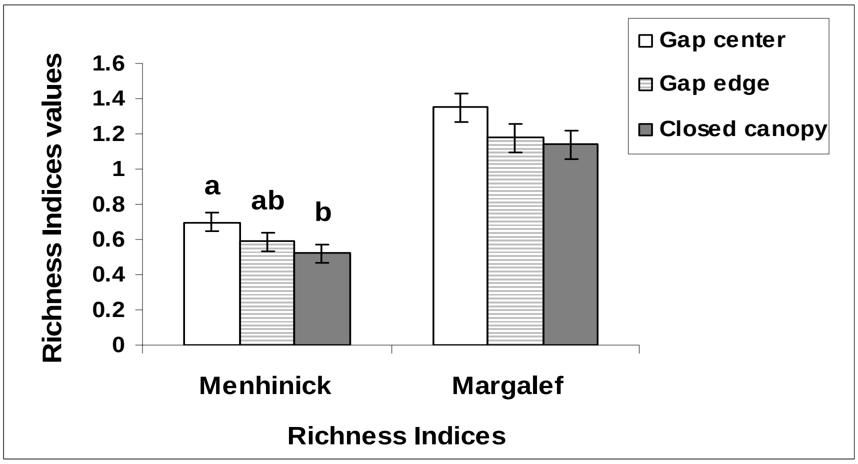

Fig. 6. Mean of richness indices in gap different positions

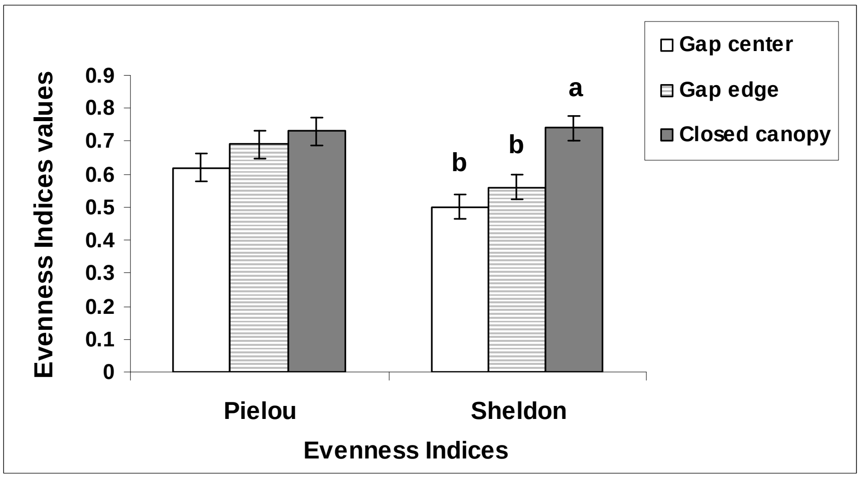

Fig. 7. Mean of evenness indices in gap different positions

Soil features: Analysis of data showed that soil pH, organic matter and carbon and total nitrogen increased with increasing of gap area. Soil pH was significantly (P <0.05) higher in within gaps in comparison to closed canopy. Also the highest value of organic matter and carbon and total nitrogen were detected in within gaps (Table 3 and Fig. 8, 9, 10 and 11). Greater amounts of carbon to nitrogen ratio were found in medium gap and closed canopy position (Fig. 12). Whereas saturated moisture of soil decreased with increasing of gap area and the highest value of this character was detected in closed canopy (Fig. 13). Compare means of available P, K, Ca and Mg in the gap size indicated that medium gaps had the higher amounts than in the small and large gaps. Also, these characters were significantly (P < 0.05) greater in within gaps in comparison to closed canopy (Fig. 14, 15, 16 and 17).

