ASIAN JOURNAL OF FORESTRY
Volume 7, Number 2, December 2023 E-ISSN: 2580-2844
Pages: 107-114 DOI: 10.13057/asianjfor/r070205

Comparison of plant diversity between managed and unmanaged forests in Haftkhal, Mazandaran Province, North of Iran

SHIRZAD MOHAMMADNEZHAD KIASARI[1,♥], KHOSRO SAGHEB-TALEBI[2], RAMIN RAHMANI[3], HASSAN GHELICHNIA[1]

[1]Agriculture and Natural Resources Research and Education Center of Mazandaran, Agricultural Research Education and Extension Organization. Mazandaran, Iran. Tel.: +98-9112550427, Fax.: +98-1133136589, ♥email: ms.mohammadnezhadk@gmail.com

[2]Research Institute of Forests and Rangelands, Agricultural Research Education and Extension Organization. Tehran, Iran

[3]Department of Silviculture and Forest Ecology, Faculty of Forest Sciences, Gorgan University of Agricultural Sciences and Natural Resources. Gorgan, Iran

Manuscript received: 6 January 2023. Revision accepted: 28 May 2023.

Abstract. *Kiasari MSh, Sagheb-Talebi Kh, Rahmani R, Ghelichnia H. 2023. Comparison of plant diversity between managed and unmanaged forests in Haftkhal, Mazandaran Province, North of Iran. Asian J For 7: 107-114.* The relationship of plant diversity with silvicultural practices has not been fully understood for the oriental beech forests (*Fagus orientalis* Lipsky), which is a widespread forest tree in the Hyrcanian Region, Iran. The implementation of appropriate forestry practices in the oriental beech forests is therefore crucial in terms of sustainable forest management. Hence, assessing the impacts of silvicultural practices on plant diversity is essential with the regard to sustainable forest management. This study aimed to compare plant species diversity between two managed and unmanaged forest stands in Mazandaran Province, Iran. Forest inventory in an area of 131 ha was performed using in a systematic random sampling with a 150 × 200 m grid size. In addition, the area of sampling was 100 m^2 (10 × 10 m). Twenty and thirty sampling plots were established in managed (compartment No. 8) and unmanaged (compartment No. 36) forests, respectively. Shannon-Wiener and Simpson Indices were used to calculate plant species diversity, while Margalef and Sheldon indices were used to determine species richness and evenness, respectively. The results revealed that 50 and 56 plant species were found in managed and unmanaged forests, respectively. Rosaceae, Asteraceae, and Fabaceae were the main families in these studied areas. This study showed that the diversity and richness of plants in the managed forest slightly increased compared to the unmanaged forest. On the other hand, the evenness of plants in the managed forest slightly decreased compared to the unmanaged forest. Changes in plant diversity indices between managed and unmanaged forests were not statistically significant. This research showed that forest management of oriental beech forests using the single-tree selection cutting has not reduced or weakened the diversity of plant species in the managed forest compared to the unmanaged forest.

Keywords: Biodiversity indices, evenness, Hyrcanian forests, richness, single-tree selection cutting

INTRODUCTION

A decrease in the diversity of plant species reduces forest ecosystem services. Therefore, plant species diversity is one of the most important variables in evaluating the management of forest areas (Baran et al. 2018; Miller et al. 2019). The amount of plant species diversity in the forest is influenced by the location of the forest areas in terms of elevation, aspect, slope, rainfall, average temperature and fertility (Mahmodi et al. 2019; Muys et al. 2022; Tynsong et al. 2022), the type of vegetation (Lelli et al. 2019), the evolutionary stages of natural stands (Mohammadnezhad-Kiasari et al. 2018), the type of management (Kazemi et al. 2015; Wulandari et al. 2018), the history of forest exploitation (Nasiri et al. 2022) and the influence of canopy gaps size (Hamrang et al. 2014). Numerous studies have shown that the protection of forest areas increases the biodiversity of plant species compared to abandoned forests (Miller et al. 2019; Muys et al. 2022; Opuni-Frimpong et al. 2021; Rezaipoor et al. 2022). Furthermore, according to some studies, the partial and scattered exploitation of forest areas has caused an increase in plant species diversity compared to unmanaged forests (Hosseinpour et al. 2019; Amini et al. 2021). The implementation of forestry plans in managed forests affects the plant species diversity due to the protection of forest areas (Miller et al. 2019; Rezaipoor et al. 2022), forestation activities (Pourbabaei et al. 2012), the implementation of silvicultural practices, the stand structure changes (Sefidi et al. 2022), the creation of man-made canopy gaps (Amini et al. 2021; Mirzazadeh et al. 2022), road construction and the removal of wood from the forest (Mohammadnezhad-Kiasari et al. 2020).

