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ORIGINAL ARTICLE

Determination of the best canopy gap area on the basis of soil characteristics using the Analytical Hierarchy Process (AHP)

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Abstract

The assessment of canopy gap areas on the basis of soil characteristics in forest ecosystems could be one of benefit points for management of forests. This research was conducted in 20 ha areas of Experimental Forest Station of Tarbiat Modares University that is located in a temperate forest of Mazandaran province in the north of Iran. Twenty one canopy gaps with different areas were found in studied areas and classified as small (85.12 m^2), medium (325.21 m^2), large (512.11 m^2) and very large (723.85 m^2) gaps. These areas classes of canopy gaps were assessed with respect to nine criteria (soil pH, carbon to nitrogen ratio, cation exchange capacity, phosphorus, potassium, calcium, nitrogen mineralization, microbial respiration and earthworm's biomass). Soil samples (0–45 cm depth from the gap center and edge positions) were measured in the laboratory. The Analytical Hierarchy Process (AHP) was used for assessment of canopy gap areas. This method is widely used the Multiple Criteria Decision Support (MCDS) method and perhaps the most popular in many fields, including natural resource management, especially in forest sciences. Results of AHP indicate that the maximum of local priority belongs to small areas of canopy gaps when considering all soil characteristics. However, medium, large and very large canopy gap areas have priorities, respectively. The calculated overall priority showed that with respect to considered criterias, small and medium gap areas have higher, more ideal condition in comparison to large and very large areas. AHP results emphasise that considering soil characteristics canopy gap areas should be less than 400 m^2 in Hyrcanian forests of Iran. Also, AHP can be introduced as an effective instrument in decision-making processes for investment planning and prioritization in compliance with environmental regulations.

Key words

canopy gap, soil characteristics, Hyrcanian forest, beech, Iran

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INTRODUCTION

Forestry and forest planning are influenced by changes within internal and external operational environments. In forest planning, most of the concern has been traditionally focused on the internal environment, assuming the external environment to be stable. Recently, applications and methods dealing with changes arising from external environment have been presented and applied in forest planning (Kurttila et al. 2000). The Analytic Hierarchy Process (AHP), since its invention, has been a tool for decision makers and researchers, being one of the most widely used multiple criteria decision-making tools (Vacik and Lexer 2001; Kooch and Najafi 2010). Many outstanding works have been published based on AHP: they include applications of AHP in different fields such as planning, selecting the best alternative, allocating resource, resolving conflict, optimizing,and so on as well as numerical extensions of AHP (Reynolds 2001; Vacik and Lexer 2001; Kooch and Najafi 2010). The analytic hierarchy process, originally developed by Saaty (1977, 1980), is the widely used Multiple Criteria Decision Support (MCDS) method and perhaps the most popular in many fields, including natural resource management. Mendoza and Sprouse (1989), Murray and Von Gadow (1991), and Kangas (1992), among others, used AHP in forestry applications, and the number of applications is continuously increasing (Rauscher et al. 2000; Reynolds 2001; Vacik and Lexer 2001; Kooch and Najafi 2010). AHP has also gained interest among forestry practitioners. For a review of AHP forestry applications, readers are referred to Kangas (1999) and Schmoldt et al. (2001) AHP has several advantages from the viewpoints of multiple-use and participatory planning. Using AHP, objective information, expert knowledge and subjective preferences can be considered together. Also, qualitative criteria can be included in the evaluation of alternative plans. AHP is based on the theory of ratio-scale estimation (Saaty 1977), and by using it, pairwise comparisons of qualitatively expressed measures can be transferred into the ratio scale. In contrast, other related methods usually require criteria values to be quantitative and to be measured in the ratio or interval scale.

