Annals of Silvicultural Research
48(2), 2023: 60-72
https://creajournals.crea.gov.it/asr/

Research paper

# Assessing the state of forest health in Oriental beech (*Fagus orientalis* L.) dominated forests in Iran

Roghayeh Jahdi[1]*, Atiyeh Shahamati Nejad[1], Farshad Keivan Behjou[1]

*Received: 17/12/2022 Accepted: 9/03/2023 Published online: 19/04/2023*

**ABSTRACT** We assessed landscape-scale forest health in northern Iran based on the Forest Health Monitoring (FHM) method. Using five plot clusters, we collected, analyzed, and reported information on the four key selected indicators (i.e., tree biodiversity, crown condition, natural regeneration, and deadwood) in FHM. To obtain a numerical value of forest health to make the indicators operational we used an analytical networking process to assess the contribution of each indicator to forest health. The results demonstrated that tree species diversity and species evenness were high (Shannon–Wiener index= 2.11; Simpson index= 0.8; Pielou index= 0.76), but species richness was at an intermediate level in the forest (Margalef index= 2.81). In terms of crown condition, with an average crown diameter of 7.1 m, the results of crown dieback classification showed that the most-healthy class had the highest frequency with 65.2% in the study area. The mean density of natural regeneration was 273 individuals $ha^{-1}$ and 80% of which were represented by healthy seedlings. Total deadwood was 44.12 $m^3$ $ha^{-1}$ and was formed by 168 individuals per $ha^{-1}$. A great contribution to the total deadwood in number (89%) falling in the lower DBH class (<50 cm), representing 51% by volume. From the point of wood decay, Class 1 (least decomposed) had the most numerous and the most significant volume of deadwood. The assessment results of FHM show that the major indicator influencing forest health is tree diversity which contributes 61%. The remaining three indicators include crown condition, natural regeneration, and deadwood contributing 21.7%, 13%, and 4.4%, respectively. It must be highlighted that forest health monitoring information in temperate Hyrcanian forests is currently not available, and therefore, this paper presents the first experimental study carried out. The findings of this study are required to assess the state of current health and identify trends that will be used in the decision-making process for better management of the forests.

**KEYWORDS**: FHM, Hyrcanian forests, tree diversity, deadwood, crown condition.

## Introduction

Forests are subject to ever-increasing disturbances, both abiotic and anthropogenic, that affect the structure, composition, function, and health of forest ecosystems (Trumbore et al. 2015). To gain a better understanding of the effects of attributes associated with different disturbances and support the sustainable management of forest ecosystems, a holistic approach to monitoring and the assessment of forest health on different spatial scales is imperative (Lausch et al. 2018). Forest health has been defined by producing forest situations related to human demands (Kolb et al. 1995). This definition is closely related to sustainability, which is defined to meet the forest resource and ecosystem services of current and future generations (Lu et al. 2015). Measuring and monitoring forest health is a critical part of risk management and requires information on forest conditions (Vakili et al. 2021, Gupta and Pandey 2021). Four stage approach has been needed for measuring and monitoring forest health, which is: stage 1: selecting sets of ecological indicators for specific ecosystems; stage 2: adopting historical baseline data, such as historic range of variation as a baseline; stage 3: developing standards that can set expectations for comparing current conditions; and stage 4: integrating a monitoring system to assess current conditions and modify baseline data to respond to new conditions (O'Laughlin 1994, O'Laughlin et al. 1994).

Despite the knowledge of forest health and current approaches to forest health, and all the available methodological strategies, the development of monitoring methods is still required to assess the forest health changes. Methodological approaches to forest health monitoring and assessment are varied, and their use depends on the goals sought to achieve in each study (Torres et al. 2021). For instance, the Forest Health Surveillance (FHS) plan was established in the 1990s in Australia (Robinson 2008). The main aim of FHS is to detect and map pests and diseases, and climatic disorders in forest ecosystems (Stone 1999, Carnegie et al. 2018). As well as Forest Health Monitoring (FHM) performed by the USDA forest service is one of the methods to provide trustworthy and transparent information on the status of forests in a consistent way over time and space. The main aim of the FHM plan is to conduct a systematic annual assessment of the forest ecosystem conditions. To provide information on forest health, the FHM plan was developed in 1990, which includes detection monitoring, assessment monitoring, research on monitoring methods, and intense site monitoring operations (Conkling et al. 2002, Bennett and Tkacz 2008). Based on the FHM method, several ecological indicators have been created around the world to evaluate the health of ecosystems. These indicators are dynamic and adaptive, which can be used and adjusted to local forest ecosystems and ensure the sustainability of forest resources (Safe'i et al. 2021). The most common of these indicators are biodiversity, vegetation profile, nonnative invasive plants, regeneration and browse impact, crown condition, tree damage, lichen communities, tree mortality and standing dead trees, down woody materials, soil quali-

1 – Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili - Iran
*Corresponding author: roghayeh.jahdi@uma.ac.ir

 http://dx.doi.org/10.12899/asr-2444

ty, and fragmentation and landscape context (USDA Forest Service 2020, Anderson et al. 2021).

Natural and planted forests encompass ~14.4 million hectares and ~8.8% of the total land area in Iran (Department of Environment 2017). All these forests are publicly owned and are mainly divided into two regions: northern and western forests. The northern region contains the Hyrcanian temperate forest (~ 1.8 million hectares) as the only source of industrial wood, managed for a mix of timber production, recreation, and conservation uses. While western Iran is dominated by Zagros semi-arid forests (~ 6 million hectares), which are heavily utilized as fuel wood for villagers and livestock grazing. Hyrcanian extensive and diverse forests provide a basis for multiple uses, including but not limited to timber and wood fiber and lumber extraction, non-timber products, biodiversity conservation, recreation, wildlife habitat, and the protection of watersheds, i.e. clean water, soil, and air, and carbon sequestration. In the northern region, the state of the watersheds indicates reduced forest resilience, and their environmental services are declining due to the human-induced rapid environmental changes. Indeed, improper management and over-exploitation of natural resources have threatened the country's biosecurity. Comprehensive watershed management is thus a key concern for sustainable development, as discussed in international scientific forums, as well as ecosystem health assessment and monitoring are fundamental for sustainable watershed management (Sadeghi and Sharifi Moghadam 2021, Sadeghi et al. 2022). Forest health monitoring has been carried out already at multiple spatial scales from several different perspectives (Xiao et al. 2004, Fraser and Congalton 2021, Torres et al. 2021). Most of these works have been limited to a few countries and usually use small-scale resource-extensive fieldwork combined with conventional remote sensing techniques. Using ecological indicators, the present study aims to assess forest health based on a landscape in the Masuleh watershed in Guilan Province, northern Iran. The inventory of forest ecosystems is generally difficult and costly, and the measured indicators of forest ecosystem health vary based on achieved forest management efforts. Therefore, in this study, tree biodiversity, crown condition, natural regeneration, and deadwood characteristics were used as health indicators for the forest.

## Materials and method

### *Study area*

The study area was selected from the Masouleh forest watershed (4,000 ha) in Gilan province with a geographic location between 37°06´to 37°12´ N and between 48°54´to 49°01´ E. The minimum elevation above sea level is 700 m, and the maximum is 2,900 m (Fig. 1). The average annual temperature is 10°C, and the average rainfall amounts to 930 mm per year. In the Amberje climate classification, the area has a cold, humid climate (Bigdeli et al. 2014). Regarding vegetation, this area is one of the temperate Caspian forests of Iran and has pastures in highlands (Sarvati and Fathollahzadeh 2003). The forests include pure and mixed oriental beech (*Fagus orientalis* Lipsky) stands and also the mixed beech- hornbeam (*Carpinus betulus* L.); hornbeam- beech- Caucasian alder (*Alnus subcordata* C.A. Mey.) stands, as well as plantation and hazel (*Corylus avellana* L.) forest reserve (Fig. 1). This study was conducted in the mixed beech stand with an area of 1,000 ha and at an altitude of 700-2,200 mm, in the eastern part of the watershed. This forest stand has three strata (i.e., upper, middle, and lower strata), uneven-aged high forest structure. There are no records of forest management plans and commercial logging operations in this area. However, the area is under the pressure of grazing and illegal harvesting of tree species like other parts of the Hyrcanian region. In this study, forest health indicators were investigated in two altitude ranges (700-1,500 m and more than 1,500 m) using the cluster sampling method in mixed beech stands.

