RESEARCH ARTICLE

Comparing the structure and regeneration diversity of woody species in temperate managed stands

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Natural regeneration is a critical factor in ensuring the survival and sustainability of forests. Natural processes and human activities influence the transformation of natural ecosystem landscapes. In this way, we have conducted a study to compare the species diversity and structural characteristics of woody species' natural regeneration in six managed Hyrcanian forest stands in Iran. Each stand's regeneration was classified based on diameter and height. Sample plots measuring 9 m^2 were selected for assessing regeneration in a systematic random network. The sampling method employed for this research was a full inventory sampling within each sample plot. We found that the Zilkiroud area had the highest number of regeneration stems across different diameters and heights, while the Fariroud area had a higher species diversity than other stands. Furthermore, the number of woody species in standard and coppice forms was highest for <2.5 cm collar diameters and <30 cm heights. Except for diameters <2.5 cm, beech species had fewer seedlings in the seedlings and ticket stage compared to other species. Our findings suggest that the sustainability of these stands can be achieved by implementing nature-like forestry management, livestock exclusion, and community participation in project implementation.

Key Words: *Species diversity; Regeneration structure; Hyrcanian forest; Growth form; Beech*

INTRODUCTION

The Hyrcanian forests represent a significant biological resource, boasting remarkable plant cover and genetic reserves [1-3]. They are a global natural heritage and international natural sanctuary and are considered among the most diverse temperate forests in terms of native tree and shrub species [4]. Situated in northern Iran, the Hyrcanian forest region spans 1.9 million hectares and is the only productive forest in the region that has been subject to managed forestry plans in recent years [5-7]. As such, it provides a critical source of wood products required for development [8-10].

The continuity of production in these forests is dependent on the establishment and development of natural regeneration [11]. Wood species dominate forest stands and are fundamental structural components of natural ecosystems [12,13]. When a tree species reaches old age and falls as a results of environmental factors, it creates a canopy gap [14,15]. The dispersed seeds of wood species germinate under favorable environmental conditions in these gaps [16]. The resulting seedlings, through competition and various stages of growth, contribute to the ultimate forest stand *via* natural regeneration [17].

Natural regeneration is one of the most vital factors affecting the survival and sustainability of natural forests [18]. Understanding the diversity, distribution, and status of natural regeneration of wood species is essential to gaining insights into the ecological health of forest ecosystems and ecosystem services [19].

Natural regeneration is a crucial process for maintaining the diversity of native species and generating new tree generations in forest ecosystems [20]. The dynamics of this process have a significant impact on the stability and performance of forest stands, which underscores the importance of natural regeneration for forest sustainability.

Wood species regeneration through seed and vegetative propagation, a complex natural process that ensures their survival in ecosystems. This process significantly influences the structure of forests and the diversity of wood species during ecological succession. The successful establishment of populations of native wood species adapted to forest environmental conditions is a significant advantage of natural regeneration, as it can tolerate adverse conditions to eventually become dominant trees. This plays a vital role in the continuity of old-growth forests and the sustainability of natural ecosystems.

The diversity of woody plant species and their potential for regeneration are essential elements in natural ecosystems, providing diverse habitats for plants and animals. Therefore, acquiring knowledge and information about the density of juvenile and sapling populations is crucial, as it determines the population structure and the quantitative and qualitative status of regeneration in each forest community.

Given the importance of natural regeneration for forest sustainability, extensive studies have been conducted worldwide. For instance, Shen and Nelson conducted a study that examined the natural regeneration patterns of coniferous species in temperate forests in the northwestern United States. Their results showed that both high canopy cover and understory vegetation could either enhance or hinder the natural regeneration of coniferous species, depending on shade tolerance and site conditions.

A study was conducted to examine the vegetation cover and tree regeneration in the understory in China. Their research indicated that areas of lower density had a higher diversity of shrubs along with greater plant species diversity.

They performed a study to investigate the diversity, distribution patterns, and regeneration status of tree species in Indian forests. Their findings revealed that higher elevations had a greater richness of broad-leaved species in lowland forest types. Additionally, they discovered a significant positive correlation between mature tree density and sapling density.

Furthermore, Tüfekcioğlu and Tavşanoğlu accomplished a comparative analysis on the diversity and regeneration of woody plant communities in southwestern Turkey. They examined five regions with different vegetation cover types, including closed forest, open forest, closed shrubland, open shrubland, and short shrubland. Their research revealed distinct differences in species diversity, plant species composition, and structural density of saplings among different vegetation cover types.

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The preservation of natural ecosystems is contingent upon the continuity and natural regeneration of forests, which warrants the prioritization of these aspects in forestry management plans. Notably, the comprehensive status of seedlings and saplings in natural ecosystems provides valuable evidence about the regeneration capacity of mature trees and the establishment of seedlings in the forest. Given the ecological and productive significance of Hyrcanian forests, a comprehensive study of their existing natural regeneration status is deemed crucial. Therefore, this study, examines the community structure of saplings and seedlings of woody plant species in six managed stands in the Hyrcanian forests of northern Iran in a multidisciplinary approach.