Hyrcanian forests in Iran are approximately 800 km long and 110 km wide with a total area of 1.85 million ha, or equivalent to 15% of the total Iranian forests and 1.1% of the country area (Sagheb-Talebi 2017). These forests in northern Iran have important tree and shrub elements of Euro-Siberian; among them, oriental beech (*Fagus orientalis* Lipsky) is one of the most important industrial species and widely covers from the Western to the Eastern Hyrcanian region (Espahbodi et al. 2021; Nasiri et al. 2022). Oriental beech is native to Eurasia, from Eastern Europe to Western Asia, and the implementation of appropriate management in beech forests is highly important due to economic and ecological values (Sagheb-Talebi et al. 2014; Francesco et al. 2023).

Over the past two decades, many areas of productive forests in the north of Iran have been managed using the uneven-aged mixed forest method with the single-tree selection cutting (Alipour and Mohammadnezhad-Kiasari 2017). Initially, many areas of oriental beech forests in the north of Iran have been managed using the even-aged forest method with the shelterwood cutting system. The results of numerous researches on the effect of shelterwood cutting system on stand structure and regeneration abundance have confirmed that instead of shelterwood cutting system, other silvicultural practices such as the single-tree selection cutting should be applied for the mountainous beech stands of Hyrcanian forests. The selection silvicultural system is a system of tree harvesting in which one (tree-selection) or a few (group-selection) numbers of trees are being cut at each intervention (Pourmajidian et al. 2010; Sagheb-Talebi et al. 2014; Habashi and Waez-Mousavi 2018; Nasiri et al. 2022). In the context of this study, forest management is referred to the single-tree selection cutting.

There have been previous studies that used the diversity of plant species to evaluate forestry plans with the single-tree selection cutting in the lower and middle altitude areas in the north of the country (e.g., Pourbabaei et al. 2012; Hosseinpour et al. 2019; Amini et al. 2021). Nonetheless, no similar study has been conducted in Hyrcanian forests at high elevation. Therefore, this study is the first to evaluate forestry plans with the single-tree selection cutting in the high altitude areas of Mazandaran Province. This study was conducted to analyze the diversity of woody species (trees and shrubs), herbaceous species, and natural regeneration, as well as all plant species between the managed and unmanaged (control) forests. In this research it is assumed that the management of forest using the single-tree selection cutting did not have a significant negative effect on the diversity of plant species. The results of this study can be potentially useful for all foresters and ecologists working in other Fagus-dominated forests worldwide, particularly those dominated by *Fagus sylvatica* L. in Europe, which seem to be highly similar to the oriental beech forests in the north of Iran.

MATERIALS AND METHODS

Study area

This study was performed in the northern forests of Iran known as the Hyrcanian forests (Neka City, Mazandaran Province, Iran) (Figure 1). The management of forests in the north of the country takes place in the form of a ten-year forestry plan and is regulated at the extent of 1000 to 2000 ha. The annual implementation of the forestry plan is also carried out at smaller extent of 50 to 70 ha, which is called compartment. Each compartment is a management unit. We used compartment No. 8 to represent managed forest using the single-tree selection cutting and had been applied two stages of harvest, i.e., 2688 m^3 of wood were harvested for the first stage (2004) and 1266 m^3 for the second stage (2014). The unmanaged forest was represented by compartment No. 36, which was a protected forest and never been harvested. To be comparable, these managed and unmanaged forests had similar edaphic conditions and the least economic and social problems or issues such as the presence of mines and landfill sites (Forest and Rangelands Organization of Iran 2011).

The total studied forest had an extent of 131 ha, and it was located between 53° 31′ 55″ to 53° 33′ 18″ E and 36° 20′ 41″ to 36° 21′ 37″ N. Elevation ranges between 1480 and 1610 m asl. The bedrock is limestone, dolomitic limestone, and marl limestone, and the pH is approximately 7.7-8.2. The texture of the soil is silt loam at the medium level and clay at the bottom depth. The soil depth is about 80 to 85 cm, and the root penetration depth is 65 to 70 cm. Furthermore, the mean annual precipitation is 618.8 mm, and the mean annual temperature is 14.7°C. The climate is moderate semi-humid according to the Emberger climate classification (Forest and Rangelands Organization of Iran 2011).