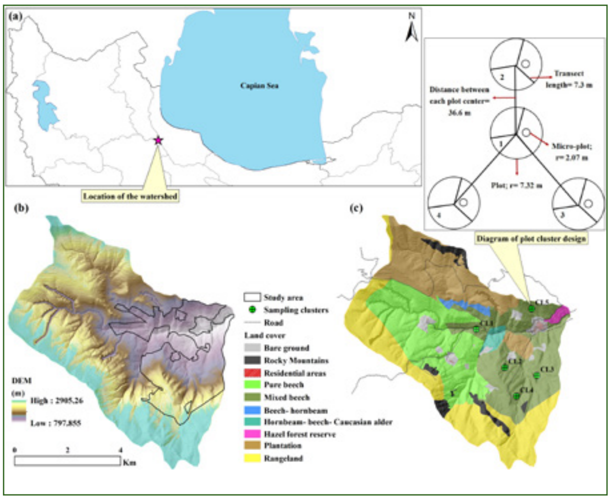



**Figure 1** - Maps of the study area (a), digital elevation model (DEM) (b), and land cover and sampling plot clusters (CL1-CL5) locations (c). Maps were created using Esri ArcGIS ArcMap 10.8 (http://www.arcgis.com). Top-right insert, diagram of plot cluster design for measuring forest health indicators in the study area based on the Forest Health Monitoring (FHM) method (Mangold 1999).

### *Sampling procedure*

In this study, information on four selected forest health indicators (tree biodiversity, crown condition, natural regeneration, and deadwood characteristics) was collected using cluster sampling based on the Forest Health Monitoring (FHM) method (Mangold 1999, USDA Forest Service 2005, 2020). This method was first developed in the United States in 1992 and is more commonly used for monitoring forest health status, changes, and trends on different scales (e.g., Steinman 2004, Woodall et al. 2011, Berryman and McMahan 2019, Potter and Conkling 2022). In other countries, however, the FHM method was expected to determine forest conditions based on the measurement results of predetermined ecological indicators. Many countries in the tropics and subtropics were among the first to use the FHM method to monitor forest ecosystems (Lestari et al. 2019, Putra et al. 2019, Safe'i et al. 2020, Haikal et al. 2020). The plot cluster design for measuring forest health in this method includes four plots with a fixed radius of 7.3 m in a triangular arrangement, which is presented in Figure 1. A total of 5 plot clusters, including 20 plots, were considered in the study area based on purposive sampling which is selecting samples based on the needs of the research, not the area (Fig. 1, Tab. 1). In each plot, a micro-plot with a radius of 2 m was determined from the center of the plot, where live tree saplings were counted to estimate the natural regeneration of the forest stand. Furthermore, transects with a length of 7.3 meters were implemented in each plot to measure deadwood characteristics. Field sampling in this study was done during the growing season (August and September 2019).

**Table 1** - Characteristics of plot clusters in the study area.

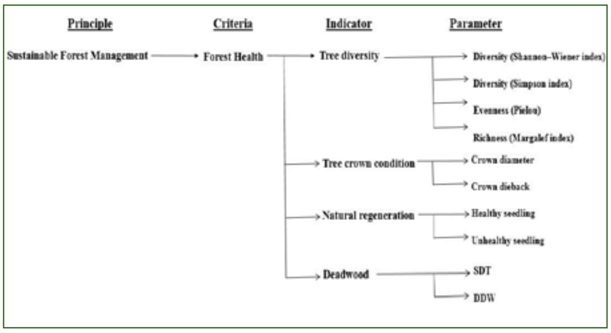
| Plot cluster | Altitude (m asl) | Latitude (N) | Longitude (E) | Aspect | Slope (%) |
|---|---|---|---|---|---|
| CL1 | 1,340 | 4113870 | 319142 | North-east | 50 |
| CL2 | 1,640 | 4112433 | 320213 | East | 60 |
| CL3 | 1,420 | 4112132 | 321420 | East | 35 |
| CL4 | 1,940 | 4111353 | 320650 | East | 65 |
| CL5 | 1,340 | 4114650 | 321224 | South | 70 |

To measure tree diversity, in each plot, species composition, diameter at breast height (DBH), and height of all live trees with a DBH ≥7.5 cm were recorded. To measure crown condition, two crown indicators, including crown diameter and crown dieback, were measured. In each plot, the crown diameter of all trees greater than 7.5 cm DBH was measured in two directions, north-south and west-east, by determining the width of horizontal tree crown projections (Nasiri et al. 2021). The percentage of recent mortality within the live crown (the terminal part of branches with a diameter of less than 2.5 cm) in the upper part facing the sun was defined as crown dieback. Crown dieback was measured in 5% classes across 0% to 100%. It is assumed that the drying of these branches results from stresses other than competition and shading (Zarnoch et al. 2004). To measure natural regeneration, tree seedlings with a DBH<7.5 cm and at least 1 m height were recorded in each plot. Then, the quality of regeneration in terms of crown multi-branching, trunk inclination, and crown asymmetry was also evaluated based on visual observation (Vosoghian and Shojaie Shami 2017, USDA Forest Service 2015). In this study, two deadwood components, including standing dead trees (SDT) and downed dead wood (DDW), were measured. SDT was measured with the same methodology as for living trees. In addition, the quantity and condition of DDW were measured in a different practice compared to that of standing dead trees. The species, diameter classes (four classes: <35 cm, 35-50 cm, 50-75 cm, and >75 cm), and degree of decay (1–4 scales from less decayed to more decayed) were recorded (Sefidi et al. 2018, Woodall et al. 2019).

### *Forest Health Assessment*

We needed to determine the numerical value of each forest health indicator to make the indicators operational. While the numerical measurement of the indicators is challenging, we used a multicriteria analysis process to combine four ecological indicators of forest health. To weigh the contribution of each indicator to forest health, we used the analytical hierarchy process (Saaty 1980) in a meeting with a group of nine decision-makers-academic experts in forest management. Forest health assessment of the study area was performed based on the weighting of the results of the ten forest health parameters related to the four ecological indicators measured in the study area. To derive these weights, we made an iterative series of trade-offs between pairs of parameters. Figure 2 represents the general hierarchy of the principle, criteria, indicator, and parameter selected to assess the forest health. Selecting the principle, criteria, and indicators, the measured values of indicators and the weights of indicators were estimated to assess the forest health. Weights are defined for each indicator from 0 to 1, where 1 is the reference state (healthy), and 0 implies that an area is entirely unhealthy. We multiplied the weight of each indicator by its measured value and summed the values for all the indicators to obtain the final forest health value. The value provides a quantitative perception of the forest health condition in the study area.

**Figure 2** - Hierarchy of principle, criteria, indicators, and parameters selected to assess the forest health of the study area.




### *Data analysis*

The parameters commonly used to characterize the stand structure in this study area are the number of individuals, average DBH, total height, number, volume, and basal area of trees per hectare. To estimate tree diversity, diversity indices, including Shannon–Wiener index and Simpson's index, were used to quantify the tree diversity. Furthermore, Pielou's measure of evenness and the Margalef richness index was used to determine the evenness of species and species richness, respectively. Crown conditions were characterized by crown diameter and crown dieback. We used a four-class model for crown dieback classification, where Class 1= the most healthy (crown dieback degree of 1% to 25%) and Class 4= the least healthy or declining (crown dieback degree of 75% to 100%) (Evans et al. 2012). Natural regeneration was defined as the percentage, number, and health of the seedlings. The number and volume of deadwood (SDT and DDW), as well as mean diameters and degree of decay, were calculated.

For data analysis, first, we performed the Kolmogorov-Smirnov test to assess the data's normality at a confidence level of p-values of < 0.05. These quantitative data were evaluated for homogeneity using Leven's test. To test the means for equality, we used a one-way analysis of variance

(ANOVA), and Duncan's multiple tests were used to compare groups. Biodiversity indicators were calculated using PAST software. Data analysis and graphs were conducted with SPSS 24 software and Excel 2016 software, respectively.

## Results

### *Species composition and stand structure*

A total of 425 individuals representing 19 tree species and 13 families were recorded in the study area (Tab. 2). Betulaceae was the most species-rich family with three species (23.29%), followed by Aceraceae, Fagaceae, and Rosaceae, which contained two species (57.18%). The remaining nine families were presented by single species. The frequency values of tree species ranged from 0.24% to 36.71% in the study area. Oriental beech (*Fagus orientalis* Lipsky, 156 individuals, 36.71%) followed by hornbeam (*Carpinus betulus* L., 90 individuals, 21.18%) were the most frequently found species in the study area. Five species *Alnus glutinosa* (L.) Gaertn., *Corylus avellana* L., *Robinia pseudoacacia* L., *Pinus nigra* J.F.Arnold, *Pyrus glabra* Boiss., exhibited low-frequency values (<1% each). Both mean values of DBH and height parameters were higher in oak trees (DBH= >40 cm, height = > 20 m) than in the other tree species, followed by black alder, oriental beech, and hornbeam species with DBH ~30-35 cm and height ~14-16 m. *Buxus hyrcana* Pojark., *Corylus avellana* L., and *Diospyros lotus* L. were represented by lower values of mean DBH and height with DBH ~18-20 cm and height ~9 m.

