

VEGETATION AND SOIL BIODIVERSITY ASSESSMENT IN TEMPERATE FORESTS SURROUNDING THE KHAZAR NABI MARSHES, IRAN

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VEGETATION AND SOIL BIODIVERSITY ASSESSMENT IN TEMPERATE FORESTS SURROUNDING THE KHAZAR NABI MARSHES, IRAN. A thorough understanding of biodiversity is crucial for the sustainable management and conservation of forest ecosystems. This study investigates vegetation cover in conjunction with key environmental factors—including physiographic features, soil characteristics, and climatic conditions—in the Nimvar Forest of Nowshahr, Iran. Vegetation zoning was conducted in areas surrounding the Khazar Nabi Marshes based on the degree of homogeneity and heterogeneity among vegetation units. The primary objective of this research is to evaluate vegetation and soil biodiversity within the temperate forests adjacent to the marshes. Plant diversity was quantified using the Simpson and Shannon-Wiener indices, while species richness was assessed through the Margalef and Menhinick indices. The Berger-Parker and Pielou's indices were also employed to evaluate species dominance and evenness. Results indicated that both species diversity and richness reached their highest levels in the eastern, northern, and northeastern parts of the study area. Statistically significant differences in species richness and evenness ($p < 0.05$) were observed among these regions. The predominant soil texture in areas surrounding the marsh was sandy clay loam (62.5%). Notable variation was found in clay content ($p < 0.01$), organic matter ($p < 0.01$), and soil pH ($p < 0.05$). Beech species were most abundant on the northern slopes, whereas the Gramineae family represented the most dominant plant group overall. These findings emphasize the marsh's role in shaping local vegetation patterns and soil attributes, contributing to the development of a distinct microhabitat with unique microclimatic conditions.

Keywords: Biodiversity, Forest trees, *Fagus orientalis*, Hyrcanian forest

PENILAIAN KEANEKARAGAMAN HAYATI VEGETASI DAN TANAH DI HUTAN BERIKLIM SEDANG DI SEKITAR RAWA-RAWA KHAZAR NABI, IRAN. Pemahaman menyeluruh tentang keanekaragaman hayati sangat penting untuk pengelolaan dan konservasi ekosistem hutan yang berkelanjutan. Studi ini meneliti tutupan vegetasi beserta faktor lingkungan utama—termasuk fitur fisiografi, karakteristik tanah, dan kondisi iklim—di Hutan Nimvar Nowshahr, Iran. Zonasi vegetasi dilakukan di area sekitar Rawa Khazar Nabi, berdasarkan tingkat homogenitas dan heterogenitas di antara unit vegetasi. Tujuan utama penelitian ini adalah untuk mengevaluasi keanekaragaman hayati vegetasi dan tanah di dalam hutan beriklim sedang yang berdekatan dengan rawa-rawa. Keanekaragaman tumbuhan diukur menggunakan indeks Simpson dan Shannon-Wiener, sedangkan kekayaan spesies dinilai melalui indeks Margalef dan Menhinick. Indeks Berger-Parker dan Pielou juga digunakan untuk mengevaluasi dominasi dan pemerataan spesies. Hasil penelitian menunjukkan bahwa keanekaragaman dan kekayaan spesies mencapai tingkat tertinggi di bagian timur, utara, dan timur laut dari area penelitian. Perbedaan yang signifikan secara statistik dalam kekayaan dan pemerataan spesies ($p < 0,05$) diamati di antara wilayah-wilayah ini. Tekstur tanah yang dominan di area sekitar rawa adalah lempung berpasir (62,5%). Variasi yang signifikan ditemukan pada kandungan lempung ($p < 0,01$), bahan organik ($p < 0,01$), dan pH tanah ($p < 0,05$). Spesies beech paling banyak ditemukan di lereng utara, sedangkan

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famili Gramineae merupakan kelompok tanaman yang paling dominan secara keseluruhan. Temuan ini menekankan peran rawa dalam membentuk pola vegetasi lokal dan atribut tanah, yang berkontribusi pada pengembangan mikrohabitat yang berbeda dengan kondisi iklim mikro yang unik.