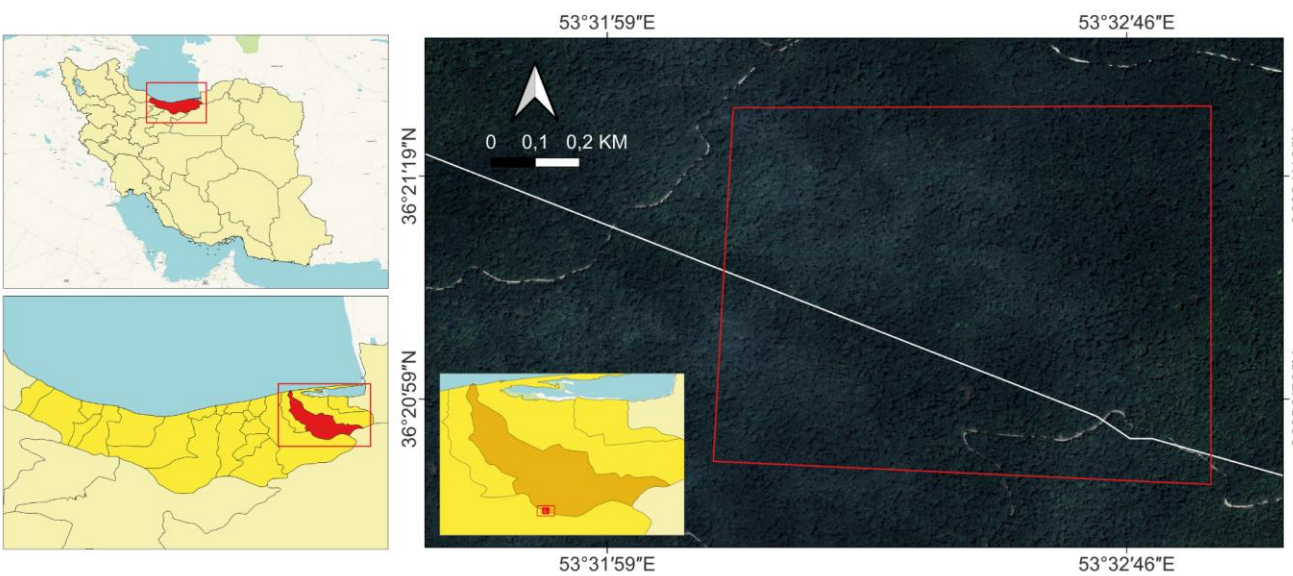

Figure 1. Location of study areas in the Neka forests, Mazandaran Province, Iran

After field inspection and based on the forestry plan information, two adjacent compartments were selected that were similar in terms of soil type, plant community, and site quality. The forests of the studied areas included broad-leaved trees of different ages, and in terms of composition, they included pure beech with a mixture of other hardwood species. The average number of trees per ha were 322.22 and 297.65 trees, the average basal areas per ha were 26.25 m^2 and 22.37 m^2, the average diameter of trees were 34.69 cm and 32.19 cm and the average height of trees were 24.89 m and 24.58 m in unmanaged and managed forests respectively. Also, the average rates for total regeneration abundance were accounted for 109.52 and 129 tree per 100 m^2 in unmanaged and managed forests, respectively. Significant differences were not observed for these quantitative parameters between the unmanaged and managed forests (Mohammadnezhad-Kiasari et al. 2020).

Field sampling

The sampling of canopy coverage used systematic random method with the sampling network size was 150 × 200 m. The starting point was randomly selected, and the sampling network was systematically located on the map (Figure 1). The forest inventory was conducted on 131 hectares, which included 20 and 30 sample plots in the managed and unmanaged forests, respectively (Mohammadnezhad-Kiasari et al. 2020; Mirzazadeh et al. 2022). The inventory operations of this research was done in the middle of the summer. The average canopy cover is the most appropriate variable in the summer season to determine the diversity of plant species (Mohammadnezhad-Kiasari et al. 2018). The area of square plots was obtained by the minimal area method (Pourrahmati et al. 2018; Mahmodi et al. 2019). In the center of each plot, the canopy coverage of all plant species was estimated using the Van der Maarel criterion in 100 m^2 (10 × 10 m). The collected plant samples were identified using Colored Flora of Iran (Ghahreman 1990-1999). In this research, apart from calculating the species diversity of plants, the diversity of the variables of herbaceous species, natural regeneration, and woody species (trees and shrubs) were measured as well. In addition, given that the minimum area was different in each of the vegetation layers, the highest minimum area obtained for the variable of all plant species (100 m^2) was used for the other variables (Pourbabaei et al. 2012).