Table 3. Two - way analysis of soil features in gap different areas and positions

Soil character	Variables source	F - Value	Sig.
Saturated moisture (%)	Gap area	0.042	0.959
	Gap position	0.966	0.339
	Gap area × Gap position	0.059	0.943
pH	Gap area	1.364	0.281
	Gap position	5.554	0.030
	Gap area × Gap position	0.521	0.603
Organic matter (%)	Gap area	0.155	0.858
	Gap position	2.465	0.134
	Gap area × Gap position	0.034	0.966
Organic carbon (%)	Gap area	0.337	0.719
	Gap position	2.028	0.171
	Gap area × Gap position	0.049	0.952
Carbon to nitrogen ratio	Gap area	0.233	0.795
	Gap position	1.516	0.234
	Gap area × Gap position	0.089	0.916
Total nitrogen (%)	Gap area	0.058	0.944
	Gap position	2.581	0.126
	Gap area × Gap position	0.180	0.837
Available P (mg/kg)	Gap area	1.561	0.237
	Gap position	5.060	0.037
	Gap area × Gap position	0.082	0.922
Available K (mg/kg)	Gap area	0.758	0.483
	Gap position	5.851	0.026
	Gap area × Gap position	0.130	0.879
Available Ca (me/l)	Gap area	1.267	0.306
	Gap position	4.711	0.044
	Gap area × Gap position	0.021	0.979
Available Mg (me/l)	Gap area	0.618	0.550
	Gap position	4.998	0.038
	Gap area × Gap position	0.082	0.921