Kata kunci: Keanekaragaman hayati, Pobon butan, Fagus orientalis, Hutan Hyrcanian

I. INTRODUCTION

The northern forests of Iran, known as the Hyrcanian forests, are among the most ecologically significant temperate forests in the world, harboring a rich diversity of valuable tree species. These include *Fagus orientalis* Lipsky (oriental beech), *Quercus castaneifolia* C.A. Mey. (chestnut-leaved oak), *Carpinus betulus* L. (european hornbeam), *Parrotia persica* C.A.M. (ironwood), *Pterocarya fraxinifolia* Land. (false walnut), *Populus caspica* Bornm. (caspiian poplar), *Alnus subcordata* C.A. Mey. (caucasian alder), *Buxus hyrcana* Pojark (box tree), *Gleditschia caspica* Desf. (caspiian honey locust), *Acer velutinum* Boiss. (velvet maple), and *Sorbus torminalis* (L.) Crantz. (wild service) (Marvie Mohadjer, 2011; Aghajani et al., 2014, 2019). Biodiversity encompasses the variability among living organisms from all sources—terrestrial, marine, and freshwater ecosystems—along with the ecological complexes they form. It is commonly described across three levels: genetic diversity, species diversity, and ecosystem diversity. As such, biodiversity represents the full spectrum of life's variety, complexity, and interactions (Ejtehadhi et al., 2009). The conservation of forest ecosystems and the protection of their unique species are vital for maintaining genetic reservoirs and ensuring ecological stability. Sustainable forest management practices, are essential for health and preserving these ecosystems over the long term (Aghajani et al., 2013). Environmental factors, such as humidity and temperature, play a pivotal role in shaping biodiversity, particularly fungal communities (Bari et al., 2021; Aghajani et al., 2018). Forest and marsh ecosystems are recognized as biodiversity hotspots that support a wide range of plant, fungal, animal, and microbial life. Marshes are defined as wetlands characterized by dominant herbaceous vegetation in inland

settings (Wang et al., 2023). Forests, in contrast, are dynamic ecosystems constantly influenced by both natural processes and human interventions. Any disruption to marshes—whether through direct degradation or indirect impact—can profoundly disturb ecological cycles (Mahmoodi et al., 2019). Macrofauna are reliable indicators of habitat productivity and serve as valuable tools in evaluating sustainable forest management practices. Ghorbanzadeh et al. (2018) investigated the impact of various afforestation approaches on soil fauna, biodiversity metrics, and their relationship with key soil physical and chemical properties. Their findings revealed that microbial respiration, microbial biomass carbon and nitrogen, and bacterial populations were highest in poplar plantations, followed by natural forest sites. Vegetation, as one of the most dominant and observable forms of life on Earth, is deeply intertwined with human life and culture. As Miller (1978) observed, vegetation is not merely a natural element but a foundational component of human existence. Studying vegetation alongside physiographic, edaphic, and climatic factors enables a better understanding of the stability of plant communities and the ecological dynamics that govern them—an essential prerequisite for the restoration and sustainable development of forest ecosystems.

The importance of biodiversity management, particularly in the context of conservation and the sustainable use of ecological resources, remains a foundational goal in natural resource policy (Es-hagh Nimvari et al., 2011). Numerous studies have explored the biodiversity of woody species. For instance, Mao et al. (2020) emphasized the irreplaceable ecological role of wetlands as some of the world's most productive ecosystems. Mahmoodi et al. (2019) analyzed vegetation diversity along a catena

in managed and unmanaged stands of the Asalem forest, concluding that slope position significantly influenced the Simpson index and Camargo's evenness for trees, as well as Simpson and Margalef indices for herbaceous species. HajMirzaAghaei et al. (2021) examined the impact of native broadleaf and exotic conifer plantations on understory diversity in northern Iran, revealing that monoculture plantations led to reduced biodiversity, whereas mixed stands supported greater species richness. Similarly, Mosavi et al. (2022) demonstrated that physiographic variables such as slope aspect and elevation significantly affect biodiversity and aboveground biomass, with beech forests on mid-elevation northern slopes showing the highest biomass. Kianmehr et al. (2022) compared herbaceous diversity and regeneration in pure and mixed stands of beech and hornbeam. Their findings confirmed the practicality of biodiversity indices in forest assessments due to their reliability, cost-effectiveness, and adaptability. The study predicted a future dominance of oriental beech in the regeneration composition. Other research has underscored the value of structural indices, analyzed using advanced tools like machine learning and airborne laser scanning. Ette et al. (2023) investigated the correlation between different biodiversity indices, while Ette and Geburek (2021) addressed concerns regarding the reliability of biodiversity reporting in Europe. The UNECE-FAO (2020) report and Heym et al. (2020) highlighted the essential role of forest inventory data in biodiversity monitoring and sustainable forest governance. Ataei et al. (2023) assessed plant diversity along an elevational gradient in the Hyrcanian forests and found that species richness peaked between 800 and 1,300 meters above sea level, based on Shannon-Wiener and Simpson indices. Alijanpour et al. (2009) investigated woody species diversity in protected versus unprotected zones of the Arasbaran forest and found that conservation measures significantly enhanced biodiversity. In the Kalardasht