Data analysis

In this research, Shannon-Wiener (H'), Simpson (1-D), Margalef richness (R) and Sheldon evenness (E) indices were used to investigate the diversity of plant species and in different life forms (Mohammadnezhad-Kiasari et al. 2018). The Shannon-Wiener Index (H') was used due to its greater sensitivity to the abundance of rare species. Also, the Simpson diversity Index (1-D) was used due to its sensitivity to species that are present in greater abundance (Pourbabaei et al. 2012; Mirzazadeh et al. 2022). The formulas are given in Table 1.

Table 1. Biodiversity indices and their equations

Index	Equation
Shannon-Wiener (H´)	$H' = -\sum_{i=1}^{s} p_i \ln p_i$
Simpson (1-D)	$D = \sum_{i=1}^{s}\left[\frac{n_i(n_i-1)}{N(N-1)}\right]$
Margalef (R)	$R = \frac{S-1}{LnN}$
Sheldon (E)	$E = \frac{e^{H'}}{S}$

Note: H'= Shannon-Wiener, Pi = the relative frequency of the ith species, D= dominance index, N= total number of all individuals, ni= the number of individuals of the ith species, R= Margalef, E= Sheldon, S= the total number of species, e= 2.71828

After grouping and rearranging the data, the normality of the data was evaluated with the Kolmogorov-Smirnov test, and the homogeneity of variances was evaluated with the Levene test. The indices of diversity, richness, and evenness in different life forms were calculated using PAST software (Hosseinpour et al. 2019; Amini et al. 2021). Then, the average of each of these data was compared between the managed and unmanaged forests using independent samples *t* test using SPSS version 18 (SPSS Inc., Chicago, Ill, USA).

RESULTS AND DISCUSSION

In the unmanaged forest, 56 plant species belonging to 30 families and 51 genera were recorded. The most species-rich families were Rosaceae, Asteraceae, and Fabaceae, with 6, 4, and 3 genera and 6, 4, and 4 species, respectively. In this forest, 8 tree species, 3 shrub species, and 45 herbaceous species were identified. On the other hand, in the managed forest, 50 plant species belonging to 31 families and 49 genera were recorded. The most species-rich families were Rosaceae, Asteraceae, and Fabaceae, with 5, 4, and 3 genera and 5, 4, and 2 species, respectively. In this forest, 6 tree species, 3 shrub species, and 41 herbaceous species were identified. Also, the life forms in these forests include cryptophytes at 36.06%, hemicryptophytes at 34.43%, phanerophytes at 26.23%, and chamaephytes at 3.28%, respectively (Tables 2 and 3).

The means of different biodiversity indices for herbaceous species (Table 2) in managed and unmanaged forests are presented in Table 4. This research showed that based on the single-tree selection cutting, there were no significant differences in the managed and unmanaged compartments in terms of herbaceous species. However, the mean of diversity (Shannon-Wiener and Simpson indices), richness (Margalef index), and evenness (Sheldon index) of herbaceous plants in the managed forest had a slight increase compared to the unmanaged forest (Table 4).

Table 2. The recorded herbaceous species and the average percentage of their presence in the unmanaged and managed forests