Table 3 summarizes the quantitative structure of the stand in the study area. The total basal area was 42.78 $m^2$ $ha^{-1}$. Stand density reached 425 individuals $ha^{-1}$, and their volume reached 504.19 $m^3$ $ha^{-1}$. The mean diameter at breast height (dbh) of all trees was 30.6 cm, and for height, it was 14.32 m. The diameter frequency histogram of the studied forest results in a typical reversed J-shaped diameter frequency plot in the Hyrcanian forest, indicating the dominance of lower-diameter trees in the area (Fig. 3).

**Figure 3** - Diameter frequency distribution of the living trees in the study area using DBH classes of 15 cm bins. Abbreviations: N — number of individuals, DBH — diameter at breast height.

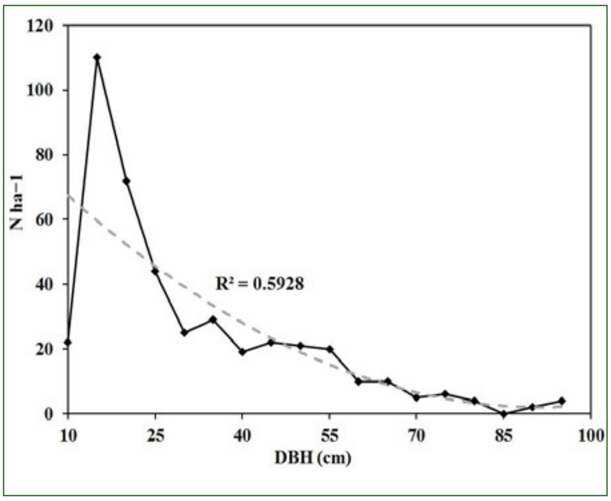



**Table 2** - Composition of 19 tree species in the study area. Abbreviations: N — number of individuals, RF — relative frequency, DBH — diameter at breast height.

| Family | Scientific Name | N | RF (%) | Mean DBH (cm) | Mean height (m) |
|---|---|---|---|---|---|
| Aceraceae | *Acer velutinum* Boiss. | 26 | 6.12 | 25.85 | 12.38 |
| | *Acer cappadocicum* Gled. | 11 | 2.59 | 23.18 | 10.91 |
| Betulaceae | *Carpinus betulus* L. | 90 | 21.18 | 30.56 | 14.44 |
| | *Alnus subcordata* C.A.Mey. | 6 | 1.41 | 32 | 14.83 |
| | *Alnus glutinosa* (L.) Gaertn. | 3 | 0.71 | 35.67 | 13 |
| Buxaceae | *Buxus hyrcana* Pojark. | 5 | 1.18 | 20.20 | 9 |
| Corylaceae | *Corylus avellana* L. | 4 | 0.94 | 18 | 9 |
| Ebenaceae | *Diospyros lotus* L. | 12 | 2.82 | 18.08 | 9.08 |
| Fabaceae | *Robinia pseudoacacia* L. | 1 | 0.24 | 21 | 10 |
| Fagaceae | *Quercus castaneifolia C.A.Mey.* | 31 | 7.29 | 43.48 | 20.10 |
| | *Fagus orientalis* Lipsky. | 156 | 36.71 | 34.86 | 16.19 |
| Hamamelidaceae | *Parrotia persica* (DC.) C.A. Mey. | 4 | 0.94 | 18.50 | 11 |
| Juglandaceae | *Juglans regia* L. | 9 | 2.12 | 22.67 | 10.78 |
| Oleaceae | *Fraxinus excelsior* L. | 18 | 4.24 | 21.33 | 10.50 |
| Rosaceae | *Cerasus avium* (L.) Moench. | 17 | 4.00 | 21.12 | 9.94 |
| | *Pyrus glabra* Boiss. | 2 | 0.47 | 20.50 | 13.50 |
| Tiliaceae | *Tilia begonifolia* Stev. | 19 | 4.47 | 23.74 | 12.32 |
| Ulmaceae | *Ulmus carpinifolia* Gleditsch | 4 | 0.77 | 20.12 | 8.30 |
| | *Zelkova carpinifolia* (Pall.) K. Koch. | 7 | 1.81 | 26.64 | 10.09 |

**Table 3** - Descriptive statistics of stand structure and tree diversity, crown condition, natural regeneration, and deadwood indices for the investigated forest stand in the study area. Abbreviations: DBH — diameter at breast height, N — number of individuals, SDT— standing dead trees, DDW— downed dead wood.

| Indicator | Statistic | Plot cluster | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | CL1 | CL2 | CL3 | CL4 | CL5 | |
| Stand structure descriptors | Mean DBH (cm) | 37.78 | 26.29 | 25.26 | 27.34 | 36.70 | 30.60 |
| | Mean Height (m) | 16.16 | 13.42 | 13.12 | 12.47 | 16.89 | 14.32 |
| | Basal area ($m^2$ $ha^{-1}$) | 12.20 | 5.95 | 6.86 | 6.36 | 11.40 | 42.77 |
| | Stem density (N $ha^{-1}$) | 79 | 78 | 102 | 85 | 81 | 425 |
| | Volume ($m^3$ $ha^{-1}$) | 148.33 | 64.23 | 76.96 | 60.30 | 154.37 | 504.19 |
| Tree diversity | Diversity (Shannon–Wiener index) | 2.05 | 2.17 | 1.89 | 1.92 | 2.06 | 2.11 |
| | Diversity (Simpson index) | 0.82 | 0.85 | 0.78 | 0.78 | 0.82 | 0.80 |
| | Evenness (Pielou) | 0.78 | 0.82 | 0.74 | 0.73 | 0.78 | 0.76 |
| | Richness (Margalef index) | 2.98 | 2.96 | 2.70 | 3.03 | 2.98 | 2.81 |
| Crown condition | Mean crown diameter (m) | 8.59 | 8.36 | 6.42 | 5.99 | 6.21 | 7.09 |
| | Crown dieback (%) | Class 1 | 40.21 | 70.69 | 65.88 | 80.39 | 68.72 |
| | | Class 2 | 29 | - | 34.12 | 0.82 | 2.11 |
| | | Class 3 | 18.01 | 9.2 | - | 14.81 | 9.15 |
| | | Class 4 | 12.78 | 20.11 | - | 3.98 | 20.02 |
| Natural regeneration | Density (N $ha^{-1}$) of healthy seedlings | 254 | 195 | 241 | 213 | 190 | 219 |
| | Density (N $ha^{-1}$) of unhealthy seedlings | 60 | 59 | 55 | 64 | 33 | 54 |
| | Total density (N $ha^{-1}$) | 314 | 254 | 296 | 277 | 223 | 273 |
| Deadwood | Density (N $ha^{-1}$) of SDT | 6 | 2 | 1 | 2 | 4 | 15 |
| | Density (N $ha^{-1}$) of DDW | 28 | 36 | 26 | 45 | 18 | 153 |
| | Total density (N $ha^{-1}$) | 34 | 38 | 27 | 47 | 22 | 168 |
| | Volume ($m^3$ $ha^{-1}$) of SDT | 2.06 | 3.73 | 1.23 | 2.46 | 0.74 | 10.22 |
| | Volume ($m^3$ $ha^{-1}$) of DDW | 11.72 | 5.93 | 6.05 | 7.43 | 2.77 | 33.90 |
| | Total Volume ($m^3$ $ha^{-1}$) | 13.78 | 9.66 | 7.28 | 9.89 | 3.51 | 44.12 |

### *Tree diversity*

Table 3 illustrates the Shannon–Wiener diversity index and Simpson's diversity index, as well as Pielou's measure of evenness and Margalef richness index of the study area. The Shannon-Wiener diversity index is the most widely used species diversity measure. A rich ecosystem with high species diversity has a considerable value for the Shannon-Wiener diversity index, whereas an ecosystem with little diversity has a low value. Concerning the tree species, the Shannon-Wiener diversity index and Simpson's diversity index of the stand were 2.11 and 0.80, respectively. The value of the Shannon-Wiener diversity index is almost average, and Simpson is close to the maximum value (1). This shows the high tree diversity of the area. The value of Pielou's measure of evenness is close to the maximum value (1). In addition, the numerical value of the Margalef index was 2.81, which indicates the intermediate level of richness in the study area. About the plot clusters, CL2 was more diverse than other plot clusters, with the highest mean values of the Shannon-Wiener diversity index (2.17) and Simpson's diversity index (0.85). The minimum values of the diversity indexes of Shannon Weiner (1.89) and Simpson index (0.78) belong to CL3 at altitudes of 700 to 1,500 m. The maximum (0.82) and minimum (0.73) values of Pielou's measure of evenness belonged to CL2 and CL4, respectively. The maximum species richness (3.03) belongs to CL4 at altitudes of more than 1,500 meters. The minimum values of species richness (2.70) belong to CL3 at altitudes of 700 to 1,500 m.