region of Mazandaran, Razaghi Kamroodi and Akbarzadeh (2002) identified 21 woody species and nine tree species, noting a temporal increase in species richness. Kazemnezhad et al. (2009) compared biodiversity in managed and unmanaged hornbeam-beech stands in the Laroochal region of Nowshahr. The average species richness index for trees was 3.37 in unmanaged areas and 2.43 in managed sites; tree evenness averaged 0.71 and 0.78, respectively. The Shannon-Wiener index was 0.79 in unmanaged and 0.57 in managed stands, while the Simpson index was 0.43 and 0.34, respectively. Neumann and Starlinger (2001) evaluated the effectiveness of various diversity metrics and concluded that the Shannon-Wiener index remains one of the most suitable for assessing tree species diversity.

Due to its floristic uniqueness and ecological richness, the Nowshahr forest region was selected as the study area, representing one of the key biodiversity reservoirs in Iran. This research aims to assess biodiversity status in the region, with the understanding that detailed knowledge of species composition and distribution is critical for sustainable forest management. Considering the ecological value of the Hyrcanian forests as biodiversity hotspots and refuges for native ecosystems, there is a pressing need to employ effective biodiversity indicators. Accordingly, six widely accepted biodiversity indices were used in this study: Margalef and Menhinick indices (species richness), Shannon-Wiener and Simpson indices (species diversity), and Berger-Parker and Pielou's indices (dominance and evenness). Given the growing threats to forest ecosystems and the irreplaceable ecological role of northern Iran's forests within the national phytogeographic framework, this study offers a comprehensive evaluation of biodiversity that can inform conservation policies and guide the future management of similar ecosystems, including the forested marshes and ecotonal zones of the Hyrcanian region.

II. MATERIALS AND METHODS

A. General Conditions and Geographical Location

defined by national watershed classification systems, and represents the fourth delineated series within this watershed. Administratively, it falls under the jurisdiction of the Kheyroud Natural Resources Division and the Noor-

Royan Natural Resources Administration. Ecologically and topographically, the Darro Series 4 is located within the mid-mountain zone, characterized by a broad elevational gradient. The elevation ranges from approximately 400 meters above sea level in compartment 401 to about 1,800 meters in the upper administrative zone 430 (see Figure 1).



Figure 1. A: Map of Iran B: map of administrative area C: Study area in Khezre-Nabi marshes in northern Iran

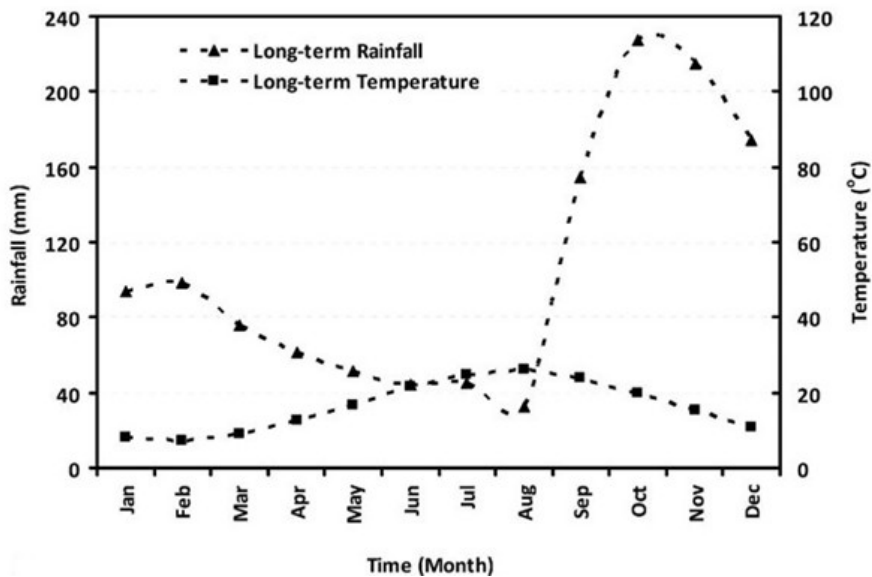


Figure 2. Ombrothermic curve of Nowshahr Synoptic Station in 1991 to 2011

B. Ombrothermic Curve

Based on a 20-year dataset (1991–2011) from the Nowshahr synoptic station, the study area receives an average annual precipitation of 1,273 mm and has a mean annual temperature of 19.6°C. The region’s climate is classified as semi-humid, characterized by cold winters. October is the wettest month, with an average precipitation of 227.4 mm, while August is the driest, receiving only 32.1 mm of rainfall. The ombrothermic diagram for the area (Figure 2) illustrates the seasonal precipitation-temperature relationship and indicates approximately 40 dry days annually (Aghajani et al., 2016).