Scientific name	Family name	Life form	The presence of each species	
			Unmanaged forest	Managed forest
Sanicula europaea L.	Apiaceae	He	23.53	14.81
Dryopteris filix-mas (L.) schott	Aspidiaceae	Cry	22.22	11.76
Polystichum aculeatum (L.) Roth.	Aspidiaceae	Cry	7.41	0
Asplenium adiantum-nigrum L.	Aspleniaceae	Cry	3.70	5.88
Phyllitis scolopendrium (L.) Newm.	Aspleniaceae	Cry	7.41	5.88
Athyrium filix-femina (L.) Roth.	Athyriaceae	Cry	25.93	17.65
Erigeron acer L.	Asteraceae	He	3.70	17.65
Lapsana communis L.	Asteraceae	He	7.41	7.41
Sonchus oleraceus L.	Asteraceae	Cry	7.41	7.41
Tussilago farfara L.	Asteraceae	Cry	44.44	41.18
Sambucus ebulus L.	Caprifoliaceae	He	3.70	11.76
Stellaria media (L.) Cyr.	Caryophyllaceae	Cry	37.04	58.82
Calystegia sepium (L.) R. Br.	Convolvulaceae	He	0	5.88
Convolvulus arvensis L.	Convolvulaceae	He	0	5.88
Sedum stoloniferum S. G. Gmel.	Crassulaceae	He	7.41	5.88
Carex sylvatica L.	Cyperaceae	Cry	70.37	58.82
Tamus communis L.	Dioscoraceae	Cry	11.11	11.76
.*Euphorbia amygdaloides* L	Euphorbiaceae	He	3.70	0
Mercurialis perennis L.	Euphorbiaceae	Cry	3.70	0
Lathyrus laxiflorus (Desf.) O. Kuntze	Fabaceae	Cry	7.41	52.94
Lathyrus vernus (L.) Bemh.	Fabaceae	He	7.41	17.65
Polygonum hydropiper L.	Fabaceae	Cry	3.70	0
Rumex acetosa L.	Fabaceae	He	3.70	11.76
Hypericum androsaemum L.	Hypericaceae	Ch	29.63	35.29
Calamintha aquatic L.	Lamiaceae	He	7.40	5.88
Calamintha officinalis Moench	Lamiaceae	Cry	29.63	41.18
Lamium album L.	Lamiaceae	He	59.26	47.06
Circaea lutetiana L.	Onagraceae	Cry	11.11	0
Cephalanthera caucasica Kranzl	Orchidaceae	Cry	5	17.65
Epipactis persica (Soo) Nannfeldt	Orchidaceae	Cry	33.33	23.53
Chelidonium majus L.	Papaveraceae	He	66.67	47.06
Bromus adjaricus Sommier & Levier	Poaceae	Cry	29.63	52.94
Poa nemoralis L.	Poaceae	Cry	22.22	17.65
Geranium robertianum L.	Poaceae	Cry	25.93	0
Cyclamen coum Miller	Primulaceae	Cry	37.04	5.88
Primula heterochroma vulgaris L.	Primulaceae	He	25.93	47.06
Fragaria vesca L.	Rosaceae	He	29.63	29.41
Geum kokanicum Regel & Schmalh	Rosaceae	He	3.70	0
Asperula odorata L.	Rubiaceae	He	100	51.85
Galium verum L.	Rubiaceae	He	3.70	0
Galium rotundifolium L.	Rubiaceae	He	7.41	11.76
Solanum kieseritzkii C. A. Mey	Solanaceae	Ch	29.63	0
Solanum nigrum L.	Solanaceae	Cry	7.41	5.88
Urtica dioica L. *var. dioica*	Urticaceae	He	0	5.88
Viola odorata L.	Violaceae	He	59.26	64.71

Table 3. The recorded woody species and the average percentage of their presence in the unmanaged and managed forests

Scientific name	Family name	Life form	The presence of each species	
			Unmanaged forest	Managed forest
Ilex aquifolium L.	Aquifoliaceae	Ph	44.44	11.76
Danae racemosa (L.) Moench	Asparagaceae	Ph	11.11	17.65
Ruscus hyrcanus Woron.	Asparagaceae	Ph	18.52	17.65
Hedera pastuchovii L.	Araliaceae	Ph	0	5.88
Alnus subcordata C. A. Mey.	Betulaceae	Ph	14.81	11.76
Carpinus betulus L.	Betulaceae	Ph	92.59	100
Fagus orientalis Lipsky	Fagaceae	Ph	100	100
Quercus castaneifolia C. A. Mey.	Fagaceae	Ph	29.63	47.06
Acer cappadocicum Gled.	Sapindaceae	Ph	7.41	0
Acer velutinum Boiss.	Sapindaceae	Ph	85.18	82.35
Crataegus melonocarpa M.B.	Rosaceae	Ph	48.15	58.82
Mespilus germanica L.	Rosaceae	Ph	14.81	23.53
Prunus spinosa L.	Rosaceae	Ph	25.93	41.18
Rubus hyrcanus Juz.	Rosaceae	Ph	18.52	17.65
Tilia platyphylloss Scop. subsp. caucasica	Tiliaceae	Ph	22.22	11.76
Ulmus glabra Hudson	Ulmaceae	Ph	3.70	0