MATERILAS AND METHODS

Site description

The Caspian forests of Iran are situated in the northern region of the country, covering a vast area that extends from the northern slopes of the Alborz mountain range to the Iranian sub-coastal region. These forests are estimated to be between 25 to 50 million years old and are classified as part of the broad-leaved and Mediterranean forests, located in the Hyrcanian phytogeographical region. The coordinates of the forests range from 308409 to 407748 in longitude and from 4257281 to 4166983 in latitude at the UTM (Universal Transverse Mercator) system.

The Caspian forests are a remarkable sight, bearing a striking resemblance to the broad-leaved forests of Central Europe, northern Turkey, and the Caucasus. However, they exhibit a greater diversity of plant species, making them a unique natural wonder. Out of the total area of approximately 1.9 million hectares, around 1.2 million hectares are classified as commercial and high-quality forests.

The climate in the region where the Caspian forests are located is semi-Mediterranean, with an average annual precipitation of about 1000 mm. The precipitation is mostly concentrated in the west and least in the east, painting the forest in a beautiful array of colors that varies with the seasons. The average annual temperature in the region ranges between 15 to 18 ℃, creating a comfortable environment for both the residents and visitors. The soil types in the northern forests of Iran are as diverse as the plant species that they support. They consist mainly of Rendzina, forest brown soils, and Rankers in high-altitude areas. The parent rock of these soils is typically Jurassic and Cretaceous limestone, with some sandstone and loam, creating a unique landscape that is worth exploring. Lastly, the Caspian forests exhibit high plant diversity, with approximately 44% of Iran's plant species diversity found in this area.

The forests are home to an array of impressive native species, including Beech (*Fagus orientalis* Lipsky), Hornbeam (*Carpinus betulus* L.), Alder (*Alnus glutinosa* (L.) Gaertn.), Oak (*Quercus castaneifolia* C.A.Mey.), Maple (*Acer velutinum Boiss.*), Elm tree (*Tilia begoniifolia Steven*), and Ash (*Fraxinus excelsior* L.).

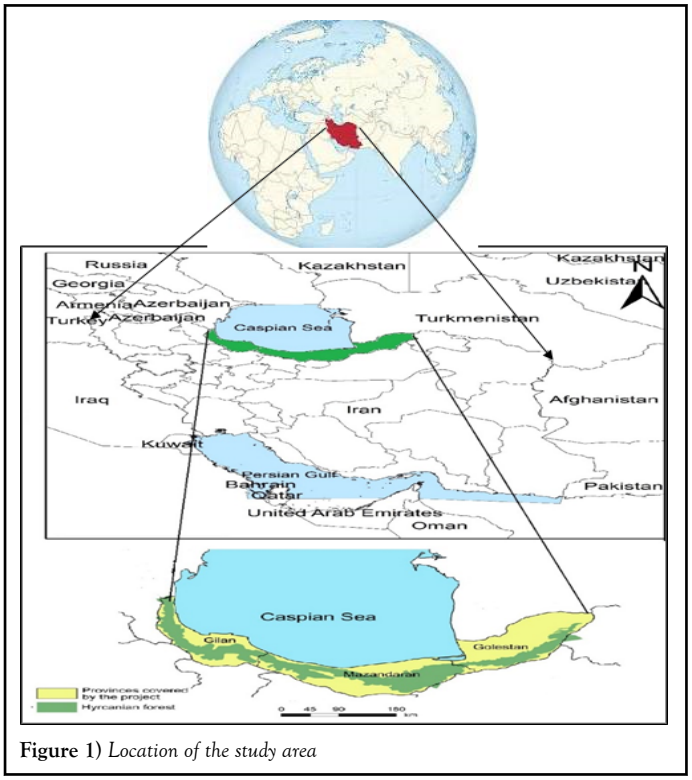

Figure 1) *Location of the study area*

Samples and sampling techniques

Samples of bee honey were gathered from places that sold it in Nekemte tow and kept at room temperature for the night before being subjected to microbial and physiochemical analysis in the biology department of Wollega University. The Ethiopian Public Health Institute in Addis Ababa, Ethiopia provided the cultures of pathogenic bacteria. Among these are *S. aureus* (ATCC 25923), *S. flexneri* (ATCC 12022), S. typhimurium (ATCC 14028), *P. aeruginosa* (ATCC 27853), and *E. coli* (ATCC 25922).

To achieve comprehensive regeneration analysis, six natural forest stands-Chehel Chai, Beliran, Dohezar, Sehezar, Zilkiroud, and Fariroud were selected based on their geographic distribution and ecological diversity. The selection of the stands was prepared in a manner that ensures the representation of all three northern-forested provinces (Golestan, Gilan, and Mazandaran) and the coverage of the region's forested areas.