Disturbances caused by canopy gaps have received much attention in the last decades and they are regarded as important factors in forest dynamics. Canopy openings as a result of tree falls create the environment different from the adjacent forest which influences plant regeneration. In addition, gap processes partly determine the forest structure and play an important role in maintaining plant species richness (Muscolo et al. 2010). Thus, the creation of gaps in forests may lead to changes both in species dynamics and ecological processes, by increasing environmental heterogeneity and altering abundances and distribution of abiotic and biotic resources. This has been recognized to have a less severe impact on forest ecosystems than traditional silvicultural treatments, such as clearcutting, followed by regeneration (Muscolo et al. 2007a). For studies on forest natural regeneration, measuring gap size is an important issue (Auno´s et al. 2003) to calculate the forest turnover rate related to regeneration patterns, because the gap area influences availability of resources such as light, water and nutrients which are critical for seedling establishment and growth. Thus, natural variation within and among gaps of different sizes results in highly variable responses in key ecological processes. Most studies on gaps have addressed vegetation dynamics, regeneration through seedling establishment and effect of microclimatic variables on the regeneration. In general, studies have concentrated on above-ground processes (Muscolo et al. 2010). Relatively few studies have addressed below-ground effects of gaps such as soil-related aspects and their effects on the regeneration processes after disturbance (Arunachalam and Arunachalam 2000; Muscolo et al. 2007a, 2007b; Kooch et al. 2010). Purposely, this study was designed to test the hypothesis that the gap size is an important factor in controlling soil chemical, biochemical and biological activities.

In Iran Hyrcanian forests, formation of gaps by windthrow is a characteristsic natural disturbance event. The 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 the gap size and position (Holeksa 2003; Kwit and Platt 2003). Consequently, it is not easy to predict how soil properties react to gap formation. Disturbances caused by canopy gaps have received much attention in the last decades and they are regarded as important factors in forest dynamics. Canopy openings as a result of tree falls create the 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. Thus, the creation of gaps in forests is an opportunity for the system to change in both: species dynamics and ecological processes (Kooch et al. 2010). The present study deals with the development of AHP analysis connected to the decision situation of whether or not to adopt a certification system for management of forest ecosystems. Its rationale and justification are based on the importance of versatile environmental analysis in strategy formulation and strategic decision-making processes and in suggesting the potential usability of the common strategic planning tools in forest planning. The objective of this research is to apply utilizing pairwise comparisons of the AHP technique in determination of the best canopy gap area on the basis of soil characteristics in Hyrcanian forests of Iran. The survey has been the first of this type in these forests.

MATERIAL AND METHODS

Description of the study site: This research was conducted in Tarbiat Modares University Experimental Forest Station located in a temperate forest of Mazandaran province in the north of Iran, between 36° 31’ 56” N and 36° 32’ 11” N latitudes and 51° 47’ 49” E and 51° 47’ 56” E longitudes. The maximum elevation is 1700 m a.s.l. and the minimum is 100 m a.s.l.. Minimum temperature in December equals 6.6° C and the highest temperature of 25° C is recorded in June. Mean annual precipitation of the study area ranged from 280.4 to 37.4 mm at the Noushahr city metrological station, which is located 10 km away from the study area. For performing this research, 20 ha area of reserve parcel (relatively undisturbed), covered by *Fagus orientalis* and *Carpinus betulus* dominant stands was considered. The study area had inclination 60–70% with northeast exposure at 546–648 m a.s.l. Its bedrock is limestone-dolomite with silty-clay-loam soil texture. Presence of logged and bare roots of trees indicated rooting restrictions and soil heavy texture. The current study was based on several windthrow events in the experimental forest station in during 2005 to 2006 (Kooch et al. 2010).

Gap selection: For this study, 20 ha areas of Tarbiat Modares University Experimental Forest Station were considered. Geoghraphical position and all of canopy gaps were recorded by the Geoghraphical Position System (GPS). The gaps required a minimum canopy opening of 30 m^2 and trees growing in the gap to be less than two thirds the height of the closed adjacent forest (Runkle 1992). Canopy gaps areas were measured in the field according to Runkle (1992). 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. Twenty one canopy gaps with different areas were detected in the study site (Fig. 1). The gaps were classified in four classes: four gaps in 30–200 m^2 area class (small gap with area mean of 85.12 m^2), five gaps in 200–400 m^2 area class (medium class with area mean of 325.21 m^2), eight gaps in 400–600 m^2 area class (large class with area mean of 512.11 m^2) and four gaps in more than 600 m^2 area class (very large class with area mean 723.85 m^2).