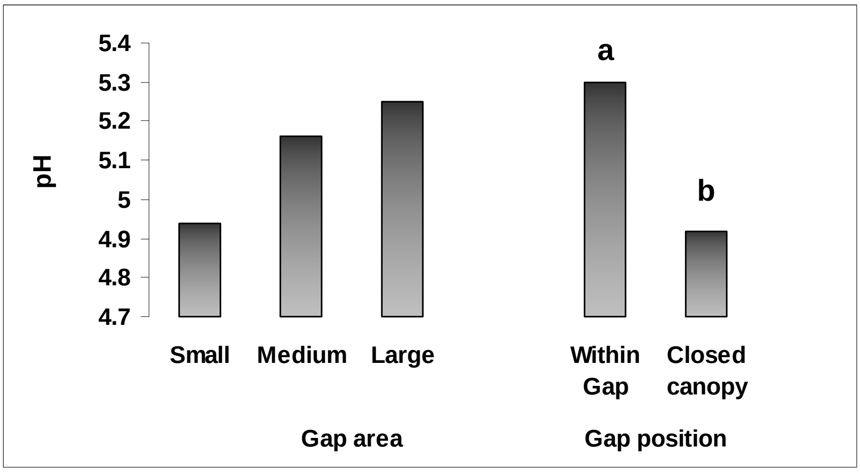

Fig. 8. Mean of soil pH in gap different areas and positions

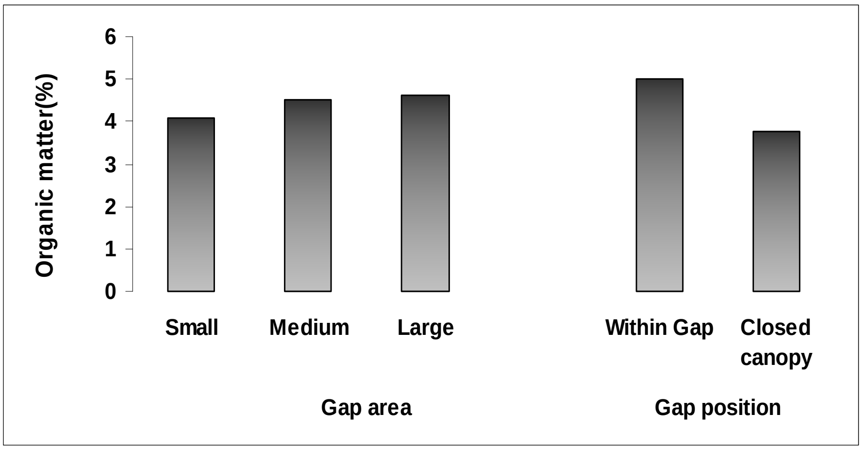

Fig. 9. Mean of soil organic matter in gap different areas and positions

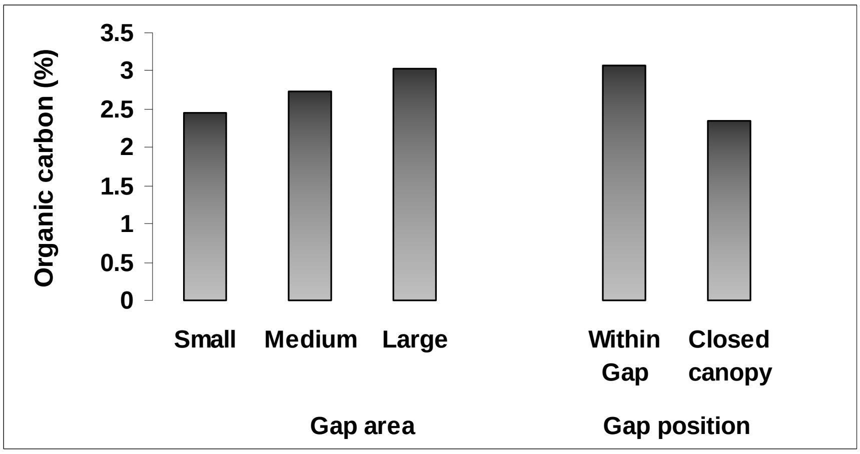

Fig. 10. Mean of soil organic carbon in gap different areas and positions

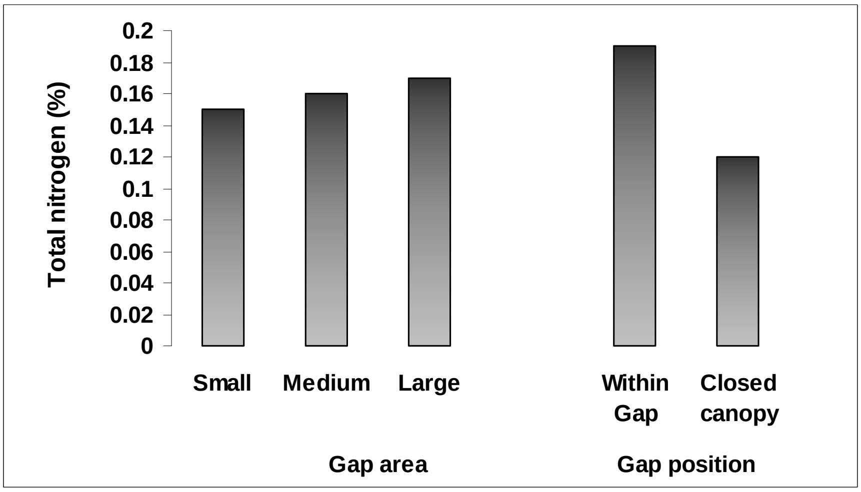

Fig. 11. Mean of soil total nitrogen in gap different areas and positions

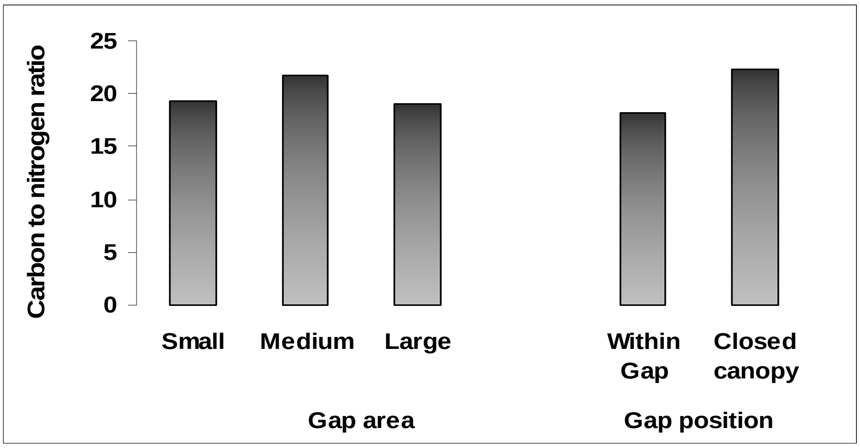

Fig. 12. Mean of soil C/N ratio in gap different areas and positions

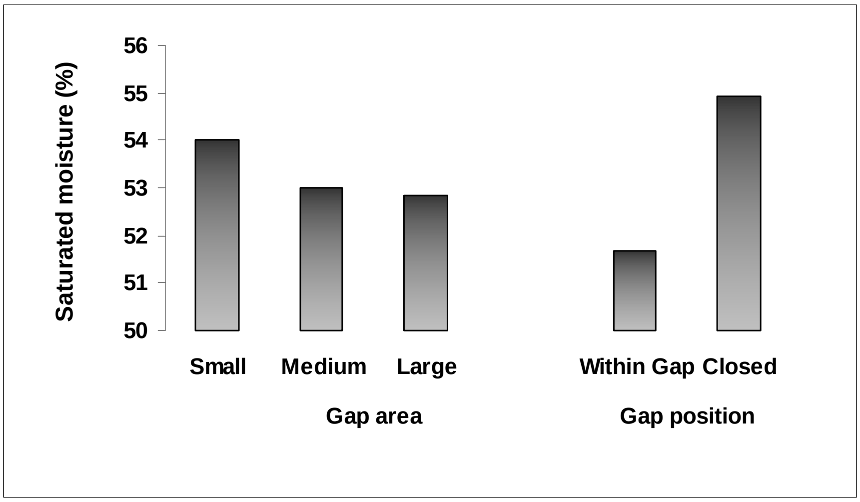

Fig. 13. Mean of soil saturated moisture in gap different areas and positions

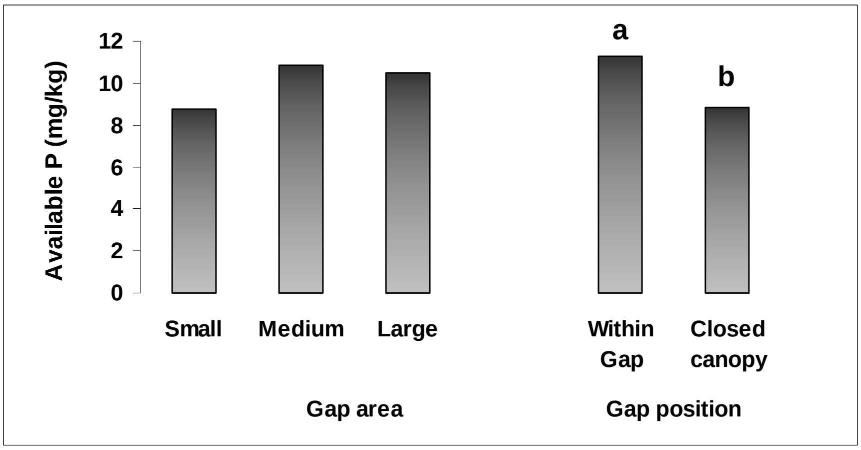

Fig. 14. Mean of soil available P in gap different areas and positions

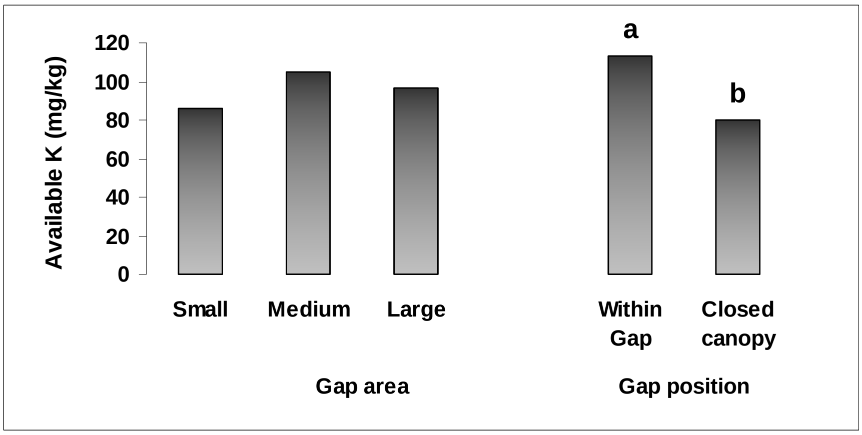

Fig. 15. Mean of soil available K in gap different areas and positions

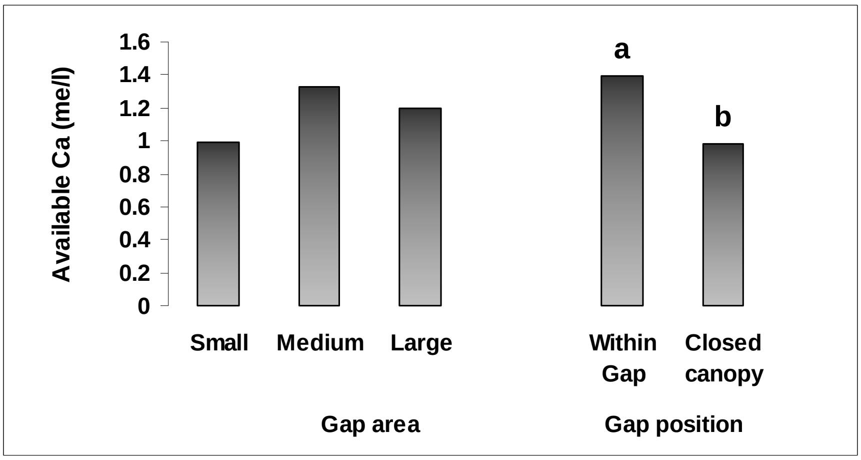