The means of different biodiversity indices for the variables of natural regeneration and woody plants (Table 3) in managed (using the single-tree selection cutting) and unmanaged forests are presented in Table 5, while those for all plant species can be seen in Figure 2. There was no significant difference between the managed and unmanaged compartments with regard to these variables. The mean of the diversity (Shannon-Wiener and Simpson Indices) and richness (Margalef Index) of natural regeneration, woody species, and all plant species in the managed forest represented a slight increase in comparison to the unmanaged forest. On the other hand, the mean of the evenness (Sheldon Index) of these variables in the managed forest had a slight decrease compared to the unmanaged forest (Table 5, Figure 2).

Table 4. Mean, standard deviation and *t* test of the mean biodiversity indices in herbaceous species layer

Vegetation layer	Biodiversity indices	Mean in managed forest	Mean in unmanaged forest	T	P-Value
Herbaceous species	H′	2.348±0.304	2.214±0.763	0.686	0.497
	1-D	0.896±0.032	0.828±0.245	1.132	0.264
	R	2.614±0.700	2.606±1.198	0.027	0.979
	E	0.962±0.024	0.960±0.027	0.182	0.857

Note: H′= Shannon-Wiener diversity, 1-D= Simpson diversity, R= Margalef richness, E= Sheldon evenness

Table 5. Mean, standard deviation and *t* test of the mean biodiversity indices in different vegetation layers

Vegetation layers	Biodiversity indices	Mean in managed forest	Mean in unmanaged forest	T	P-Value
Natural regeneration	H′	1.432±0.230	1.359±0.344	0.779	0.441
	1-D	0.742±0.063	0.713±0.111	0.958	0.344
	R	1.094±0.255	1.020±0.326	0.839	0.432
	E	0.947±0.050	0.951±0.037	0.263	0.795
Woody species (tree and shrub)	H′	1.379±0.233	1.313±0.310	0.801	0.428
	1-D	0.711±0.067	0.689±0.102	0.875	0.387
	R	1.196±0.294	1.092±0.343	1.061	0.295
	E	0.866±0.049	0.889±0.039	1.615	0.117

Note: H′= Shannon-Wiener diversity, 1-D= Simpson diversity, R= Margalef richness, E= Sheldon evenness

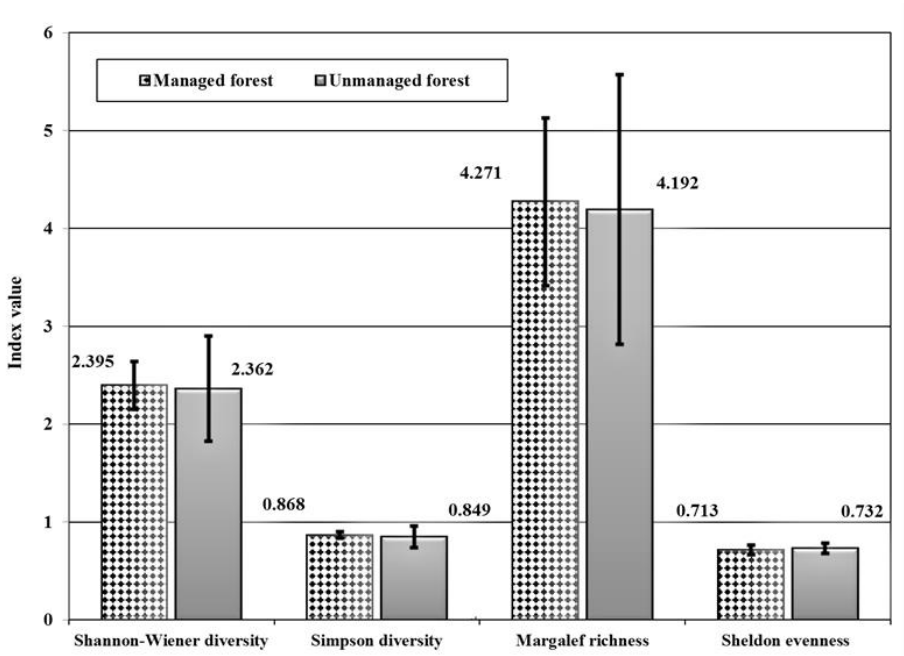

Figure 2. Mean of diversity indices and their standard deviation for plant species