C. Methodology

A preliminary reconnaissance survey was conducted in the study area, and the site was mapped using GPS. Based on the homogeneity and heterogeneity of vegetation units relative to their distance from the marshes, the area was stratified into three distinct sampling zones. Zone I, adjacent to the marshes, represents shoreline vegetation; Zone III, the farthest, corresponds to the surrounding forest; and Zone II lies between these two extremes. A total of sixty plots, each measuring 1 × 2 meters, were established along eight geographical transects. Plant species that could not be identified in the field were collected and later

identified to the species level using standard taxonomic references. Within each plot, data were recorded on species composition and abundance, canopy and trunk health, diameter at breast height (DBH), and total tree height. Additionally, soil samples were collected from the forest edge near the marshes and analyzed in the laboratory for texture, organic matter content, pH, salinity, and moisture. The data were subjected to one-way analysis of variance (ANOVA), followed by Duncan’s multiple range test to assess differences among indices and evaluate spatial variability within the study area. The findings were further contextualized through comparison with relevant literature.

1) Biodiversity Indices Analysis

The following biodiversity indices were calculated based on Ludwig & Reynolds (1988) and Hammer et al., (2001)

2) Simpson’s Diversity Index:

Simpson’s Diversity Index is one of the earliest diversity indices used in ecology. The index ranges from 0 to 1; a higher value indicates a greater probability that two individuals randomly selected from a sample belong to the same species, implying lower diversity. It was introduced by Ludwig & Reynolds (1988) and is defined according to Formula 1:

(1):
$$\lambda = 1 - \sum_{i=1}^0 \left[\frac{ni(ni-1)}{N(N-1)} \right]$$

Where:

ni: number of individuals of each species

N: total number of individuals in the community

λ: Simpson's diversity index

3) Shannon–Wiener Diversity Index:

The Shannon–Wiener index is more sensitive to the presence of rare species. The Shannon–Wiener equation uses the natural logarithm and is expressed as follows:

(2):
$$H' = - \sum_{i=1}^s p_i \ln(p_i)$$

$$p_i = \frac{n_i}{N}$$

Where:

H : Shannon–Wiener Diversity Index:

Pi: Relative abundance of individuals of species *i* in the sample

ni: Number of individuals of species

N: Total number of individuals in the community

4) Species Richness Indices

Species richness, also referred to as species density, refers to the total number of species present. The main mathematical indices used to quantify species richness include:

5) Margalef's Richness Index

This index uses the following formula (Equation 3) to calculate species richness:

(3):
$$R = \frac{S-1}{LnN}$$

Where:

R = Species richness (Margalef's index)

S = Total number of species

N = Total number of individuals in the community

6) Menhinick's Species Richness Index.

This index is calculated using the

Formula (4):

(4):
$$R = \frac{S}{\sqrt{N}}$$

Where:

R = Species richness

S = Total number of species

N = Total number of individuals in the community

7) Species Evenness Index

To calculate species evenness, several indices are used. The most important ones are as follows:

8) Pielou's Evenness Index

The Pielou's evenness index is calculated using the following formula (5):

Where:

(5):
$$j' = \frac{H'}{H'_{max}}$$

H' : Shannon–Wiener Index:

j' : The Pielou's Evenness value

H'_{max} : The maximum possible value of the Shannon-Wiener index is equal to:
 $LnS = -H'_{max}$

9) Dominance – Berger-Parker Index

The Berger-Parker dominance index is one of the most commonly used dominance indices. It provides a straightforward understanding of the concept of dominance within a community and is easy to calculate. The Berger-Parker index is based on the most dominant species and is calculated using the following formula (6):

(6):
$$D_d = \frac{N_{max}}{N}$$

Where:

Dd = Berger-Parker dominance

Nmax = Dominant species abundance

N = Total number of individuals in the community

10) Statistical Analysis

Duncan's multiple range test (DMRT) was employed to compare the means of quantitative characteristics, while analysis of variance (ANOVA) was utilized. Biodiversity indices for the Marshes were computed using PAST software (Hammer et al., 2001), whereas all statistical analyses were performed using SPSS software (Kahrizi et al., 2020).