### *Crown condition*

The average values measured for crown diameter (m) and crown dieback (%) are presented in Table 3. The average crown diameter of all existing trees is 7.1 m. Considerable differences in the mean crown diameter of measured trees by each tree species were found (Tab. 4). *Alnus glutinosa* (L.) Gaertn. and oak species showed the highest measured crown diameter (approximately 10 m) among the species in the study area. *Diospyros lotus* L., *Corylus avellana* L., and *Pinus nigra* J.F.Arnold. represented the lowest mean crown diameter (approximately 4.5 m) in the area. CL1 had the highest mean values of crown diameter compared to other plot clusters in the study area. Classification results obtained with the degree of crown dieback showed that the most-healthy class (1) has the highest frequency with 65.18%. 11.38% of trees were in the least healthy class (4) in the study area. In addition, the distribution of crown dieback classes among the plot clusters showed that CL4 with 80.39% and CL1 with 40.21% have the highest and lowest frequencies in the most-healthy class (1), respectively. Based on Figure 4, the degree of crown dieback of the trees in the study area in some species is proportional to the trend of changes in the crown diameter. Especially for three common species in the study area (i.e., Oriental beech, hornbeam, and oak), crown dieback increased with increasing crown diameter.

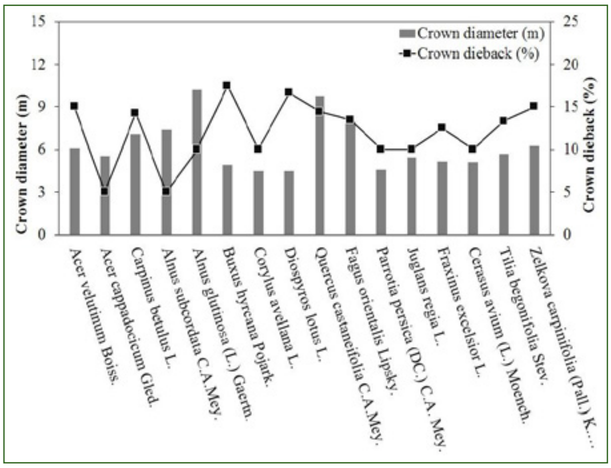
The results of the descriptive statistics of crown dieback percentage among the tree species of the studied forest are presented in Table 4. All the surveyed trees had less than 20% crown dieback. The results indicate that the tree species of *Buxus hyrcana* Pojark., and *Diospyros lotus* L. had the highest crown dieback with values of 17.5% and 16.7%, respectively.

occurred in CL1, where 254.44 healthy seedlings ha$^{-1}$ and 59.56 unhealthy seedlings ha$^{-1}$ from natural regeneration were found. The proportion of oriental beech in natural regeneration was significant (on average 643.5 seedlings ha$^{-1}$, 15.1%). Other species occurring in the area were as follows: hornbeam (548.3 seedlings ha$^{-1}$), oak (443.5 seedlings ha$^{-1}$), Caucasian alder (293.3 seedlings ha$^{-1}$), and sporadically other species. Among healthy seedlings, species of oriental beech, hornbeam, oak, Caucasian alder, and Cappadocian maple (*Acer cappadocicum* Gled) accounted for the highest number of individuals/ha (more than 230 healthy seedlings ha$^{-1}$), while among the unhealthy seedlings species of walnut (*Juglans regia* L.), *Diospyros lotus* L. and *Buxus hyrcana* Pojark., had the lowest number of individuals/ha (less than 25 unhealthy seedlings ha$^{-1}$).

**Table 4** - Descriptive statistical results of crown condition, natural regeneration, and deadwood indices among the tree species of the study area. Abbreviations: N — number of individuals, SDT— standing dead trees, DDW— downed dead wood.

| Crown condition | Crown condition | | Natural regeneration | | | | Deadwood | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | N ha$^{-1}$ | | | | N ha$^{-1}$ | | Volume (m$^3$ ha$^{-1}$) | |
| | Crown diameter (m) | Crown dieback (%) | Healthy seedlings | Unhealthy seedlings | Total | Percent. | STD | DDW | STD | DDW |
| *Acer velutinum* Boiss. | 6.11 | 15 | 187.5 | 46.6 | 234.1 | 5.51 | 2 | 12 | 0.48 | 1.57 |
| *Acer cappadocicum* Gled. | 5.56 | 5 | 232.5 | 41.9 | 274.5 | 6.46 | - | 8 | - | 0.73 |
| *Carpinus betulus* L. | 7.08 | 14.25 | 438.4 | 109.8 | 548.3 | 12.9 | 4 | 46 | 3.01 | 13.78 |
| *Alnus subcordata* C.A.Mey. | 7.39 | 5 | 230.5 | 62.8 | 293.3 | 6.9 | - | 6 | - | 0.46 |
| *Alnus glutinosa* (L.) Gaertn. | 10.22 | 10 | 179.3 | 34.6 | 213.9 | 5.03 | - | - | - | - |
| *Buxus hyrcana* Pojark. | 4.94 | 17.5 | 81.8 | 24.5 | 106.3 | 2.5 | - | 12 | - | 0.41 |
| *Corylus avellana* L. | 4.49 | 10 | 34.1 | 10.2 | 44.3 | 1.04 | - | 2 | - | 0.09 |
| *Diospyros lotus* L. | 4.5 | 16.66 | 157.4 | 36.7 | 194.1 | 4.57 | - | 12 | - | 0.35 |
| *Robinia pseudoacacia* L. | 5.11 | - | 51.1 | 15.3 | 66.4 | 1.56 | - | - | - | - |
| *Quercus castaneifolia* C.A.Mey. | 9.76 | 14.41 | 364 | 79.5 | 443.5 | 10.43 | 2 | 10 | 3.72 | 7.18 |
| *Fagus orientalis* Lipsky. | 7.98 | 13.46 | 518.5 | 125 | 643.5 | 15.14 | 3 | 36 | 2.59 | 9.17 |
| *Parrotia persica* (DC.) C.A. Mey. | 4.59 | 10 | 80 | 40 | 120 | 2.82 | - | - | - | - |
| *Juglans regia* L. | 5.45 | 10 | 61.3 | 18.4 | 79.7 | 1.87 | - | - | - | - |
| *Fraxinus excelsior* L. | 5.17 | 12.5 | 141.7 | 42.2 | 184 | 4.33 | 4 | 7 | 0.32 | 0.2 |
| *Cerasus avium* (L.) Moench. | 5.13 | 10 | 121.1 | 38.9 | 151 | 3.55 | - | - | - | - |
| *Pyrus glabra* Boiss. | 5 | - | 112.4 | 33.7 | 146.2 | 3.44 | - | - | - | - |
| *Tilia begonifolia* Stev. | 5.68 | 13.33 | 144.3 | 45.8 | 190.1 | 4.47 | - | 2 | - | 0.06 |
| *Ulmus carpinifolia* Gleditsch | 4.21 | - | 122.2 | 33.8 | 156 | 3.67 | - | - | - | - |
| *Zelkova carpinifolia* (Pall.) K. Koch. | 6.27 | 15 | 126 | 35.8 | 161.8 | 3.81 | - | - | - | - |

**Figure 4** - Relationship between crown diameter (m) and crown dieback (%) for tree species in the study area.




### *Natural regeneration*

The natural regeneration status of the study area is presented in Table 3. The overall mean seedlings population density was 273 individuals ha$^{-1}$. Assessing the health condition, it was found that unhealthy conditions occurred in 20% of the total number. The average density of healthy seedlings was ~219 individuals ha-$^{1}$ and for unhealthy seedlings, it was ~54 individuals ha$^{-1}$. Most individuals

### *Deadwood*

Based on Table 3, total deadwood was 44.12 m$^3$ ha$^{-1}$ and was formed by 168 individuals per ha$^{-1}$. Therefore, the dead-to-live wood ratio was ~9%, as the living volume was 504.19 m$^3$ ha$^{-1}$. CL4 and CL1 had the largest share of deadwood in terms of number and volume, respectively. DDW accounts for approximately 90% and 77% of deadwood in density and volume, respectively.

The number and volume of deadwood categories were calculated by diameter class in the study area (Fig. 5). This shows that as the diameter of the deadwood categories increases, the number of deadwood categories decreases much faster than dead volume. An apparent decrease in the trend was observed for the DDW category. Another result is that deadwood with a diameter ≤ 50 cm represented ~90% and ~50% of deadwood number and volume, respectively. In addition, the number and volume of deadwood categories were calculated by wood decay classes in the study area (Fig. 6). The significant proportion of deadwood number (77%) and deadwood volume (81%) belonged to Class 1 (least decomposed). About one-third (21%) of all deadwood numbers or 15% of the deadwood volume belonged to Class 2 (the wood was moderately soft). 1.8% and 1.6% of the deadwood number and volume were in Class 3 (the wood was soft and easy to defragment), respectively. Finally, 0.6% and 2.4% of the deadwood number and volume were in Class 4 (the wood had little structural integrity), respectively.

There is considerable variation in the contribution to the number and volume of deadwood by each tree species in the study area. Hornbeam made a major contribution (~38%), followed by oriental beech and oak species with ~25%, whereas *Tilia begonifolia* Stev. demonstrated a minor role for that (~0.1%) (Tab. 4).