Discussion

The Fagus (beech) genus is one of the most abundant and economically important hardwood genera in the northern hemisphere temperate forests. Beech forests play a primary role in the context of climate change mitigation and biodiversity conservation. They are also the primary sources of timber and firewood (Latterini et al. 2023). So far, 20 beech species have been identified, while all these species are distributed in the northern hemisphere, and only the oriental beech (*F. orientalis*) occurs in Iran. The oriental beech belt is connected to the European forests and plant composition in this study is highly similar to Balkan's beech forests. The natural range of the oriental beech tree's extends from southeastern Bulgaria's Strandja mountain, through northwest Turkey, and east to the Caucasus Mountains in Georgia and Russia, to the Alborz Mountains in Iran (Sagheb-Talebi et al. 2014).

Biodiversity loss is a major threat to ecological, social, and economic stability. Different forest management practices have various different impacts on biodiversity. In managed forests, biodiversity is often extremely lower than in natural forests, mainly due to the decrease of diversity in relationship with tree species, the heterogeneity of tree age, and special habitat niches, such as deadwood or tree microhabitats. Forest management traditionally focused on wood production but has now evolved to include multiple ecosystem services. With this new approach, forest management is a key driving factor to restore, maintain, and promote biodiversity in forests (Muys et al. 2022). On the other hand, protected areas are vital for conserving biodiversity and minimizing biodiversity loss. Protected forests have become a vital component of the biodiversity conservation strategy due to the increasing extinction and vulnerability of different species (Opuni-Frimpong et al. 2021). The current study sought to evaluate forest management using the single-tree selection cutting regime by comparing the diversity of plant species with unmanaged forests.

The use of plant species diversity measures has become one of the most important variables in evaluating the sustainability of forest operations (Kazemi et al. 2015; Hosseinpour et al. 2019; Rezaipoor et al. 2022). Diversity is affected by richness and evenness. Therefore, apart from determining the average species diversity of plants, the average amount of richness and evenness variables is calculated. In this study, the indices of richness, evenness, and diversity in various variables did not show a significant difference between the managed and unmanaged forests. These results are mostly related to the choice of the single-tree selection cutting in forest management and its correct implementation (Eshaghi et al. 2009; Tavonkar et al. 2011; Kazemi et al. 2015; Hosseinpour et al. 2019). The effects of forest management regime were investigated by the single-tree selection cutting on tree diversity indices in the Watson Forest (Eastern Mazandaran Province), representing that after the 10-year period of the implementation of the forest management, the species diversity indices increased by 30% of the area. Approximately 60% of the area remained unchanged, while about 11% of the area had reduced species diversity (Hosseinpour et al. 2019). In another study, after the implementation of the forest management regime using the single-tree selection cutting, the variations of woody species diversity were evaluated in the Beech-Hornbeam and Hornbeam stands of the Janbe-Sara District located in the west of Guilan Province. In this research, shrub and tree species sampling was applied in the first and last year of the 10-year period. The results revealed that species richness with Simpson and Shannon-Wiener diversity indices in Hornbeam and Beech-Hornbeam stands somewhat increased with no significant differences (Eshaghi et al. 2009). Moreover, the impact of the implementation of the single-tree selection cutting on the diversity of tree species in the forests of Nave-Asalem, Guilan Province, demonstrated that the index of species diversity in all stages of seedlings, young stems, and trees at the end of the 10-year period had a slight increase compared to the beginning of the period, but these increases were not statistically significant (Tavonkar et al. 2011). The study of the effect of forest management on plant diversity in two unmanaged (protected) and managed compartments in the lower altitude area of a forestry plan in Khalil-Mahalleh, Mazandaran Province indicated that the indices of the diversity and richness of woody species and herbaceous species were more in the managed compartment than in the unmanaged compartment (Kazemi et al. 2015).