Fig. 16. Mean of soil available Ca in gap different areas and positions

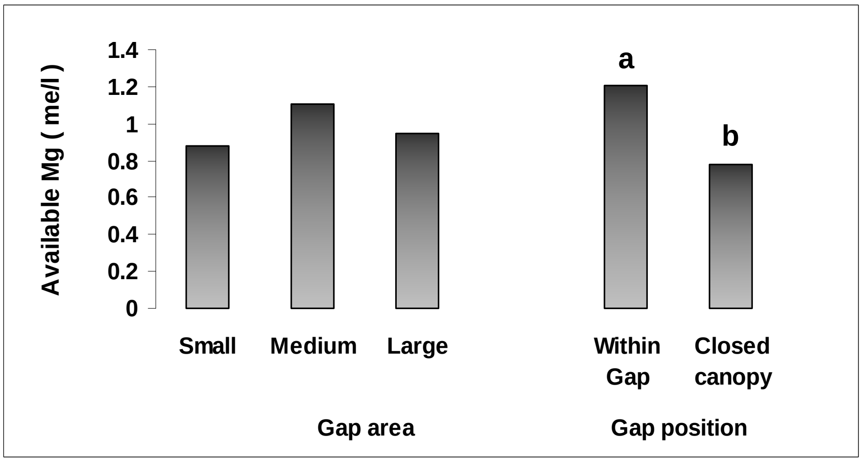

Fig. 17. Mean of soil available Mg in gap different areas and positions

DISCUSSION

Effects of gap on biodiversity

As the results showed diversity and richness indices for herb layer increased with increasing of gap area, whereas evenness indices decreased. Also results indicated that the highest amount of diversity and richness indices were observed in gap center in comparison to gap edge and closed canopy, whereas closed canopy position had the greatest value of evenness indices. In forest ecology, the features of the gaps (area, shape and age) and the landscape (territory) are important because of richness and species combination. The gap area is more important than the age [18]. However; the age has its own important effects which can cause the small gaps to close quicker after a while. In the last decades, numerous studies have been done on the effects of gap size on the understory vegetation [27, 53, 23, 41]. Canopy openings as a result of tree falls create an environment different from the adjacent forest, which influences plant regeneration. In addition, gap processes partly determine forest structure and play an important role to maintain plant species richness [40, 19]. Gap microclimates may enhance seed germination and increase growth rates of herbs and woody species in comparison with rates in the forest understory [27]. However, changes in abiotic and biotic conditions depend to both on gap size and within-gap position [32, 37]. Several authors have stressed that on an undisturbed forest floor spatial patterns may be maintained for many years after gap creation [34, 27, 32]. Understory plants already present in the area (including in the seed - bank) increase in number and size in response to changed environmental conditions, in addition to other species that can invade.