III. RESULTS AND DISCUSSION

A. Biodiversity Indices in the Marshes and Geographic Directions

The analysis of biodiversity indices across the Marshes and geographic directions showed no significant differences at the 0.05 level for Simpson's diversity index ($p = 0.812$), Shannon-Wiener diversity index ($p = 0.256$), Margalef's richness index ($p = 5.423$), Menhinick's richness index ($p = 1.3325$), evenness ($p = 0.312$), and the Berger-Parker dominance index ($p = 0.213$) (Table 1).

B. ANOVA for Biodiversity Indices in the Marshes and Geographic Directions

Analysis of variance for biodiversity indices across the three marsh zones revealed no statistically significant differences at the 5% level for Simpson's diversity index ($p = 0.652$), Shannon-Wiener diversity index ($p = 0.120$),

Menhinick's richness index ($p = 0.374$), or the Berger-Parker dominance index ($p = 0.556$). However, Margalef's richness index ($p = 0.018$) and Pielou's evenness index ($p = 0.021$) showed significant differences. Similarly, across different geographic orientations, no significant differences were observed for Simpson's index ($p = 0.282$), Shannon-Wiener index ($p = 0.254$), Menhinick's index ($p = 0.550$), or the Berger-Parker index ($p = 0.221$). In contrast, Margalef's richness index ($p = 0.012$) and evenness ($p = 0.017$) exhibited statistically significant variation at the 5% significance level (Table 2).

Species richness refers to the total number of species present within a given sample plot, with higher species counts indicating greater ecological richness. In contrast, evenness describes the relative distribution of individuals among different species within a community. Communities dominated by one or two species demonstrate lower diversity than those with a more balanced species composition. Both high species richness and high evenness contribute to greater overall biodiversity in a region. In the present study area, which is characterized by the dominance of three major tree species, species richness was found to be relatively adequate (Ejtehadi et al., 2009).

The calculated Shannon-Wiener and Simpson diversity indices for the study area

Table 1. Values for biodiversity indicators between marshes and geographical directions

Dominance of Berger-Parker	Evenness of Pielou's	Richness of Manhanic	Richness of Margalef	Shannon Weiner Variety	Simpsons Variety	Geoghrapical direction
0.2314	0.3564	1.669	4.562	2.331	0.7523	North
0.1456	0.4521	2.3287	5.2598	2.233	0.8365	Northeast
0.1468	0.5419	1.6520	5.2135	2.4523	0.9254	Eastern
0.2014	0.6621	2.214	4.5637	1.3675	0.5602	Southeast
0.6210	0.2397	1.6579	2.4412	2.0345	0.2112	South
0.6376	0.6341	1.375	4.0397	2.752	0.973	Southwest
0.6321	0.5520	1.8820	5.3674	1.8932	0.6482	West
0.331	0.6541	1.9971	3.8531	2.8823	0.2236	Northwest
0.2136	0.3125	1.3325	5.4236	2.256	0.8124	Marsh

Table 2. Finding of two-way ANOVA (A marshes and B geographical direction) for biodiversity indicators

P	F	Mean Squares	df	Unit element (orientation relative to marsh)	Biodiversity index
0.652ns	0.225	0.001	2	Marsh	Simpsons Variety
0.282ns	1.325	0.002	7	direction	
0.120ns	2.221	0.186	2	Marsh	Shannon Weiner Variety
0.254ns	1.114	0.183	7	direction	
0.018 *	1.154	6.365	2	Marsh	Richness of Margalef
0.012 *	1.654	3.562	7	direction	
0.374ns	1.325	0.44	2	Marsh	Richness of Manhanic
0.550 ns	0.85	0.235	7	direction	
0.021*	2.730	0.033	2	Marsh	Evenness of Pielou's
0.017*	2.360	0.021	7	direction	
0.556 ns	0.125	0.001	2	Marsh	Dominance of Burger parker
0.221 ns	2.154	0.005	7	direction	

suggest a comparatively high level of species diversity relative to other regions. For instance, Amini and Pourbabaei (2004) reported average Shannon-Wiener index values of 2.22 for Norway maple (*Acer platanoides*) forests and 2.17 for pristine forests in Gilan Province. Similarly, Kazemi et al. (2015) found average Simpson and Shannon-Wiener index values of 0.63 and 1.16, respectively, in the Khalil Mahalleh forests of Mazandaran Province. Numerous studies have emphasized the suitability of the Shannon-Wiener index for evaluating tree species diversity (Bahmani et al., 2014). Mohammadzadeh et al. (2015) further highlighted that evenness plays a critical role in enhancing Simpson's index, while species richness has a greater influence on the Shannon-Wiener index. Their findings from the Arasbaran forest, a natural broadleaf deciduous ecosystem with high biodiversity, are consistent with the results of the present study. Additionally, Chao (1999) underscored the role of marshes in moderating microclimatic conditions during colder seasons, which in turn promotes increased plant and animal diversity in surrounding areas.