**Figure 5** - Distribution of the number (left axis) and volume (right axis) of deadwood categories (SDT; a, DDW; b) by diameter class in the study area. Abbreviations: N — number of individuals, SDT— standing dead trees, DDW— downed dead wood.

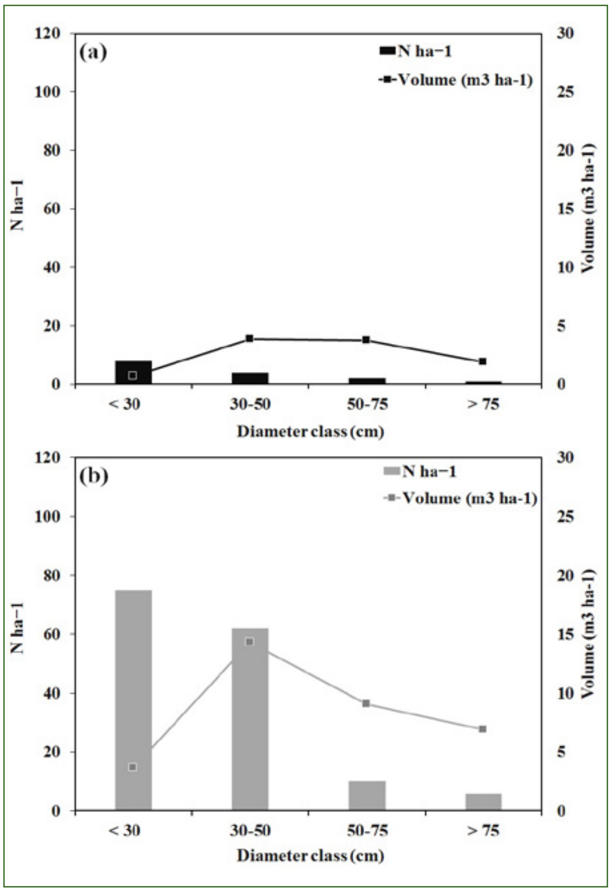
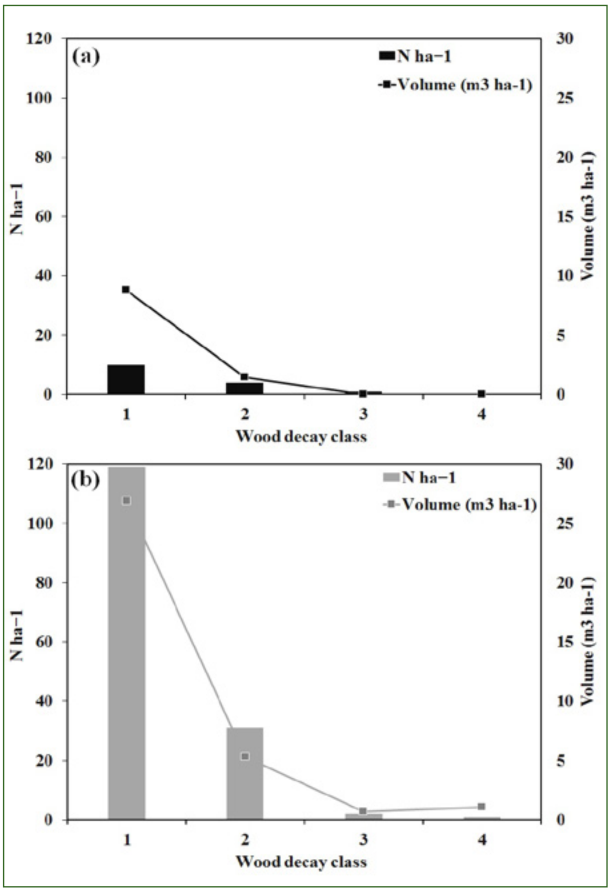



**Figure 6** - Distribution of the number (left axis) and volume (right axis) of deadwood categories (SDT; a, DDW; b) by wood decay class in the study area. N — number of individuals, SDT— standing dead trees, DDW— downed dead wood




### *Forest Health Assessment*

We combined the ten parameters related to the four indicators to obtain a numerical value of forest health. The measured values of these parameters and indicators selected in the study area and assessment of forest health are presented in Table 5. Overall, the estimated forest health value of the study is 0.23, and the proportion of tree diversity that contributed to forest health was weighted highest (61 %), followed by crown condition (21.7 %), natural regeneration (13 %), and deadwood (4.4 %). High proportional contribution by tree diversity indicator.

### *Discussion*

First, we tried to demonstrate some stand structural features of the study area. The measurement of all trees in the study area shows the average density of living trees of 425 per hectare, which is particularly high and is clearly associated with the big-sized dominant trees across the forest. The measured density of tree species was almost similar to the study of Moridi et al. (2015) and Parhizkar et al. (2022). The obtained value was higher than those reported in other studies (Marvie Mohadjer et al. 2009). On the other hand, the density was lower compared to 651 N $ha^{-1}$ (Eslami 2017), and 587 N $ha^{-1}$ (Kahriman et al. 2016) observed in oriental beech forests. Oriental beech

**Table 5** - Details of the contributing indicators for assessing the forest health of the study area. Higher values indicate higher relative importance.

| Indicator | Indicator parameter measure | Indicator parameter weight | Indicator weight | Measured value of indicator | Indicator contribution to forest health |
|---|---|---|---|---|---|
| Tree diversity | Diversity (Shannon–Wiener index) | 0.12 | 0.42 | 0.33 | 0.14 (60.9 %) |
| | Diversity (Simpson index) | 0.12 | | | |
| | Evenness (Pielou) | 0.08 | | | |
| | Richness (Margalef index) | 0.08 | | | |
| Crown condition | Crown diameter | 0.1 | 0.18 | 0.29 | 0.05 (21.7 %) |
| | Crown dieback | 0.1 | | | |
| Natural regeneration | Healthy seedlings | 0.16 | 0.24 | 0.11 | 0.03 (13 %) |
| | Unhealthy seedlings | 0.04 | | | |
| Deadwood | SDT | 0.12 | 0.16 | 0.09 | 0.01 (4.4 %) |
| | DDW | 0.08 | | | |
| | Sum | 1 | 0.85 | 0.23 | |

is the main tree species of the forest, with a mean DBH of ~34 cm and a mean height of ~16.2 m. The same results were reported in the oriental beech stands in the north of Iran (Moridi et al. 2015). Most trees belonged to the smallest diameter class in the study area. The diameter frequency distribution of the living trees in the study area within size classes showed the same pattern in the study of Pourmajidian et al. (2010) and Khanalizadeh et al. (2020) in Oriental beech-dominated forests in Iran. The average volume of living trees in the stand was 504.19 $m^3$ $ha^{-1}$, and the basal area was 42.78 $m^2$ $ha^{-1}$, close to the reference values identified in the temperate forests (Mervi Mohadjer 2005).

Regarding species diversity, Shannon-Wiener's index (1.89 to 2.17) and Simpson's index (0.78 to 0.85) showed high diversity, which demonstrates that the probability that a species become dominant is low. The Pielou's evenness varied from 0.73 to 0.82 (high diversity). While the Margalef species richness index varied from 2.7 to 3.03 (intermediate diversity). Based on the results obtained from the characteristics of tree diversity, evenness, and species richness, it has been determined that the values of these indicators are relatively high in the forest stand of the study area. The tree diversity was expected to be high considering the position of this measured stand in the Hyrcanian sub-mountain forest, as well as its intactness. The results of these indicators in this study are also comparable to those obtained in other works investigating tree diversity in oriental beech forests (Sohrabi et al. 2011, Tavankar et al. 2014). Furthermore, the forest stands under investigation were in an optimal stage, and beech species—the dominant species—provided suitable environmental conditions for the presence of retaining live trees. Considering that the selected forest stand is a natural broadleaf forest, the high biodiversity in these temperate deciduous forests can be attributed to the appropriate temperature, soil, and high humidity (Hosseini 2004). This result is in accordance with the results of Brockerhoff et al. (2017) and Mori et al. (2017) in temperate forest ecosystems.

In the present study, we assessed crown condition using a quantitative characteristic, i.e., crown diameter, and a qualitative characteristic, i.e., crown dieback. The large size of tree crowns in the study area with the average tree crown diameter of 7.1 m across the study area indicates the high fertility of the habitat and the low competitive effect between species, which is in accordance with previous findings in ecologically equivalent areas (Bakhshandeh Navroud et al. 2018, Dieler and Pretzsch 2013). Based on the obtained results, trees with larger crown diameters showed more crown dieback. This result is in accordance with the studies of Hosseinzadeh and Pourhashemi (2015) and Raptis et al. (2018), where a higher percentage of trees with a larger crown size were in the severe crown dieback class. In contrast, in the study of Fallah and Haidari (2018), trees with a smaller crown size are more exposed to dieback. In this study, on average, almost 14% of the crowns of the investigated trees were dry. In the study of Marvie Mohadjer and Moradi (2012) evaluating the crown health of beech trees in northern Iran, the results showed that 84% of the examined trees had a healthy crown. Also, the frequency of trees in crown dieback classes showed that the healthiest class (Class 1) has the highest frequency with 65% and the lowest healthy class (Class 4) has only 11% frequency. While in the study of Dezfoli et al. (2020), the severe dieback class has the highest frequency compared to the other dieback classes. Furthermore, most of the trees with closed and medium-sized crowns are in the dieback Class 1 and have a relatively better crown condition. In contrast, trees with open crowns showed higher dieback in the study area.