Shrubs and herbs exhibit sensitivity to a variety of forest disturbances [39], including forest management practices [49, 6], and are likely to respond individualistically to the changing environment created by canopy tree removal [56]. However, the species composition in gaps is often very similar to that under a closed canopy, although in several cases certain gap species could be identified [53]. Plant species typically or exclusively occurring in gaps are often described as shade-intolerant and typical for non-forest habitats [27, 2]. Early succession species and mid-succession species had higher density in gaps in comparison to closed canopy whereas shade tolerant species were observed in closed canopy .Gaps have higher total plant species richness in the understory than closed canopy , whereas Higher evenness was observed in closed canopy than in gaps. Also Gap size was positively correlated with the total density of saplings, the density of several species, and species richness [53]. Spatial extent of gap influence on understory species diversity did not follow a simple pattern. In general, edge locations appear to support lower understory plant species diversity than surrounding thinned forest or gap interiors. Gap influence on diversity exhibited both an interior (high diversity) component and an edge (low diversity) component [21]. Furthermore, plant diversity will increased with increasing of opening areas in canopy gaps [54] that are observed in study area, also.

Naaf and Wulf [41] reported that species composition was relatively homogenous in different gaps size but significantly determined by gap size, light availability, with more favorable light conditions, an increasing proportion of generalist species occurred within gaps. The fall of canopy trees results in increased total incident light levels at the ground and in some cases also in increased nutrient and moisture availability [16]. As shown by many studies, light availability increases with gap size [13, 23]. The increasing effect of area on species numbers is known for a long time [4]. Higher species numbers in gaps due to more favorable light conditions were found in most gap studies [2, 53]. Ritter, et al. [46] indicated that Gap size had a significant effect on the cover of tree regeneration .It can be interpreted as the favoring effect of higher resource availability in larger gaps comprising more light, more space and less root competition by canopy trees. Richness, composition and total cover of herbaceous vegetation were different in small versus large gaps .Much of this difference was attributed to the presence of specific relative light intensities and also to the increased amount of available soil moisture in gaps. Species were differently affected by the combined effects of light and soil moisture, as well as by differences in available substrates. All this resulted in species - specific distribution patterns within gaps [23].

Small gaps may have been dominated by competitor species in part because of the lower levels of ground - layer disturbance associated with this gap size [20]. In the absence of high levels of disturbance, ruderal species are unable to take advantage of canopy removal and subsequent reduction in abundance of stress-tolerant species. In small gaps, levels of direct radiation may not have been elevated enough to cause competitive reduction of stress - tolerates except at the very center of the gaps, resulting in the negative gap influence extent observed in smaller gaps [21]. In small gaps, the trees around the gap put remarkable shadow on inner parts of the gaps and marginal effect of such trees exist in central parts of the gaps [24]. If such circumstance continues and the crown closes in following years [22, 31], a large number of species, especially those which shade-intolerant, are not able to grow [27].

Under such conditions, only species which shade tolerant can survive and ecological condition turns to be tough for other species, thus, wood covering richness reduces [2]. Harsh environmental conditions, particularly regarding light condition, in closed canopy and small gaps can cause the reduction or omission of various species [48]; therefore species homogeneity increases and is harmony with the results of present study. However, the more the size of the gap, the more suitable conditions for the growth of various species. Thus, establishment and survival of herbaceous species in canopy gaps of different sizes should be observed more widely [27, 53].

Effects of gap on soil features

Soil pH: The result is indicating that large gaps and within gap position had greater pH than in the other gap size and positions .Meanwhile, significant different was observed between gap positions. Small gaps tended to have lower amounts of soil pH that can be related to presence complexes of sustain organic acids as in gaps with more openings these complexes are leaching from soil upper layers. Thus, gap larger areas tended to have higher pH. Similar status can be considered in different positions of gaps as in gap center leaching of acid complexes more occurred and soil pH is increased. Scharenbroch and Bockheim [52] detected no significant differences in soil pH character for gap different areas.