The spatial distribution of flora, as assessed through various diversity indices, revealed no

significant differences at the 5% level. Notably, the southern aspect of the Khazr Nabi Marshes exhibited the highest species evenness. Although diversity and dominance indices showed no statistically significant variation across geographic directions, the greatest species richness and evenness were observed on the southern and southeastern slopes. This pattern may be attributed to the elevated positions of these slopes, which receive optimal sunlight—an observation consistent with the findings of Adamus et al. (1991). However, significant directional differences were identified in species diversity, richness, and dominance indices. Specifically, the southwestern and western slopes exhibited the highest species richness and diversity, whereas the southern slope was dominated by a few species, indicating lower evenness. These trends correspond with the findings reported by Grigal (2002).

Further analysis of species abundance and richness across geographic directions revealed that the greatest abundance occurred on the northwestern slope, while the northeastern slope exhibited the highest species richness. These observations are in agreement with those of Kiesecker et al. (2001). An interaction

analysis between geographic direction and biodiversity indices in the Khazr Nabi Marshes demonstrated that only Margalef's richness index and evenness were significantly affected, whereas other biodiversity indices remained unaffected.

C. Species Abundance in the Study Area

The findings revealed that *Fagus orientalis* Lipsky (oriental beech) exhibited the highest abundance among the recorded tree species, whereas *Carpinus betulus* L. (European hornbeam) and *Tilia platyphyllos* Scop. (large-leaved lime) had the lowest abundance (Figure 3). The study area, situated within a protected zone dominated by mixed oriental beech forests, underscores the ecological and commercial importance of *Fagus orientalis*. The predominance of this species suggests that the habitat conditions in the region—particularly those influenced by the nearby Marshes—are highly favorable for its growth and regeneration. The Marshes likely contribute to stable moisture regimes and a moderated microclimate, creating optimal conditions for oriental beech, a finding consistent with the observations of Mitsch and Gosselink (2000).

D. Seedlings Abundance in the Study Area

The analysis indicated that seedling abundance was highest among maple species, while beech seedlings exhibited the lowest abundance in the study area (Figure 4). The Khazr Nabi Marshes, situated at an elevation of 1,400 m above sea level, are primarily characterized by beech forests. The dominant species in the region include *Alnus subcordata* (caucasian alder), *Acer velutinum* Boiss. (velvet maple), and scattered individuals of *Carpinus betulus* L. (European hornbeam) and *Tilia platyphyllos* Scop. (large-leaved lime). The notable presence of *Alnus subcordata* in proximity to the Marshes is likely attributable to its affinity for moisture-rich habitats. Similarly, the prevalence of softwood species such as *Acer velutinum* may be explained by the lightweight nature of their seeds, which facilitates wider dispersal across the landscape. These observations are consistent with the findings of Kazemi et al. (2015), who reported that the occurrence of pioneer species such as *Alnus* and *Acer* in beech-alder and beech-maple forest types contributes to a reduction in beech dominance, thereby promoting greater tree species diversity.