The chosen stands were selected to ensure that they are situated in different geographical locations within the Hyrcanian forests and represent diverse ecological conditions by taking into account variations in altitude, soil type, climate, and vegetation composition (Table 1). These factors contribute to a comprehensive representation of the Hyrcanian forests region.

TABLE 1
Characteristics of the studied habitats

Forest habitat	Province	Longitude	latitude	Total area (ha)	Production forest area (ha)	Number of micro-sample plots	Elevation (m)	Average slope (percent)	Composition of dominant tree species	Average tree canopy
Chehel Chai	Golestan	4117547	360630	25816	16340	5447	200-2500	30-60	Hornbeam-Oak-Maple, Hornbeam	60-80
Beliran	Mazandran	4024456	627999	21421	20540	6847	100-2000	Oct-60	Hornbeam-Beech	40-80

Dohezar	Mazandran	4053336	476013	30870	15556	5185	100-3800	30-80	Hornbeam-Beech-Maple	40-80
Sehezar	Mazandran	4047423	487322	30870	15556	5185	200-3950	30-80	Beech, Hornbeam-Oak, Maple	40-80
Zilkiroud	Guilan	4092134	387102	13817	13133	2627	100-2650	20-60	Beech-Hornbeam	40-80
Fariroud	Guilan	4091941	376896	16721	16035	5345	100-2500	30-60	Beech-Hornbeam-	40-80
Sum	-	-	-	139515	97160	30636	-	-	-	-

A field visit was conducted to assess the area and regeneration status of each forest stand selected for this research. The survey network used in this research had an area of three hectares. The microplates established to measure regeneration in this study were part of the comprehensive measurement plan in the studied areas. The microplots to measure regeneration in this study included 30,636 plots in six studied habitats.

Sample plots measuring 9 m^2 (3×3 meters) were chosen to evaluate the regeneration, and a full inventory sampling method was employed within each sample plot.

Due to the irregular distribution pattern of seedlings and saplings within each forest stand, their population density, quantitative characteristics (number per hectare, collar diameter, height), and qualitative characteristics (tree species, developmental ages, growth forms) were classified according to their diameter and height. This classification was carried out individually for each woody species.

The natural regeneration in each forest stand was classified into three diameter classes: Seedling (<2.5 cm collar diameter), sapling (2.5-7.5 cm collar diameter), and pole (7.5-12.5 cm collar diameter). Three height classes were also used: seedling (<30 cm), sapling (30-130 cm), and ticket (>130 cm). All these measurements were taken separately for each woody species.

Following the sampling process, to ensure a precise evaluation of stand conditions, woody species regeneration was categorized into two growth forms, namely standard and coppice. In each growth form, quantitative characteristics, such as the number per hectare, collar diameter, and height, were recorded. Moreover, qualitative characteristics, including tree species and developmental ages, were also documented. The aim of these measurements was to ensure an accurate comparison of the stand conditions.

All relevant diagrams were plotted using Excel software. Additionally, for comparing species diversity in regeneration within each forest stand, three diversity indices (Shannon-Wiener, Evenness, and Simpson's) were calculated using R 4.0.5 and SPSS 26 softwares.

RESULTS

Collar diameter

Chehel Chai, Beliran, Dohezar, Sehhezar, Zilkiroud, and Fariroud, findings indicate that woody species exhibiting both seedling and sapling forms were found to have the highest frequency (*i.e.*, 10041) amongst individuals with collar diameters less than 2.5 cm. The total count of such individuals was established at 10,041. In contrast, collar diameters ranging from 2.5 to 7.5 cm were associated with a total count of 2,245 individuals, while the lowest count of 1,260 individuals was observed in the range of 7.5 to 12.5 cm (Figure 2).

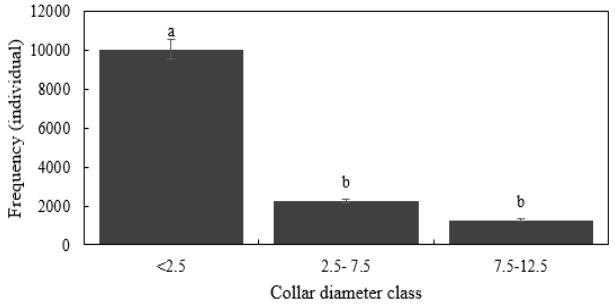

Figure 2) *Frequency of wood species based on Collar diameter class (cm)*

Seedling height

It was found that the highest number of tree species was recorded at <30 cm heights, with a total count of 9,398 individuals. In contrast, heights ranging from 30 to 130 cm had a total count of 2,746 individuals, while the lowest number of tree species was recorded at >130 cm heights, with a count of 1,402 individuals (Figure 3).