Organic matter and carbon: The highest values of these characters found in large gaps and within gaps. Density and particle size separations isolate district soil organic matter pools for relating stabilization and turnover of carbon in soil [30, 55].Soil organic matter associated with silt and clay particles are considerably more recalcitrant, with turnover times ranging from 400 to 1000 years [42, 12]. In this research by reason presence of clay higher amounts in soil texture (result is unpublished) the organic matter amounts were more considerable in large gaps. Scharenbroch and Bockheim [52] reported the canopy gaps effects on soil organic matter character was non significant.

Total nitrogen: The most values of total nitrogen found in gap large and within gap positions. Ritter, et al. [46] also found that soil solution nitrate concentrations and nitrate losses were increased as a result of forest gaps. Many researchers [43, 46] observed the non significant effects gap different areas on soil nitrogen character. Scharenbroch and Bockheim [51] claimed that canopy gaps are susceptible to nitrogen leaching less, thus the amounts of this character is less in opening areas soil than in closed canopy. In general, increased organic matter decomposition and nitrogen mineralization and reduced root nitrogen uptake tends to favor leaching of inorganic nitrogen in gaps relative to the undisturbed closed forest [10, 58, 17]. Ritter and Vesterdal [47] claimed that nitrogen concentration in growth season is more in within gaps than to closed canopy. In present study similar results detected pay attention to this research carried out in summer season. But, it is assumed that nitrogen losses will occurred after removal of the forest cover on large areas. Increased nitrogen concentration in the gaps may partly be attributed to a lack of nitrogen uptake by regeneration or ground vegetation in the early years after gap formation, as also found by Knight, et al. [35].

Carbon to nitrogen ratio: The highest value of this character detected in medium gaps and closed canopy position. With considering the greatest amounts nitrogen observed in large gaps thus greater C/N ratio found in small gaps.

Saturated moisture: The maximum values of saturated moisture observed in small gaps and closed canopy. Temporal and small-scale spatial variation in microclimate and soil moisture in and around canopy gaps has often been studied in managed forests [7, 5] or in natural forests with a different climate and species composition to that found in beech-dominated forests of Europe [25, 29, 57, 28]. Previous studies in temperate forests found that on the whole gap scale light quantity increases with opening size, whereas the pattern of soil moisture is less straightforward: it does not always increase in gaps, but it is generally more spatially variable than light [13, 14, 15]. Galhidy, et al. [23] indicated that a maximum of soil moisture was the same in small and large gaps. This indicates that even centers of small gaps (radius <10 m) are beyond the reach of the root system of surrounding trees. Soil moisture and temperature patterns are also affected by local variations in soil depth and stoniness. Ritter, et al. [46] indicated that soil water content in the gap was near field capacity and generally higher than that under the closed canopy during summer.

Available P, K, Ca and Mg: Medium gaps and within gap position had the greatest amounts of base cations. In general, solar radiation will increased with increasing of canopy opening areas that is due to accelerating decomposition of litters **[36]**. But if the opening be very large, decrease in base cations in gaps is likely a result of leaching losses. Scharenbroch and Bockheim [52] reported the leaching is the most important reason for decrease of base cations in within gaps. Their results suggest an increased nutrient leaching potential as a result of relatively large (300 - 2000 m^2) gaps in old growth northern hardwood - hemlock forests. The results of current research is indicating that base cations leaching potential increased with expanding of canopy opening areas from medium to large; thus soil is poor of nutrient elements in large canopy gaps. This important should be considered in forest management and trees marking for utilization to prevent of gaps formation with large opening areas.

CONCLUSION

Gaps promote recruitment and growth of understory vegetation that may eventually become dominant trees by altering the availability of resources, including light, soil moisture, and nutrients. The availability of these resources, and consequently species survival and vegetative growth, is a function of gap characteristics, including area, orientation, and shape. Findings show that using various but small and medium gaps will provide better condition for the forest stands. Furthermore, the understanding of natural disturbance and stand development processes is necessary for their incorporating into the practice of any type of close-to-nature silviculture.

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