In the single-tree selection cutting, exploitation is carried out in all storeys and scattered in all parts of the forest. Also, creating and maintaining uneven-aged mixed forests is one of the important goals of this system (Marvie-Mohajer 2018). The effects of low-intensity exploitation management are similar to the natural changes (Baran et al. 2018). In this regard, other research results in Haftkhal forest areas showed that quantitative and qualitative parameters of trees in managed and unmanaged forests did not differ significantly (Mohammadnezhad-Kiasari et al. 2020). On the contrary, another study investigated two managed compartment and unmanaged (protected) compartment forest stands in the Larvechal, Golband forestry plan in the west of Mazandaran Province were investigated. The results of plant species diversity in the managed and unmanaged forests showed that the richness and evenness of average tree species were 2.43 and 3.37, as well as 0.78 and 0.71, respectively. According to the Shannon-Wiener diversity index, the average tree species was 0.57 and 0.79, while based on the Simpson diversity index, it was 0.34 and 0.43. In addition, the average of all diversity indices of herbaceous species was higher in the unmanaged forest than in the managed forest. It should be explained that there were statistically significant differences between managed and unmanaged forests regarding diversity indices values. Based on the finding, their destruction of forest stands caused by cutting trees and livestock grazing in managed forests led to a sharp decrease in the diversity indices of plants compared to the unmanaged compartment (Kazemnezhad et al. 2011). In another study, the effect of protection on plant species diversity was examined Dr. Dorostkar Forest Reserve and Gisum Forest Park in the Talash region, Guilan Province.

The results of this research revealed that the average amount of richness, evenness, and diversity indices of tree species and herbaceous species was higher in the protected forest (Dr. Dorostkar Forest Reserve) than in the unprotected forest (Gisum Forest Park). Plant species in the park were heavily influenced by recreational activities and livestock grazing (Rezaipoor et al. 2022). Overall, it is obvious that for the management of forest areas, apart from the correct implementation of the forestry plan, it is necessary to take care of the non-entry of domestic animals and avoid economic and destructive human activities in the forest areas (Kazemnezhad et al. 2011; Rezaipoor et al. 2021).

Another noteworthy point is the biodiversity parameters of Shannon-Wiener and Simpson Indices with the Margalef richness of various vegetation layers had a slight increase in the managed forest than in the unmanaged forest. In the natural state, the presence of dead trees on the forest surface provides more space, light, and moisture for herbaceous plants, natural regeneration, and the growth of young trees (Eshaghi et al. 2009; Sagheb-Talebi 2017). The implementation of the Haftkhal management plan with the single-tree selection cutting during two stages (2005 and 2015) caused the creation of small and medium gaps scattered in the level of the managed forest (Mohammadnezhad-Kiasari et al. 2020). The effects of implementing two stages of tree harvesting in Haftkhal forests in terms of the values of Margalef richness, Sheldon evenness, Simpson diversity, and Shannon-Wiener diversity for herbaceous species in the managed forest were slightly increased compared to the unmanaged forests. However, it should be noted that if the area of gaps increases in the single-tree selection cutting, the frequency and percentage of invasive species coverage will increase as well (Hamrang et al. 2014). In this regard, the results of a study showed that medium-sized man-made gaps (150-300 m^2) had the highest value of richness, diversity, and regeneration density compared to the categories of small (20-150 m^2), and large (more than 300 m^2) man-made gaps (Amini et al. 2021). In general, similar to several other studies in the lower and middle altitude forests in the north of the country (Eshaghi et al. 2009; Tavonkar et al. 2011; Hosseinpour et al. 2019), the present research showed that the forest management with the single-tree selection cutting did not have a negative effect on the plant species diversity in the high altitude forest of Mazandaran Province.

Based on the results of this research, it is recommended the forest management regime for production forests should be implemented with the single-tree selection cutting. Of course, in these production forests, it is necessary to take care of the non-entry of domestic animals and avoid economic and destructive human activities. Creating and maintaining uneven-aged mixed forests are among the important goals of this system. To achieve this goal, exploitation should be performed with low intensity in all layers and scattered in all parts of the forest. Additionally, the small and medium gaps should be dispersed in all levels of the managed forest. In these circumstances, the forest management has no negative effect on the plant species diversity.

ACKNOWLEDGEMENTS

This study was performed under a research project at the Iranian Research Institute of Forests and Rangelands, Iran. We would like to thank all collaborators of this research project at Mazandaran Agricultural and Natural Resources Research and Education Center, Iran, for their support during the preparation and measurement of the samples. Also, financial support for this research was provided by the Forest and Rangelands Organization of Iran.

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