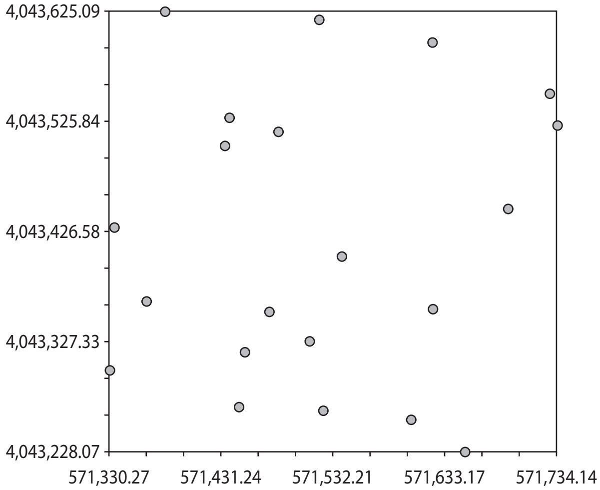

Fig. 1. Distribution of canopy gaps in the study area

Soil sampling and laboratory analyses: For this purpose, two positions were distinguished including the gap center and edge. Soil samples were taken at 0–45 cm depth from all positions using core soil sampler with 81 cm^2 cross section (Kooch et al. 2010). Roots, shoots and pebbles in each sample were separated by hand and discarded. The air-dried soil samples were sieved (aggragates were crushed to pass through a 2 mm sieve) to remove roots prior to chemical analysis. Soil pH was determined using Orion Ionalyzer Model 901 pH-meter in a 1:2.5, soil:water solution. Soil organic carbon was determined using the Walkey-Black technique (Allison 1975). The total nitrogen was measured using the semi Micro-Kjeldhal technique (Bremner and Mulvaney 1982). The available P was determined with spectrophotometer using the Olsen method (Homer and Pratt 1961). The available K and Ca (by ammonium acetate extraction at pH 9) were determined with the Atomic absorption spectrophotometer (AAS) and Cation Exchange Capacity (CEC) with flame photometer (Bower et al. 1952). Soil microbial respiration was determined by measuring CO_2 evolved in 3-day incubation experiment at 25° C, in which 50 g of each soil sample (remoistened to 55% its water holding capacity) were placed in a glass jar. A glass vial holding 10 ml of 0.5 M NaOH was placed in a glass jar to trap evolved CO_2. The excess alkali, after precipitating the CO_3^{2-} with 0.5 M $BaCl_2$ solution was titrated with standard 0.5 M dequate HCl to a phenolphthalein end point (Alef 1995).

Kinetic of nitrogen mineralization was measured using a laboratory incubation procedure under controlled conditions fpr 100 g of each soil sample. Soil samples were re-moistured to 55% its water holding capacity. The containers were closed tightly and kept in the dark, temperature controlled chamber at 25° C. The samples were re-aerated weekly for adequate oxygen supply. Nitrogen mineralization was estimated from the increase KCl extractable inorganic N after incubating soil samples for 56 days. Initial inorganic N (NO_3-N and NH_4-N) was analyzed before incubation using the steam distillation method (Bremner 1965) after extraction with 1 M KCl for 2 h (soil: extractant ratio of 1:5). Final inorganic N (NO_3-N and NH_4-N) concentrations were measured at the end of incubation on day 56. Net N-mineralization was calculated by subtracting initial mineral N from final mineral N for each sample (Robertson et al. 1999). The earthworms were collected simultaneously with the soil sampling by hand sorting, washed in water and weighed with miligram precision. Biomass was defined as the weight of the worms after drying for 48 hours on filter paper at oven (60° C) (Edwards and Bohlen 1996).

Hierarchical framework: Hierarchical decision model has a goal, criteria that are evaluated for their importance to the goal, and alternatives that are evaluated for how preferred they are with respect to each criterion. The goal, criteria and alternatives are all elements in the decision problem, or nodes in the model. An abstract view of such a hierarchy is shown in Fig. 2. The fisrt level of this diagram is showing the goal (selection of the best canopy gap area), soil characteristics are presented at the second level as criteria and alternatives (different areas of canopy gaps) are showed at the last level. The lines connecting the goal to each criterion mean that the criteria must be pairwise compared for their importance with respect to the goal. Similarly, the lines connecting each criterion to the alternatives mean that the alternatives are pairwise compared for that criterion.