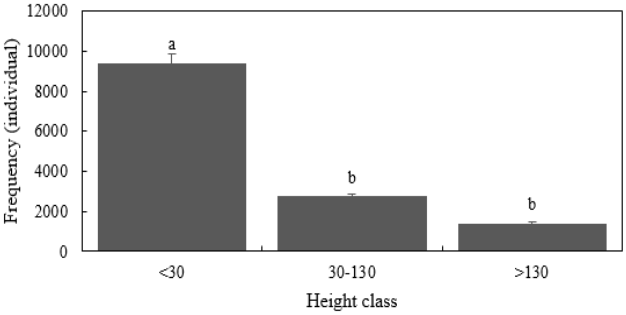

Figure 3) *Regeneration frequency of woody species in height class (cm)*

Diameter of seedlings

The highest number of tree species were observed among species like Oak, Hornbeam, Maple, beech, and other forest species. These were mostly found in seedlings with a diameter of <2.5 cm. Afterwards, they were observed in saplings with diameters ranging from 2.5 to 7.5 cm, and finally in tickets with diameters ranging from 7.5 to 12.5 cm (Figure 4).

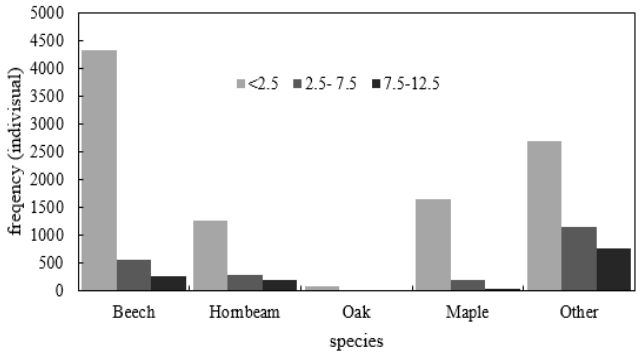

Figure 4) *Frequency of woody species on diameter classes of seedlings*

Height of seedlings

The number of woody species in all study areas, ranked from highest to lowest number of individuals among all species (Oak, Hornbeam, Maple, and other woody species), was recorded at <30 cm heights, (Oak, Hornbeam, Maple, and other woody species) at heights ranging from 30 to 130 cm. The lowest number of woody species (Oak, Hornbeam, Maple, and other woody species) was recorded at >130 cm heights (Figure 5).

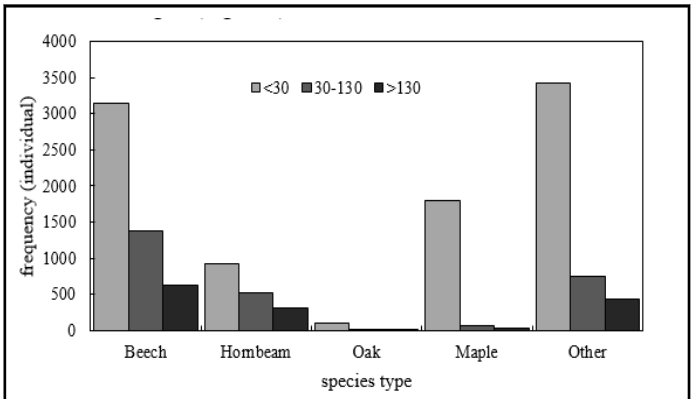

Figure 5) *Incidence of woody species regeneration based on species type in height classes*

Seedlings with <2.5 cm diameter had the highest frequency in Zilkiroud, Dohezar, Fariroud, Beliran, Sehezar, and Chehel Chai. This means that the highest amount of natural regeneration with <2.5 cm diameter occurred in the Zilkiroud site, and the lowest number of seedlings per hectare occurred in the Chehel Chai site, additionally, by comparing the number of seedlings with a diameter between 7.5 and 12.5 cm (ticket) the highest frequency was observed, respectively, in the Fariroud, Chehel Chai, Zilkiroud, Beliran, Dohezar, and Sehezar sites (Figure 6).

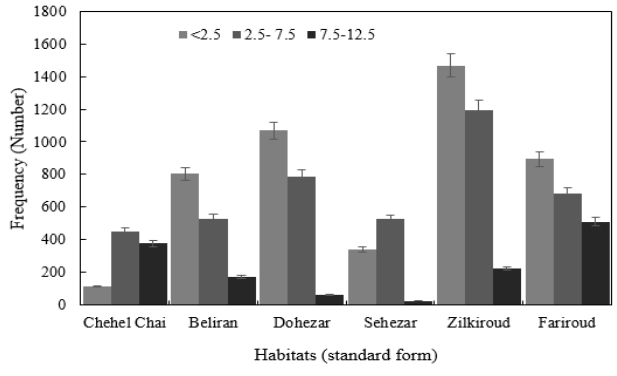

Figure 6) *Regularity of regeneration standard form based on diameter (cm) in the studied habitats*

The analysis of seedling emergence frequency based on height revealed that the greatest number of seedlings per hectare, measuring <30 cm in height, was observed in the forest sites of Zilkiroud, Fariroud, Dohezar, Beliran, Sehezar, and Chehel Chai, respectively. Similarly, the highest count of saplings, ranging from 30-130 cm in height, was identified in the locations of Zilkiroud, Dohezar, Fariroud, Chehel Chai, Beliran, and Sehezar, respectively. Furthermore, regeneration >130 cm height (*i.e.*, "ticket") exhibited the highest density per hectare in Beliran, Chehel Chai, Zilkiroud, Fariroud, Dohezar, and Sehezar, in that order (Figure 7).