Concerning the assessment of the natural regeneration in the study area, it was found that, on average, there are 273 seedlings per hectare in the total stand, which is a high seedling density compared to other studies reported by Bayat et al. (2017), Sagheb Talebi et al. (2020). Like untouched forest stands, the density of seedlings exhibited good overall regeneration in the study area in the lack of human access and degradation, and also more suitable humidity and heat conditions have made it possible for better regeneration in the area (Safari et al. 2018, Nasiri et al. 2018). Furthermore, in the study area, 80% of the seedlings were healthy, and 20% were unhealthy. The highest frequency of tree species in the regeneration layer belongs to the beech species. This is due to the shade-tolerant nature of the beech species and their establishment in the high crown canopy cover (more than 70%) in the study area, similar to the study of Mortezapour et al. (2006) and Žemaitis et al. (2019). Moreover, high regeneration density is associated with a high beech basal area in the overstory (Axer et al. 2021), which is consistent with our results. In general, the natural regeneration condition in the study area is favorable. The limited number of unhealthy seedlings can be associated with extreme cold in winter, along with dryness and extreme heat waves in summer.

The total deadwood amount exceeds 40 $m^3$ $ha^{-1}$ in the study area, which is particularly relevant in temperate Hyrcanian forests. In different types of Hyrcanian forests, the amount of deadwood ranges from 3 to 120 $m^3$ $ha^{-1}$ (Amanzadeh et al. 2013, Müller et al. 2015, Sefidi et al. 2018). The amount of deadwood has been considered the main driver of stand structure, tree species diversity, and the presence of old-growth forest specialists (Bässler et al. 2014, Müller et al. 2015). This amount in the current study is higher than the value that is considered to be a threshold for forest biodiversity conservation in old-growth forests (Badalamenti et al. 2017). Another essential feature is the relationship between two main deadwood categories, including SDT, and DDW, which both play an important role in forest plant diversity. In this study, only 23% of the total deadwood volume is found in SDT. This result is similar to the result of Sefidi and Etemad (2014) in a mixed beech forest in northern Iran, where 34% of all dead trees were SDT. A similar value of DDW share compared to what was obtained in this study (i.e., 77%) was reported by Amanzadeh et al. (2013). Regarding the density of deadwood, compared to other similar temperate forests, the study area had a moderate number of SDT (15 per hectare). At the same time, the area shows a relatively high number of DDW (153 per hectare). Moreover, the diameter distribution of the deadwood combined with the decay class provided further information. The distribution of deadwood volume, both SDT and DDW, with the most minor diameters (DBH < 30 cm), is less common (10%). In contrast, trees with DBH > 30 cm are more represented in the study area (90%), as expected in old-growth beech forests (Sefidi et al. 2013). This should occur due to the gradual natural loss of huge living and old trees, particularly in the stands affected by some natural disturbances (Badalamenti et al. 2017). 20% of deadwood volume was in the very large-sized diameter class (DBH > 75 cm) that can lead to establish and development of regeneration and stand initiation by gap opening derived from large beech trees (Stiers et al. 2019). The highest number of deadwood (90%) was noticed in the lower diameter class (DBH < 30 cm). These were dead trees that had a less favorable bio-space, and a competitive environment was the most common cause of tree death as a well-documented factor in temperate forests (Das et al. 2011). From the point of wood decay, Class 1 had the largest share (~81%) of the deadwood number and volume. In other temperate forests, a lower level of decomposition was also found (Müller-Using and Bartsch 2009, Sefidi et al. 2013). SDT was only in the first tree decay classes, whereas DDW was distributed in all four decay classes. In general, deadwood decomposition is dependent on the functional group of plants, exposure time, and precipitation, as well as species identity (Rawlik et al. 2021). Among the existing tree species, hornbeam had the highest percentage of deadwood volume, which can be due to the higher number of deadwood per hectare of this species and its faster decay rate, especially compared to beech species (Sefidi and Marvi Mohadjer 2009).

Finally, the estimated forest health value provides a sense of the quantified status of forest health but remains largely conceptual in its operability. Based on the results, the forest health value of the study area is highly related to tree diversity. Similarly, increasing importance is attributed to the tree diversity influencing forest health in previous studies (Bussotti et al. 2018, Kacholi 2019, Safe'i et al. 2022).

## Conclusions

Monitoring programs are required to manage and maintain the sustainability of forests in the Hyrcanian region. Ecological monitoring of natural forests in the region is a consistent and often long-term control measure that identifies and evaluates different phenomena and their effects on the forests based on different quantitative and qualitative criteria. Health monitoring through ecological indicators makes it possible to assess the status of forest ecosystems and then ensure the sustainability of forest activities. The forest health monitoring method (FHM) and emphasizing the biodiversity of forest ecosystems can be very efficient for forest monitoring systems. In this study, the indicators of tree diversity, crown condition, natural regeneration, and deadwood have been selected for monitoring the health of the forest, and the analysis of the forest monitoring data allows the evaluation of the general characteristics of the forest, such as stability, based on these indicators. The focus of this study was on forest health in the oriental beech forest as a result of using the FHM method as a standard method designed in temperate forests in North America, which is also used in other forest areas of the world. The results of the indicators selected in this study, considering the intactness of the investigated forest stands, can be used as a basis for assessing the health of the forest and comparing it with other similar forests, and determining the number of deviations caused by natural and human changes.

## References

Amanzadeh B.K., Sagheb-Talebi K.H., Foumani B., Fadaie F., Camarero J., Linares J. 2013 - *Spatial distribution and volume of dead wood in unmanaged Caspian Beech (*Fagus orientalis*) forests from northern Iran.* Forests 4: 751-765.

Anderson S.M., Heath L.S., Emery M.R., Hicke J.A., Littell J.S., Lucier A., Masek J.G., Peterson D.L., Pouyat R., Potter K.M., Robertson G., Sperry J. 2021 - *Developing a set of indicators* *to identify, monitor, and track impacts and change in forests of the United States.* Climate Change 165: 13.

Axer M., Martens S., Schlicht R., Wagner S. 2021 - *Modelling natural regeneration of European beech in Saxony, Germany: identifying factors influencing the occurrence and density of regeneration.* European Journal of Forest Research 140: 947–968.

Badalamenti E., La Mantia T., La Mantia G., Cairone A., La Mela Veca D.S. 2017 - *Living and dead aboveground biomass in Mediterranean forests: evidence of old-growth traits in a* Quercus pubescens *willd. s.l. stand.* Forests 8: 187.

Bakhshandeh Navroud B., Abrari vajari K., Pilehvar B., Kooch Y. 2018 - *Evaluating Plant diversity and some features of Oriental beech in different tree-layers (Case study: Beech forests, Asalem, Guilan).* Plant Ecosystem Conservation 6 (12): 109-122. [In Persian]

Bennett D.D., Tkacz B.M. 2008 - *Forest health monitoring in the United States: a program overview.* Australian Forestry 71 (3): 223-228.

Bayat M., Namiratiyan M., Pourshakouri F. 2017 - *Presentation of Ingrowth models and determination of biotic and abiotic factors affecting regeneration in the Hyrcanian forests.* Journal of Wood and Forest Science and Technology 4 (22): 447-474. [In Persian]

Berryman E., McMahan A. 2019 - *Using tree canopy cover data to help estimate acres of damage.* In: "Forest Health Monitoring: national status, trends, and analysis 2018." Potter K.M., Conkling B.L. eds. Gen. Tech. Rep. SRS-239. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 125–141.

Bigdeli A., Hojati Saeedi S., Ebadifar M. 2014 - *Climate zoning of Gilan province using rainfall and temperature raster layers in GIS.* The First National Conference on Geography, Tourism, Natural Resources and Sustainable Development, Iran Tourism Association, Tehran.

Bässler C., Ernst R., Cadotte M., Heibl C., Müller J. 2014 - *Near-to-nature logging influences fungal community assembly processes in a temperate forest.* Journal of Applied Ecology 51: 939-948.

Brockerhoff E.G., Barbaro L., Castagneyrol B., Forrester D.I., Gardiner B., González-Olabarria J.R., O'B P., Lyver N., Meurisse A., Oxbrough H., Taki I.D., Thompson F., van der Plas J.H. 2017 - *Forest biodiversity, ecosystem functioning and the provision of ecosystem services.* Biodiversity Conservation 26: 3005–3035.