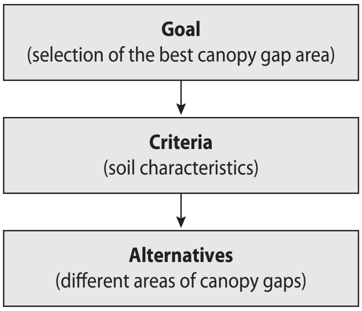

Fig. 2. Schematic diagram of the AHP process

After determinations of hierechical framework on the basis of goal, criteria and alternatives, they are compared with each other and their importance values can be found. AHP application is based on three rules as follows (a) determination of rhe structure and framework of a problem; (b) priorities determination by paired comparisons and (c) determination of reasonable consistency for measurements. Following the design of the schematic diagram for AHP, the next step is elements assessment with paired matrix. Then, for calculation of criteria and alternatives importance values, geometric mean of paired matrix cells is calculated following formula:

$$a_{12} = (a_{12}1 \times a_{12}2 \times \ldots \times a_{12}N)^{\frac{1}{N}}$$

In the next step, obtained results are normalized and the weight of criteria and alternatives are finally calculated. The inconsistency measure is useful for identifying possible errors in judgments as well as actual inconsistencies in the judgments themselves. In general, the inconsistency ratio should be less than 0.1 or so to be considered as reasonably consistent (Kooch and Najafi 2010). In this research, the Expert Choice software was used for determination of the best canopy gap areas on the basis of soil characteristics using AHP.

RESULTS

Different areas of canopy gaps were assessed with respect to nine criteria of soil characteristics including pH, carbon to nitrogen ratio, cation exchange capacity, phosphorus, potassium, calcium, nitrogen mineralization, microbial respiration and earthworm's biomass. Inconsistency ratio values for every soil characteristics in AHP are shown in Tab. 1.

Tab. 1. Definition and inconsistency ratio values for soil characteristics

Abbreviation	Definition	Inconsistency ratio
Goal	Determination of the best canopy gap area	–
Small	30–200 m^2	–
Medium	200–400 m^2	–
Large	400–600 m^2	–
Very large	> 600 m^2	–
pH	Acidity	0.04
C/N	Carbon to nitrogen ratio	0.04
CEC	Cation exchange capacity	0.04
P	Available P	0.05
K	Available K	0.06
Ca	Available Ca	0.05
N_{min}	Nitrogen mineralization	0.04
M_{res}	Microbial respiration	0.04
Bio earthworm	Earthworm biomass	0.04

According to this result, the inconsistency ratios were less than 0.1 for all soil characteristics. Results are indicating that the maximum of local priority is belonging to small areas of canopy gaps while considering all soil characteristics. The medium, large and very large canopy gap areas had next priorities, respectively (Fig. 3 to 11). Mean of the local priority for canopy gap areas on the basis of soil characters showed that small canopy gaps (0.388) has more appropriate conditions in comparison to medium (0.280), large (0.196) and very large (0.135) canopy gaps regarding the investigated characteristics (Fig. 12). Thus, determination of the criteria role in assessment of canopy gap areas and selection of the best areas as well as calculation of criteria weight were also carried out. For this purpose,

Fig. 3. Local priority of canopy gap areas based on soil pH

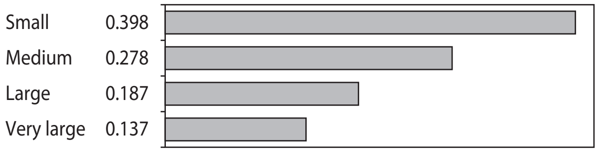

Fig. 4. Local priority of canopy gap areas based on soil carbon to nitrogen ratio

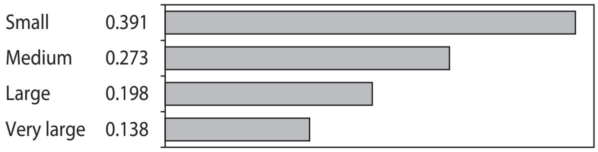

Fig. 5. Local priority of canopy gap areas based on soil cation exchange capacity