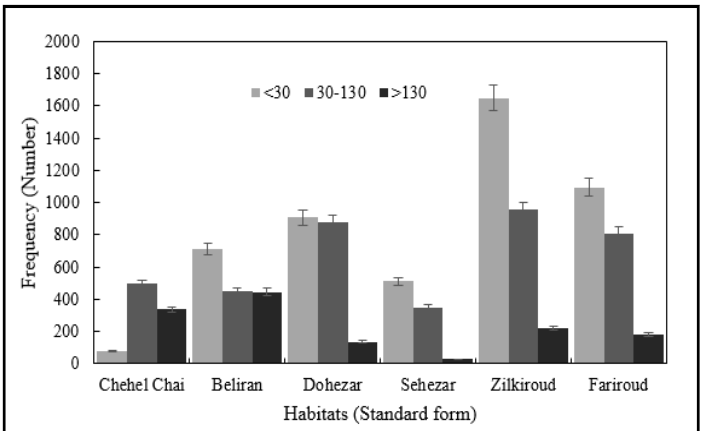

Figure7) *Rate of regeneration standard form based on height (cm) in the studied habitats*

The comparison of standard form of regeneration per hectare, categorized by woody plant species, demonstrates that Beech seedlings exhibited the highest frequency in Zilkiroud, Dohezar, Sehezar, Farirud, and Beliran, respectively. However, the Chehel Chai forest site showed no natural seedling emergence of Beech. Maple displayed the highest frequency among the six forest sites in Fariroud, Dohezar, Chehel Chai, Zilkiroud, Beliran, and Sehezar, respectively. Regarding Chestnut oak, the highest frequency was observed in Chehel Chai, Dohezar, and Beliran, while FArirOud, Zilkiroud, and Sehezar lacked natural seedling emergence of this species. The greatest frequency of Tilia begonifolia species was recorded in Beliran, Chehel Chai, Fariroud, Zilkiroud, Dohezar, and Sehezar, respectively. Additionally, the frequency of other forest species per hectare was highest in Zilkiroud, Beliran, Chehel Chai, Fariroud, Dohezar, and Sehezar, respectively (Figure 8).

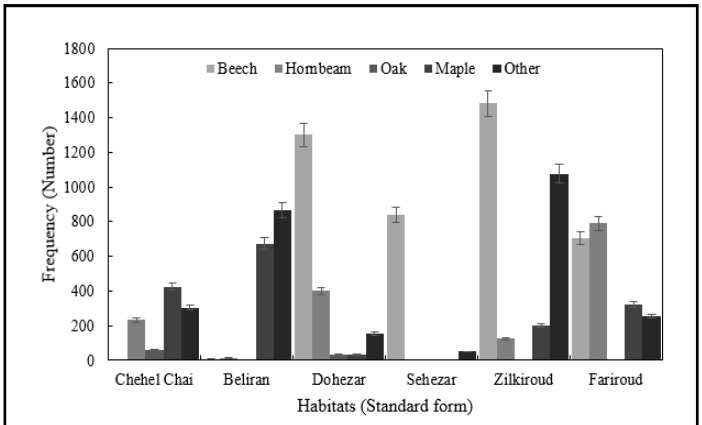

Figure 8) *Frequency of regeneration standard form based on seedling species (cm) in the studied habitats*

The highest density of woody species per hectare in coppice form regeneration, characterized by a diameter <2.5 cm, was observed sequentially in Zilkiroud, Fariroud, Dohezar, Chehel Chai, Beliran, and Sehezar. Regarding seedlings with diameters ranging from 2.5 to 7.5 cm (saplings), the order of highest density was Farirud, Zilkiroud, Dohezar, Chehel Chai, Beliran, and Sehezar. Additionally, saplings with diameters

ranging from 7.5 to 12.5 cm ("ticket") exhibited the highest density in Chehel Chai, Beliran, Fariroud, Zilkiroud, while the forest sites of Dohezar and Sehezar lacked coppice seedling emergence at the ticket stage (Figure 9).