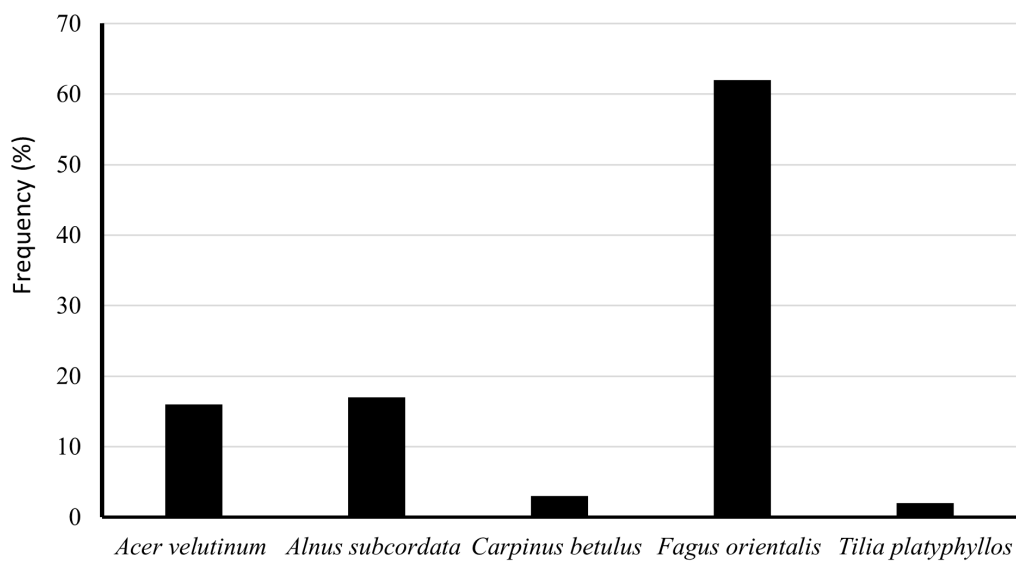


Figure 3. Species frequency in the study area

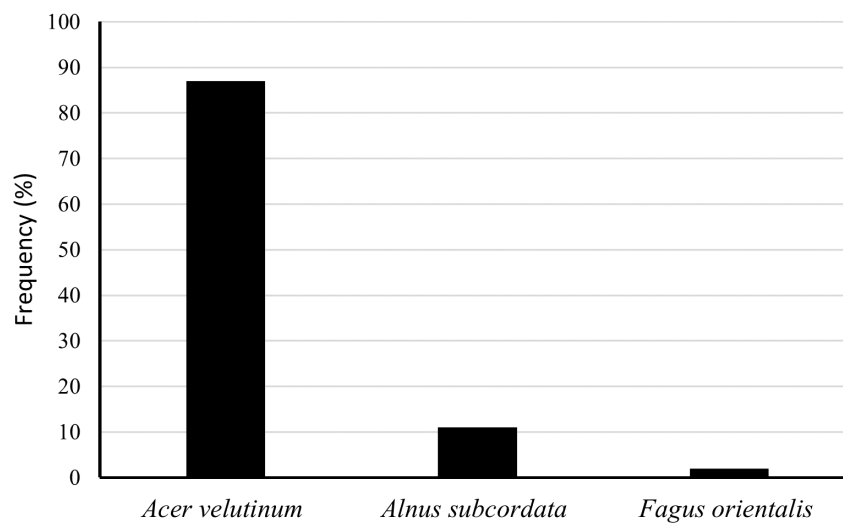


Figure 4. Regeneration species frequency in the study area

E. Crown and Stem Health Results in the Study Area

The results showed that the highest proportion of trees with healthy crowns was *Fagus orientalis* (oriental beech) trees (Figure 5).

A comparative analysis of average crown health in relation to tree height revealed that trees in the study area, which are predominantly young, exhibit generally good crown and stem vitality. In particular, the trees within the Khazr Nabi Marshes display excellent overall condition, a pattern likely attributable to the favorable microclimatic conditions and the

site’s classification as a climax forest. Statistical analysis demonstrated a highly significant relationship between crown health and tree height at the 99% confidence level. Similarly, a comparison between average stem health and diameter at breast height (DBH) showed that the greatest frequency of healthy trees occurred within the DBH range of 20–55 cm, predominantly representing young to middle-aged *Fagus orientalis* (oriental beech) individuals. The analysis of variance also indicated a highly significant difference between stem health and DBH at the 99% confidence level.