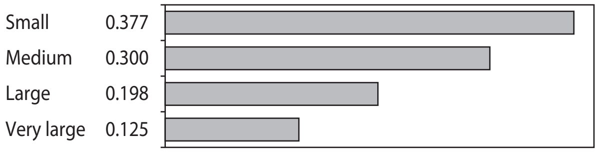

Fig. 6. Local priority of canopy gap areas based on soil phosphorus

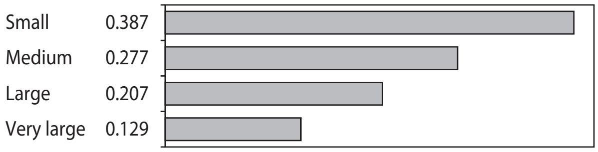

Fig. 7. Local priority of canopy gap areas based on soil potassium

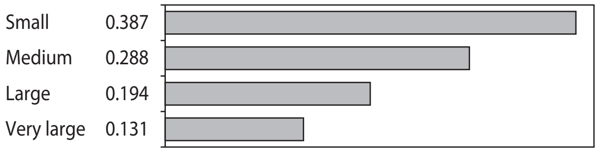

Fig. 8. Local priority of canopy gap areas based on soil calcium

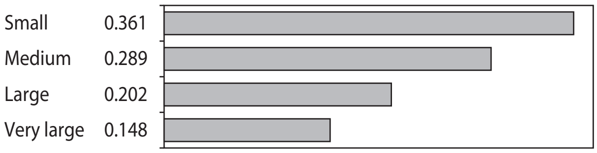

Fig. 9. Local priority of canopy gap areas based on soil nitrogen mineralization

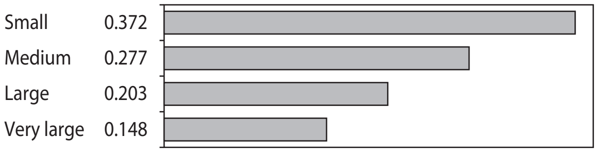

Fig. 10. Local priority of canopy gap areas based on soil microbial respiration

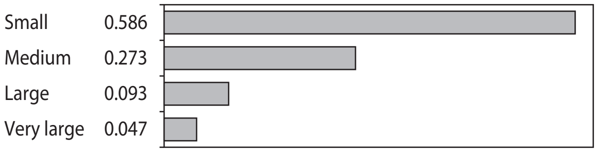

Fig. 11. Local priority of canopy gap areas based on soil earthworm biomass

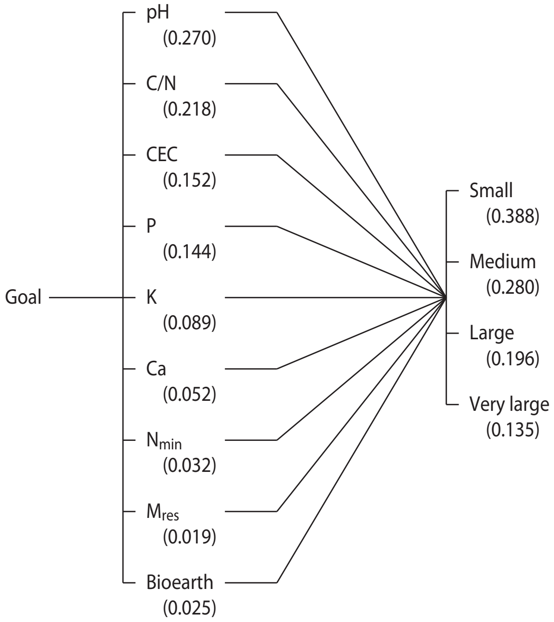

Fig. 12. Mean of local priority for canopy gap areas based on soil characteristics

the matrixes of paired comparisons were prepared and the criteria weights were calculated by arithmetic mean (Fig. 13). Overall priorities were obtained for every alternative, paying attention to calculated local priorities. In general, it was concluded that canopy gaps with the areas less than 400 m^2 have more ideal conditions with regard to soil characteristics (Tab. 2). Sensivity analysis is according to reported results also (Fig. 14).