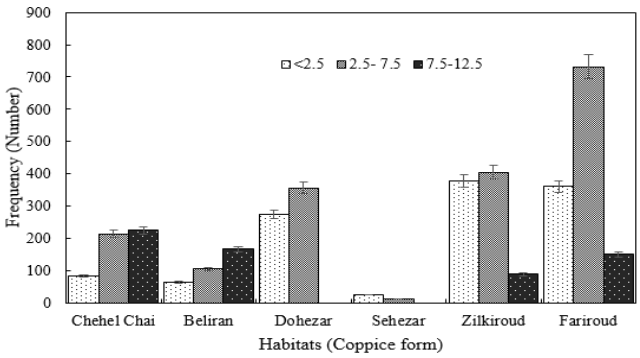

Figure 9) *Frequency of seedlings Coppice form based on diameter (cm) in the studied habitats*

The analysis of coppice seedling frequency based on height indicates that the greatest density of coppice seedlings per hectare, measuring <30 cm in height, was observed in Fariroud, Zilkiroud, Dohezar, Chehel Chai, Beliran, and Sehezar. Furthermore, comparing the frequency of saplings with heights ranging from 30 to 130 cm revealed the highest density per hectare in Fariroud, Zilkiroud, Dohezar, Chehel Chai, Beliran, and Sehezar, respectively. Moreover, the highest frequency of saplings with heights exceeding 130 cm was observed in Chehel Chai, Fariroud, Zilkiroud, and Beliran, whereas the Dohezar and Sehezar sites showed no emergence of woody species at the ticket stage (Figure 10).

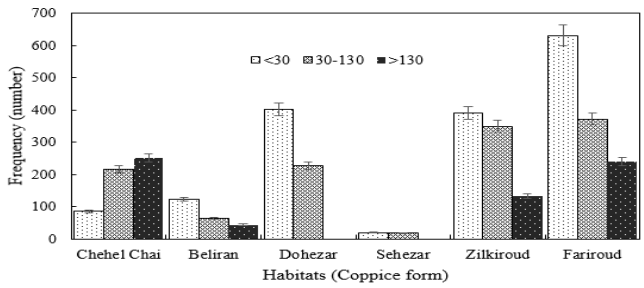

Figure10) *Regularity of regeneration Coppice form based on height (cm) in the studied habitats*

Comparison of different forest stands based on the type of woody species showed that the highest emergence of coppice seedlings of the F. orientalis was observed in the Zilkiroud, Dohezar, Fariroud, and Beliran stands, while the Chehel Chai and Sehezar stands lacked oak species. The highest presence of Hornbeam species was observed in the Fariroud, Dohezar, and Chehel Chai stands, while the Beliran, Sehezar, and Zilkiroud stands lacked Hornbeam species with coppice seedling form. Additionally, among the forest stands, only Chehel Chai had coppice seedling of Beech. The distribution of the Alder in the six forest stands showed that Chehel Chai, Beliran, Zilkiroud, and Fariroud had the highest number, while Dohezar and Sehezar lacked Alder species with the coppice seedling form. The highest frequency of other forest species was observed in Fariroud, Dohezar, Zilkiroud, Chehel Chai, Beliran, and Sehezar stands, respectively (Figure 11).

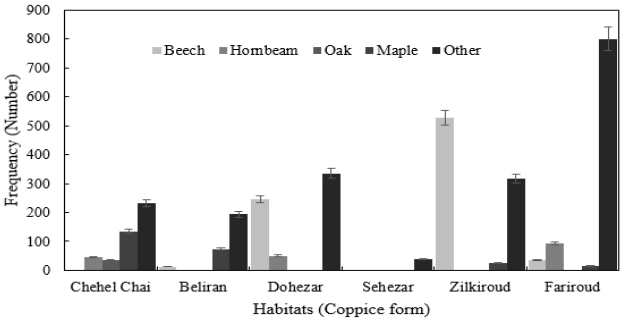

Figure11) *Occurrence of regeneration coppice form based on tree species (cm) in the studied habitats*

The results of one-way Analysis of Variance (ANOVA) indicate a significant difference in species diversity of seedling among different forest stands in terms of height, collar diameter, Shannon-Wiener, Simpson, and Evenness biodiversity indices (Tables 2-4).

TABLE 2
Variance analysis results for height and collar diameter in different classes

		Sum of squares	df	Mean square	F	Sig.
Diameter	Between groups	1725250	2	862625.2	3.89	.044*
	Within groups	3326280	15	221752		
	Total	5051531	17	-		
Height	Between groups	1720421	2	860210.7	3.543	.035*
	Within groups	3641710	15	242780.7		
	Total	5362132	17	-		

Note: **Significance at the 99% level, *Significance at the 95% level, ns: non-significance

TABLE 3
Analysis of variance analysis results for height and collar diameter in diverse habitats

		Sum of squares	df	Mean square	F	Sig.
Diameter	Between groups	2016419	5	403283.8	1.594	0.235
	Within groups	3035111	12	252925.9		
	Total	5051531	17			
Height	Between groups	1960451	5	392090.2	1.383	0.298
	Within groups	3401681	12	283473.4		
	Total	5362132	17			

TABLE 4
Analysis of variance analysis results for height and collar diameter in diverse habitats

Index		Sum of squares	df	Mean square	F	Sig.
Shanon	Between groups	1.850	5	0.370	15008983106702231000000000000	0
	Within groups	0	30	0		
	Total	1.850	35			
Simpson	Between groups	0.360	5	0.072	46730671726813420000000000000	0
	Within groups	0	30	0	0	
	Total	0.360	35			
Invsimpson	Between groups	30.050	5	6.010	12189728171794659000000000000	0
	Within groups	0	30	0	0	
	Total	30.050	35		35	

Note: **Significance at the 99% level, *Significance at the 95% level, ns: non-significance

The conditions of seedling emergence in different forest stands have significantly influenced the Shannon-Wiener, Simpson, and Evenness indices, with the Farirud treatment having the highest values and the Sehezar treatment having the lowest values for all three indices (Figure 12).