Bussotti F., Feducci M., Iacopetti G., Maggino F., Pollastrini M., Selvi F. 2018 - *Linking Forest diversity and tree health: preliminary insights from a large-scale survey in Italy.* Forest Ecosystem 5:12.

Carnegie A.J., Lawson S., Wardlaw T., Cameron N., Venn T. 2018 - *Benchmarking forest health surveillance and biosecurity activities for managing Australia's exotic forest pest and pathogen risks.* Australian Forestry *81* (1): 14-23.

Conkling B.L., Hoover C.M., Smith W.D., Palmer C.J. 2002 - *Using forest health monitoring data to integrate above and below ground carbon information.* Environmental Pollution 116 (1): S221-232.

Das A., Battles J., Stephenson N.L., van Mantgem P.J. 2011 - *The contribution of competition to tree mortality in old-growth coniferous forests.* Forest Ecology and Management 261: 1203–1213.

Department of Environment 2017 - *Third National Communication to United Nations Framework Convention on Climate Change (UNFCCC).* Department of Environment, Islamic Republic of Iran. 256 p.

Dezfoli H., Badehian Z., Naghavi H., Karami S. 2020 - *The relationship of some tree characteristics, forest stands and physiographic factors with the rate of dieback.* Wood and Forest Science and Technology 26 (3): 69-82. [In Persian]

Dieler J., Pretzsch H. 2013 - *Morphological plasticity of European beech (*Fagus sylvatica *L.) in pure and mixed-species stands.* Forestry Ecology and Management 295: 97-108.

Eslami A. 2017 - *Determination the structure of oriental beech,* Fagus orientalis *Lipsky stands (Case study: Asalem watershed forests, north of Iran).* Caspian Journal of Environmental Science 15 (1): 57-66.

Evans B., Lyons T., Barber P., Stone C., Hardy G. 2012 - *Enhancing a eucalypt crown condition indicator driven by high spatial and spectral resolution remote sensing imagery.* Journal of Applied Remote Sensing 6: 1-15.

Fallah A., Haidari M. 2018 - *Investigating the Oak Decline in different Crown-Dimensions in Middle Zagros Forests (Case Study: Ilam).* Iranian Forest Ecology Journal 6 (12): 9-17. [In Persian]

Fraser B.T., Congalton R.G. 2021 - *Monitoring Fine-Scale Forest Health Using Unmanned Aerial Systems (UAS) Multispectral Models.* Remote Sensing 13: 4873.

Gupta S.K., Pandey A.C. 2021 - *Spectral aspects for monitoring forest health in extreme season using multispectral imagery.* Egyptian Journal of Remote Sensing and Space Science 24 (3): 579-586.

Haikal F.F., Safe'i R., Kaskoyo H., Darmawan A. 2020 - *Pentingnya pemantauan kesehatan hutan dalam pengelolaan hutan kemasyarakatan (studi kasus HKm Beringin Jaya yang di kelola oleh KTH Lestari Jaya 8).* J Hutan Pulau-Pulau Kecil 4 (1): 31-43.

Hosseini S.M. 2004 - *Incomparable Roles of Caspian Forests: Heritage of Humankind.* Forest Science 3: 31- 40.

Hosseinzadeh J., Pourhashemi M. 2015 - *An investigation on the relationship between crown indices and the severity of oak forests decline in Ilam.* Iranian Journal of Forest 7(1): 57-66. [In Persian]

Kacholi D.S. 2019 - *Assessment of Tree Species Richness, Diversity, Population Structure and Natural Regeneration in Nongeni Forest Reserve in Morogoro Region, Tanzania.* Tanzania Journal of Science 45 (3): 330-345.

Kahriman A., Altun L., Güvendi E. 2016 - *Determination of stand structure in even-aged Oriental Beech Forests in Turkey.* Bosque (Valdivia) 37 (3): 557-569.

Khanalizadeh A., Rad J.E., Zahedi Amiri G.Z., Zare H., Rammer W., Lexer M.J. 2020 - *Assessing selected microhabitat types on living trees in Oriental beech (*Fagus orientalis *L.) dominated forests in Iran.* Annals of Forest Science 77: 91.

Kolb T., Wagner M., Covington W. 1995 - *Forest health from different perspectives.* United States Department of Agriculture Forest Service general technical report RM: 5–13.

Lausch A., Borg E., Bumberger J., Dietrich P., Heurich M., Huth A., Jung A., Klenke R., Knapp S., Mollenhauer H., Paasche H., Paulheim H., Pause M., Schweitzer C., Schmulius C., Settele J., Skidmore A.K., Wegmann M., Zacharias S., Kirsten T., Schaepman M.E. 2018 - *Understanding Forest Health with Remote Sensing, Part III: Requirements for a Scalable Multi-Source Forest Health Monitoring Network Based on Data Science Approaches.* Remote Sensing 10 (7): 1120.

Lestari R.N., Wulandari C., Safe'I. R., Darmawan A. 2019 - *Analysis of Above Ground Carbon as Indicator for Forest Health in Protection Forest Registers 25.* Journal of Sylva Indonesiana 2 (1): 1 – 10.

Lu Y., Wang R., Zhang Y., Su H., Wang P., Jenkins A., Ferrier R.C., Bailey M., Squire G. 2015 - *Ecosystem health towards sustainability.* Ecosystem Health Sustainability 1(1): 2.

Mangold R. 1999 - *Forest Health Monitoring: Field Methods Guide.* USDA Forest Service, USA.

Marvie Mohadjer M.R., Zobeiri M., Etemad V., Jour Gholami M. 2009 - *Performing the single selection method at compartment level and necessity for full inventory of tree species.* Iranian Journal of Natural Resources 61(4): 889-908. [In Persian]

Marvie Mohadjer M.R. 2005 - Silviculture. University of Tehran Press. 387 p.

Marvie Mohadjer M.R., Moradi M. 2012 - *Morphological and quantitative characteristics of mature beech trees (*Fagus orientalis *Lipsky) in two regions of Sistan in Guilan and Kheiroud in Mazandaran.* Iranian Journal of Forest and Poplar Research 19 (3): 300. [In Persian]

Mori A.S., Lertzman K.P., Gustafsson L. 2017 - *Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology.* Journal of Applied Ecology *54* (1): 12-57.

Moridi M., Sefidi K., Etemad V. 2015 - *Stand characteristics of mixed oriental beech (*Fagus orientalis *Lipsky) stands in the stem exclusion phase, northern Iran.* European Journal of Forest Research 134: 693–703.

Mortezapour S., Marvie Mohadjer M.R., Sagheb Talebi K.H., Zahedi Amiri G.H. 2006 - *Relationship between regeneration of oriental beech (*Fagus orientalis *Lipsky) and land form.* Iranian Journal of Forest and Poplar Research 4 (22): 447-474. [In Persian]

Müller J., Simon T., Roland B., Sagheb-Talebi K.H., Barimani V.H., Seibold S., Ulyshen M.D., Gossner M.M. 2015 - *Protecting the forests while allowing removal of damaged trees may imperil saproxylic insect biodiversity in the Hyrcanian Beech Forests of Iran.* Conservation Letters. 8 p. 10.1111/conl.12187

Müller-Using S., Bartsch N. 2009 - *Decay dynamic of coarse and fine woody debris of a beech (*Fagus sylvatica *L.) forest in Central Germany.* European Journal of Forest Research 128: 287–296.

Nasiri V., Darvishsefat A.A., Arefi H., Pierrot-Deseilligny M., Namiranian M., Le Bris A. 2021 - *Unmanned aerial vehicles (UAV)-based canopy height modeling under leaf-on and leaf-off conditions for determining tree height and crown diameter (case study: Hyrcanian mixed forest).* Canadian Journal of Forest Research 51 (7): 962-971.

Nasiri N., Marvie Mohadjer M.R., Etemad V., Sefidi K., Mohammadi L., Gharehaghaji M. 2018 - *Natural regeneration of oriental beech (*Fagus orientalis *Lipsky) trees in canopy gaps and under closed canopy in a forest in northern Iran.* Journal of Forest Research 29: 1075–1081.

O'Laughlin J., Livingston R.L., Thier R., Thornton J.P., Toweill D.E., Morelan L. 1994 - *Defining and Measuring Forest Health.* Journal of Sustainable Forestry 2 (1-2): 65-85.

O'Laughlin J. 1994 - *Assessing Forest Health Conditions in Idaho with Forest Inventory Data.* Journal of Sustainable Forestry 2 (3-4): 221-247.

Parhizkar P., Sadeghzadeh Hallaj M.H., Hassani M. 2022 - *Managed vs. unmanaged* Fagus orientalis *Lipsky forests: Structure and diversity of natural regeneration in northern Iran.* Journal of Forest Science 68: 318–328.