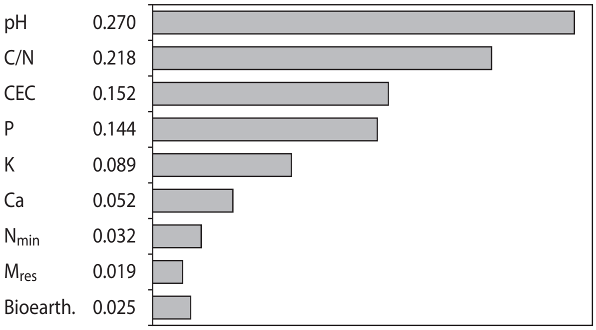

Fig. 13. Criteria priority based on arithmetic mean

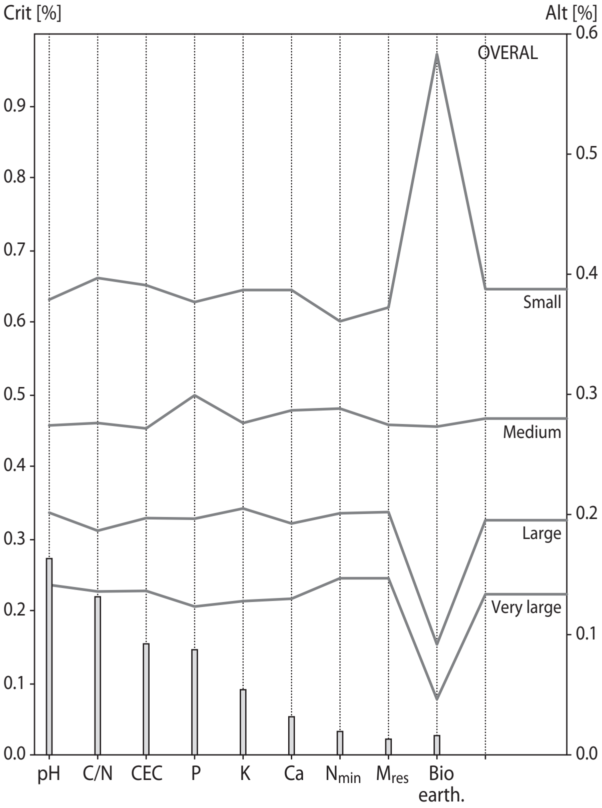

Fig. 14. Sensivity analysis based on performance alternative

Tab. 2. Overall priority of canopy gap areas based on soil characteristics

Canopy gap area	Overall priority	Assessment
Small	0.388	1
Medium	0.280	2
Large	0.196	3
Very large	0.135	4

DISCUSSION

Over recent decades there has been a growing awareness of the necessity to monitor and evaluate the ecological impact of disturbance to forest ecosystems in order to implement adequate prevention policies (Muscolo et al. 2010). AHP is the method for breaking down a complex and unstructured situation into its component parts, and then arranging these parts (or variables) into a hierarchical order. This method is based on assigning numerical values for subjective judgements of the relative importance of each variable, then synthesizing the judgements to determine which variables have the highest priority (Saaty 1994; Kooch and Najafi 2010). This study attempts to offer a method for ecological assessment of canopy gap areas on the basis of soil characteristics within the framework of the analytical hierarchy process. The canopy gaps disturbances play an important role in dynamics of different kinds of forests (De Lima and De Moura 2006). The value of regeneration density of different kinds of trees has an intense relationship with the conditions of understory environment, which this condition is variable between gaps and closed forest and also between gaps bearing different properties related to the size of gaps (Gray and Spies 1996). Because of more suitable availability of resources, the internal of covering of gaps is very different from the surrounding dense forest. As a result, this can increase the regeneration, growth and also variety and richness of vegetation in the gaps (Rose and Kendle 2000). Thus, the scientific studies for determining the influence of gaps on overstory tree responses (Payette et al. 1990), regeneration responses (York et al. 2004), modeling of tree growth and regeneration (Menard et al. 2002) and soil characteristics (Kooch et al. 2010) have increased knowledge on future composition of the forest stand which can be widely used in regulating silviculture and forestry operations. The influence of gaps on the stand areas process is not in a linear relationship with the gap size (Fahey and Puettmann 2008). It seems that using small gaps will be considered as a better managing tool in controlling the value of understorey light and the following interaction between regeneration and the variety of vegetation. Many findings show that using various but small and medium gaps will provide better conditions for forest stands (Kooch et al. 2010).