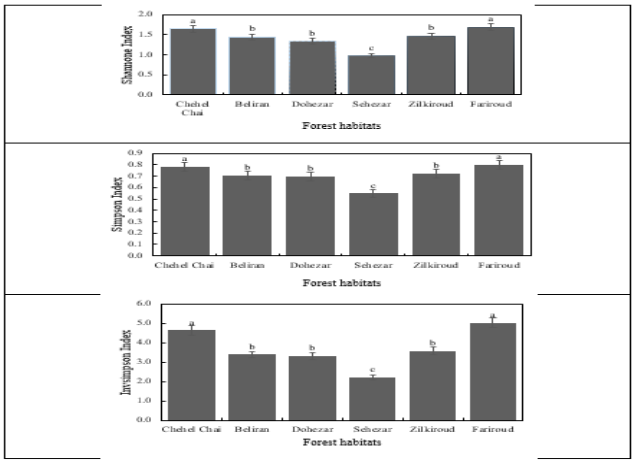

Figure 12) *Mean values of the Shannon-Wiener, Simpson, invisimpson index for different Forest habitats. The 95 percent confidence level*

DISCUSSION

The aftermath of major disturbances such as wildfires, windstorms, or clear-cutting often triggers similar processes in forests worldwide. In these scenarios, trees in open areas commence growth through seeds, sprouts, or natural regeneration. Numerous environmental and ecological factors within a natural forest stand influence various ecosystem characteristics; including plant cover composition, regeneration composition, and species diversity. These characteristics may undergo changes because of forest management practices. Natural regeneration stands as a key indicator of the optimal and natural state of a forest. The findings of this study suggest that the relative abundance of seedlings in the early stages and the qualitative attributes of regeneration exhibit variations in response to environmental conditions and forest management practices, including harvesting.

By analyzing the quantitative and qualitative characteristics obtained from managed stands across the western (Zilkiroud, Fariroud), central (Beliran, Dohezar, and Sehezar), and eastern (Chehel Chai) regions of northern forests. It becomes evident that the western stands of the Hyrcanian forests exhibit a greater number of standard and coppice seedlings with diameters <2.5 cm (seedlings), diameters ranging from 2.5 to 7.5 cm (saplings), as well as seedlings measuring <30 cm and between 30 to 130 cm in height compared to their diameter and height counterparts, indicating the youthful nature of the stand and the presence of ample light. These stands provide conducive conditions for regeneration concerning soil quality and the presence of seed trees, consistent with the findings. Similarly, based on the findings of, it can be noted that seed production is not as crucial as the survival of seedlings, and the time required for seedling growth is an important parameter for increasing tree species diversity in forest stands.

Conversely, the eastern Hyrcanian forests exhibit a higher number of standard and coppice regeneration per hectare with collar diameters of 7.5-12.5 cm and heights exceeding 130 cm (saplings) compared to their counterparts in the western Hyrcanian forests. This suggests favorable regeneration establishment in the eastern Hyrcanian forests and the presence of adverse environmental factors in the western Hyrcanian forests, where the number of seedlings diminishes with increasing age ("ticket"). Biological factors such as competition for light and environmental factors contributing to seedling destruction, such as extensive grazing in the region, play pivotal roles. reported that despite the presence of grazing in Australian forests, there does not seem to be a definitive constraint on natural regeneration. However, they demonstrated that intense grazing could indeed affect regeneration.

The evaluation of regeneration patterns indicates the potential for seed and coppice regeneration in Hyrcanian forests. However, the dominant species in the region, particularly beech, exhibits relatively fewer seedlings in the sapling and ticket stages compared to other forest species, except for diameters less than 2.5 cm. This phenomenon might indicate the potential replacement of other species better adapted to disturbances. These findings are consistent with the results. Additionally, they can lead to loss of diversity, inadvertently resulting in the invasion of unwanted exotic species, which aligns with the findings of Rusch and Varela.

Pollination, flowering, and seed production mark the initiation of the regeneration cycle. However, few studies have delved into the specific conditions of seed production in mixed forests and their evolutionary processes. In mixed forests, the temporal and spatial synchrony of flowering and fruiting in trees influences the genetic structure of future populations within and among tree populations, regeneration success, and the maintenance of tree species compositions.