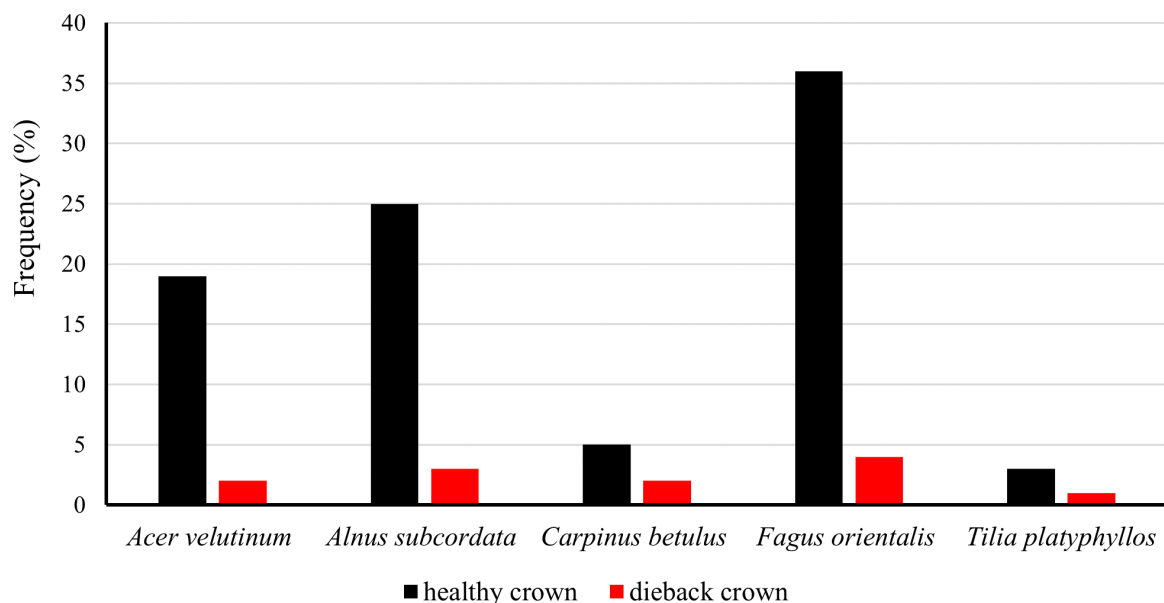


Figure 5. Crown health in the study area

In general, marsh ecosystems tend to exhibit lower environmental variability than adjacent terrestrial ecosystems due to the moderating influence of water. This hydrological buffering effect supports the persistence of marsh-adapted plant species, many of which have widespread global distributions and are commonly found in similar wetland environments.

F. Soil Characteristics of the Study Area

Soil texture analysis showed that the Khazr Nabi Marshes has a loamy sand soil texture. The soil texture comprises loamy clay sand (62.5%), loamy sand (25%), and loam (12.5%). Analysis of variance for soil factors revealed significant differences at the 1% level for clay content ($P=0.001$) and organic matter ($P=0.002$). Additionally, soil pH showed a significant difference at the 5% level ($P=0.016$). However, no significant differences were observed for silt ($P=0.283$), sand ($P=0.123$), soil salinity ($P=0.21$), and soil moisture ($P=0.301$) (Table 3).

The observed significant differences in clay content and organic matter across the Marshes can be attributed to variations in underlying soil horizons and the decomposition of forest floor litter, which contributes to elevated organic matter levels relative to other Marshes, as reported by Adamus et al. (1991). These findings corroborate the results of Eshagh-

Nimvari (2014), who documented that the Jamand Marshes exhibited the highest clay content among three studied Marshes, while no significant differences were found in sand percentage, soil salinity, or moisture levels. Notably, the highest soil pH was recorded in the Jamand Marshes. Soil texture classifications further distinguish these ecosystems: the Talur and Farakhin Marshes predominantly contain loamy sand soils, whereas the Jamand Marshes comprise loamy clay sand, loamy sand, and loam textures (Eshagh-Nimvari, 2014). The present study's results are consistent with those of Touarfia et al. (2021), who demonstrated strong interrelationships between soil properties and plant species composition in the Mekeiman Marshes, highlighting the critical role of soil-plant interactions in the effective restoration and management of Marsh ecosystems. Moreover, plant species distribution was found to be influenced by moisture gradients, with key edaphic factors—including sodium, phosphorus, active lime, magnesium, clay content, organic matter, carbon-to-nitrogen (C/N) ratio, and nitrogen levels—significantly shaping vegetation patterns. These findings underscore the importance of conserving natural habitats and prioritizing the protection of natural forest Marsh stands to ensure the long-term ecological sustainability of northern forest Marsh ecosystems.

Table 3. ANOVA results of some soil properties

P	F	df	Mean Squares	Soil Characteristics
0.001**	47.120	2	358.167	Clay
0.283 ns	1.341	2	69.292	Silt
0.123 ns	2.322	2	113.375	Sand
0.002**	8.434	2	1036.137	Organic matter
0.016*	5.033	2	2.044	pH
0.21 ns	1.683	2	0.063	EC
0.301 ns	1.271	2	173.375	Humidity

IV. CONCLUSION

The results demonstrate that the Marshes significantly influence vegetation composition and soil properties, thereby creating a unique microhabitat characterized by specific climatic conditions. Biodiversity indices proved to be essential tools for assessing and comparing species diversity across different forest regions, providing critical insights into the stability and overall health of forest ecosystems. These findings emphasize the crucial role of conserving and restoring natural habitats to sustain both plant and animal diversity. Moreover, the notable presence of species such as maple, with its high seedling abundance, and oriental beech, distinguished by its exceptional crown health, highlights the imperative for targeted conservation strategies aimed at protecting these keystone species and their associated ecosystems.

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