Forest gaps irregularly affect the availability degree of materials and micro-region resources, as well as soil and the site. The existence of the above mentioned factors is changeable in time and place. The purpose of the present study was recognizing the appropriate way in forest management that prevents wasting of materials and sources in forest ecosystems. So, it is clear that using the gaps in small and medium scales is an appropriate guideline to maintain the balance in the cycle of food materials and other considered soil characteristics, especially in temperate ecosystems. In conclusion, within the range of gap sizes included in this study, the results have shown that the gap size is effective for soil characteristics. However, on the basis of the results, we believe that the creation of small and medium gaps (less than 400 m^2 area) may be important from the ecosystem perspective and represent appropriate management procedures for adequate conservation of ecological functions, capable to preserve soil properties and favour beech natural regeneration. This result is according to Kooch et al. (2010) findings. Several studies (Aman Zadeh et al. 2007; Goleij et al. 2008; Zolfaghari 2009) claimed that canopy gaps with less than 400 m^2 areas are the best considering regeneration density in beech forests of Iran.

In general, solar radiation will increase with increasing canopy opening areas that is due to accelarating decomposition of litter. But if the opening is very large, a decrease of base cations in gaps is likely as a result of leaching losses. Scharenbroch and Bockheim (2007) reported that leaching was the most important reason for a decrease of base cations 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 forests. The results of current research indicate that base cations leaching potential increased with expanding of canopy opening areas from small to large.Thus soil is poor of nutrient elements in large canopy gaps. This important factor should be considered in forest management and marking of trees for utilization to prevent gaps formation with large opening areas. Canopies tend to enhance nutrient concentrations of incident precipitation (Lindberg and Ownes 1993). There is a strong negative relation in nutrient elements with the amounts of precipitation (Kooch et al. 2010). Total nutrient deposition, on the other hand, is positively related to precipitation amounts. Therefore, leaching potential of soil nutrients will increase with expanding canopy gaps (Kooch et al. 2010). Removal of canopy cover is generally known to increase water drainage and stream flow. This is reported from thinnings, clear-fellings, and gap formation (Lesch and Scott 1997) as well as is supported by the present study. In a study in a heterogeneous forest with mixed tree species, Zirlewagen and Von Wilpert (2001) there was emphasised the role of small-scale structural variation. The authors found crown interception to be a main factor reducing water fluxes, while crown gaps increased water fluxes. These effects were enhanced by variable root densities, and thus water uptake. Influence of the forest structure (canopy, roots), tree sizes, species composition, soil properties and soil solution chemistry was reported in other studies (Beier 1998), and hyrcanian forests of Iran are characterized by high variability of most of these parameters (Kooch et al. 2010).

In summary, ecological evaluation of forest canopy gaps could be carried out with the use of different methods, each having their advantages and drawbacks. Modern software greatly simplifies the process (Kooch and Najafi 2010). The key factor to ensure the reliability of calculations is the availability and quantity of relevant data in the required format. However, if properly performed, this evaluation could serve as an effective instrument in decision making processes for investment planning and prioritization in compliance with environmental regulations. In addition, the authors believe that the sustainability of forest ecosystems can be enhanced by selection of the best areas of canopy gaps with consideration of soil characteristics, and especially nutrient elements. These subjects are due to the implementation of a more serious management approach finally. This study was conducted to provide forest managers and decision makers with useful and effective means to improve harvesting operations, minimize harvesting damage and ultimately enhance forest productivity in harvesting operations with selection of the best areas for canopy gaps. Since this study was not replicated across a range of site types, we cannot generalize our conclusion.We hope that these results will be tested in a replicated study to determine whether they are general. We believe that such a study in different natural forests could be conducted using the set of measurements and the analytical tools we presented.

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