Pourmajidian M.R., Jalilvand H., Fallah A., Fallah A., Hosseini S.A., Parsakhoo A., Vosoughian A., Rahmani A. 2010 - *Effect of shelterwood cutting method on forest regeneration and stand structure in a Hyrcanian forest ecosystem.* Journal of Forest Research 21: 265–272.

Potter K.M., Conkling B.L. 2022 - *Forest health monitoring: national status, trends, and analysis 2021.* Gen. Tech. Rep. SRS-266. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 193 p. https://doi.org/10.2737/SRS-GTR-266.

Putra E.I., Supriyanto H., Purnomo N.F., Haneda, Matangaran J.R. 2019 - *The use of Analytical Network Process (ANP) Approach to Assess the Health of Natural Production Forest.* IOP Conf. Series: Earth and Environmental Science 394, 012040.

Raptis D., Kazana V., Kazaklis A., Stamatiou C. 2018 - *A Crown Width-Diameter Model for Natural Even-Aged Black Pine Forest Management*. Forests 9 (10): 610.

Rawlik K., Nowiński M., Jagodziński A.M. 2021 - *Short life–fast death: decomposition rates of woody plants leaf- and herb-litter.* Annals of Forest Science 78: 6.

Robinson R. 2008 - *Forest health surveillance in Western Australia: a summary of major activities from 1997 to 2006.* Australian Forestry 71(3): 202-211.

Sadeghi S.H.R., Sharifi Moghadam E. 2021 - *Integrated Watershed Management vis-a-vis water–energy–food Nexus." Water–Energy–Food Nexus.* Springer, Singapore: 69–96.

Sadeghi S.H.R., Vafakhah M., Moosavi V., Pourfallah Asadabadi S., Sadat Sadeghi Khaledi P., Darvishan A., Bagheri R., Fahraji Mosavinia S.H., Majidnia A., Gharemahmudli S., Moradi Rekabdarkolaei H. 2022 - *Assessing the health and ecological security of a human induced watershed in central Iran. Ecosyst*em Health and Sustainability 8:1.

Safari M., Sefidi K., Alijanpoor A., Elahian M.R. 2018 - *Study of natural Regeneration in* Quercus macranthera *stands in different physiographic conditions in Arasbaran forests.* Ecology of Iranian Forests 6 (12): 1-8. [In Persian]

Safe'i R., Darmawan A., Irawati A.N., Pangestu A.Y., Arwanda E., Syahiib A.N. 2022 - *Cluster analysis on forest Health conditions in Lampung Province.* International Journal of Design & Nature and Ecodynamics 17 (2): 257-262.

Safe'i R., Latumahina F.S., Dewi B.S., Ardiansyah F. 2021 - *Short Communication: Assessing the state and change of forest health of the proposed arboretum in Wan Abdul Rachman Grand Forest Park, Lampung, Indonesia.* Biodiversitas 22 (4): 2072-2077.

Safe'i R., Darmawan A., Kaskoyo H., Gayansa Rezinda C.F. 2020 - *Analysis of Changes in Forest Health Status Values in Conservation Forest (Case Study: Plant and Animal Collection Blocks in Wan Abdul Rachman Forest Park (Tahura WAR)).* Journal of Physics: Conference Series, Volume 1842, International Conference on Science Education and Technology (ICOSETH) 2020, 24 October 2020, Surakarta, Indonesia.

Sagheb Talebi K.H., Parjizkar P., Hassani M., Amanzadeh B., Hemmati A., Khanjani Shiraz B., Amini M., Mohammadnezhad Kiasari S., Mirkazemi S.Z., Karimidoost A.A., Maghsudloo K., Mortazavi M., Delfan Abazari B., Karandeh M. 2020 - *Regeneration and establishment of natural young generation in intact oriental beech stands of Hyrcanian forests.* Forest Research and Development 6 (3): 519-541. [In Persian]

Sarvati M.R., Fathollahzadeh T. 2003 - *Investigation on various erosion types in Masouleh-Rudkhan drainage basin (Gilan Province).* Iranian Journal of Natural Resources 56 (3): 155-164. [In Persian]

Saaty T.L. 1980 - *The Analytic Hierarchy Process*. McGraw-Hill: New York, NY, USA: 1–287.

Sefidi K., Pourgoli Z., Sagheb-Talebi K., Keivan Behjou K. 2018 - *Stand characteristics of gap formation phase through the development of oriental beech (*Fagus orientalis *Lipsky) stands in the Hyrcanian Forests, northern Iran.* Austrian Journal of Forest Science 135 (2): 137-158.

Sefidi K., Etemad V. 2014 - *The amount and quality of dead trees in a mixed beech forest with different management histories in northern Iran.* Biodiversitas 15(2): 162-168.

Sefidi K., Marvi Mohadjer M.R. 2009 - *Amount and quality of dead trees (snag and logs) in a mixed beech forest with different management histories.* Journal of Forest and Wood Products 62 (2): 191-202. [In Persian]

Sefidi K., Marvi Mohadjer M.R., Mosandl R.M., Copenheaver C.A. 2013 - *Coarse and Fine Woody Debris in Mature Oriental Beech (*Fagus orientalis *Lipsky) Forests of Northern Iran.* Natural Areas Journal *33* (3): 248-255.

Sohrabi V., Rahmani R., Moayeri M.H., Jabbari S. 2011 - *Assessment of Structural Diversity of Beech Forest Stands in North of Iran.* International Journal of Biological Science 3(3): 60-68.

Steinman J. 2004 - *Forest Health Monitoring in the Northeastern United States: disturbances and conditions during 1993–2002.* NA-TP-01-04. Newtown Square, PA: U.S. Department of Agriculture Forest Service, Northeastern Area State and Private Forestry. 46 p.

Stiers M., Willim K., Seidel D., Ammer Kabal C.M., Stillhard J., Annighöfer P. 2019 - *Analyzing Spatial Distribution Patterns of European Beech (*Fagus sylvatica *L.) Regeneration in Dependence of Canopy Openings.* Forests 10 (8): 637.

Stone C. 1999 - *Assessment and monitoring of decline and dieback of forest eucalypts in relation to ecologically sustainable forest management: a review with a case study.* Australian Forestry 62 (1):51-58.

Tavankar F., Picchio R., Lo Monaco A.R., Bonyad A.E. 2014 - *Forest management and snag characteristics in Northern Iran lowland forests.* Journal of Forest Science 60 (10): 431-441.

Torres P., Rodes-Blanco M., Viana-Soto A., Nieto H., García M. 2021 - *The Role of Remote Sensing for the Assessment and Monitoring of Forest Health: A Systematic Evidence Synthesis.* Forests 12: 1134.

Trumbore S., Brando P., Hartmann H. 2015 - *Forest health and global change.* Science 349: 814–818.

Xiao F., Ouyang H., Zhang Q., Fu B., Zhang Z. 2004 - *Forest ecosystem health assessment and analysis in China.* Journal of Geographical Science 14 (1): 18–24.

U.S. Department of Agriculture (USDA) Forest Service 2020 - *Forest ecosystem health indicators. Forest Service, FS-1151, March 2020*. 28 p. https://usfs.maps.arcgis.com.

U.S. Department of Agriculture (USDA) Forest Service 2015 - *A regeneration indicator for forest inventory and analysis: history, sampling, estimation, analytics, and potential use in the midwest and northeast United States.* Gen. Tech. Rep. NRS-148. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 74 p.

U.S. Department of Agriculture (USDA) Forest Service 2005 - *Forest inventory and analysis national core field guide, Vol. 1: Field data collection procedures for phase 2 plots*.

Woodall C.W., Monleon V.J., Fraver S., Russell M.B., Hatfield M.H., Campbell J.L., Domke G.M. 2019 - *The downed and dead wood inventory of forests in the United States.* Scientific Data 6:180303.

Woodall C.W., Amacher M.C., Bechtold W.A., Coulston J.W., Randolph K.C., Jovan S., Schulz B.K, Smith G.C., Tkacz B., Will-Wolf S. 2011 - *Status and future of the forest health indicators program of the USA.* Environmental Monitoring and Assessment 177: 419-436.

Vakili M., Shakeri Z., Motahari S., Farahani M., Robbins Z.J., Scheller R.M. 2021 - *Resistance and Resilience of Hyrcanian Mixed Forests under Natural and Anthropogenic Disturbances.* Frontiers in Forests and Global Change 4: 640451.

Vosoghian A., Shojaie Shami A. 2017 - *Investigation of structure and regeneration forest trees in logged and non-logged (case of study: Darabkola Forest of Sari).* Journal of Natural Ecosystems of Iran 7(4): 69-82. [In Persian]

Zarnoch S.J., Bechtold W.A., Stolte K.W. 2004 - *Using crown condition variables as indicators of forest health.* Canadian Journal of Forest Research 34: 1057–1070.

Žemaitis P., Gil W., Borowski Z. 2019 - *Importance of stand structure and neighborhood in European beech regeneration.* Forest Ecology and Management 448: 57-66.