While regeneration has garnered increased attention in recent decades, the heightened complexity in young mixed stands resulting from interspecific interactions necessitates further understanding. Species interactions encompass both negative and positive aspects and constitute key components of forest dynamics, often-underlying species coexistence and replacement processes. Negative interactions, such as interspecific or intraspecific competition, occur when simultaneous resource demand from different species or individuals negatively impacts species survival, growth, or regeneration. Conversely, positive interactions, termed facilitation, arise when one species enhances the survival, growth, or regeneration of another species. These positive effects may manifest through mechanisms such as protection against herbivores, harsh environmental conditions, or other competitors. In mixed forests, competitive reduction and facilitation effects often occur simultaneously and are challenging to distinguish, collectively described as complementary effects.

The composition of standard and coppice regeneration of beech trees in the Zilkiroud stand (western Hyrcanian forests) significantly surpasses that of other stands, indicating a favorable condition under forestry management plans. However, the stand in the eastern Hyrcanian forests (Chehel Chai) lacks beech standard and coppice regeneration, posing a risk to the future forests of the Chehel Chai area. Nevertheless, this stand can be conserved and restored through measures such as livestock removal and involving local communities in forestry management plans, ensuring sustainability and facilitating climax conditions.

The composition of standard and coppice regeneration of hornbeam and oak species in the eastern Hyrcanian forests surpasses that of other stands. Similarly, the combined regeneration of maple species in the central Hyrcanian forests exceeds that of other stands. However, the total regeneration count of other species in the western stands surpasses that of other stands.

In addition to natural phenomena and evolutionary processes, the livelihoods and activities of indigenous people directly influence regeneration. The livelihoods of local forest dwellers in Farirud and Zilkiroud primarily revolve around agriculture and animal husbandry. In Dohezar and Sehezar, local communities typically engage in tourism, animal husbandry, horticulture, and agriculture. Agriculture and animal husbandry form the core livelihood activities in the Beliran area. In Chehel Chai, forest dwellers' livelihoods are centered around animal husbandry, agriculture, beekeeping, and fruit tree cultivation, constituting the primary income sources. In areas adjacent to pastoralism and forest grazing zones, the abundance of forest seedlings directly correlates with grazing to maintain forest types and ecological characteristics of forest species.

The presence of dense canopy cover in forest floors leads to multiple layers and insufficient light penetration for grazing animals, prompting livestock farmers to resort to forest clearing, particularly in areas surrounding forest grazing fields. Forest clearing and cutting create open spaces, allowing light to reach the forest floor, fostering the growth of invasive and undesirable herbaceous plants like various grasses, thistles, and weeds. This disturbance disrupts the natural regeneration of forest species and consequently alters the evolutionary trajectory of the forest. Consequently, areas proximal to forest grazing grounds typically harbor pioneer species such as hornbeam, oak, walnut, maple, and other accompanying species.

Shannon-Wiener and Simpson diversity indices reveal that integrated management across different stands can lead to changes in species diversity. The highest diversity is observed in the Fariroud region, while the lowest is in the Sehezar region. Although the Zilkiroud region exhibits the highest number of standard and coppice regeneration in various diameters and heights, the highest level of species diversity in regeneration is observed in the Fariroud region compared to other stands. The high diversity in the Fariroud region can be attributed to environmental conditions, lower tree cover density, and the presence of more canopy gaps, enhancing heterogeneity in resource distribution and promoting coexistence among plant species with different resource utilization strategies.

Uniformity plots demonstrate that the distribution of plant species in families in the Fariroud region surpasses that of other stands, providing diverse families with growth opportunities.

Natural diversity processes in forests typically commence when trees achieve closed canopy cover (canopy closure stage). In the subsequent stage (reinitiation of understory), as the canopy cover starts to open with increasing tree age, these processes intensify. During the canopy closure stage, shade-tolerant species may establish themselves in the understory, benefitting from canopy cover protection against high temperatures and soil moisture reduction (direct facilitation), as well as competitive release because of canopy control of plant competition (indirect facilitation).

In the absence of significant disturbances, these open spaces may naturally occur (reinitiation of understory stage), but their appearance can be accelerated through thinning operations. Increased light penetration to the forest floor benefits not only previously established species but also a wide range of other herbaceous and woody species. However, ground vegetation may pose challenges to seedling survival and growth, particularly when dominated by herbaceous plants, due to their shallow and dense root systems and their ability to extract water and nutrients from the soil, leading to intense competition.

CONCLUSION

The Zilkiroud and Fariroud areas exhibit the highest stability in terms of seedling establishment. Conversely, the Sehezar area demonstrates the lowest species diversity indices, with seedling establishment less than a Dohezar per hectare, indicating a significant reduction in species diversity. In summary, the results affirm the pivotal role of natural seedling establishment in augmenting species diversity in Hyrcanian forest ecosystems. Therefore, it is recommended to strictly limit activities like grazing in these areas as part of efforts to enhance seedling establishment. Additionally, livestock removal from the forest, conservation and restoration initiatives, and the involvement of local communities in multi-purpose management plans can aid in revitalizing regeneration establishment in these invaluable ecosystems.

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