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Challenges in Managing Hyrcanian Forests with the Selective Harvesting Across 10 years (Case study: Galandroud Forestry plan, Iran)

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ABSTRACT

Aims: The primary objective of close-to-nature silvicultural practices is to utilize forest ecosystem services in a sustainable manner. These approaches promote continuous-cover forestry to maintain forest stock and regeneration while allowing for the sustainable exploitation of forest resources. While numerous studies indicate that selective cutting can conserve forest resources and enhance environmental stability and quality, other research warns that improper implementation may lead to adverse effects. This study examines the execution effects of the single-selection method in District 14 of the Galandroud Forestry Plan over a 10-year harvesting period.

Materials & Methods: To assess and compare changes over ten years resulting from the implementation of selection logging, information, and inventory data from both the initial and revised plans were utilized. Data were collected using a systematic random sampling approach with circular plots (1000 m^2). A total of 283 sample plots were surveyed at the beginning and end of the study period (2005-2015). The density, volume, and trunk quality of standing trees, as well as the abundance of regeneration per unit area, were calculated for each sampling plot. After calculating the silvicultural characteristics for all sampling plots, a t-test analysis was conducted to compare the beginning (2005) and the end (2015) of the period to investigate the impacts of forest management using the selection method.

Findings: The results indicated significant decreases in tree standing volume, tree density, and Lorrey's tree height, with reductions of 63.13 $m^3.ha^{-1}$ (25.3%), 22 trees per hectare (18.4%), and 4.2 meters (16.7%), respectively, after 10 years of management. Consequently, a total of 53,660.5 m^3 of standing volume and 18,623.5 individual trees were lost across the 850 hectares of exploited forests. Tree density for trees with a diameter greater than 95 cm remained unchanged. In comparison, the standing volume of large trees (with a DBH greater than 105 cm) increased, likely due to changes in regulations and directives from the Forests Organization of Iran concerning the utilization of thick trees. The quality of standing timber in grades 1, 3, and 4 also declined across the studied area. Furthermore, regeneration abundance for 17 major woody species in the district decreased, with the total number of seedlings dropping from 5,106 to 2,448 individuals per hectare (a 52% reduction).

Conclusion: According to the results of this research, all surveyed silvicultural and forest structural parameters in these forests indicate a state of forest destruction resulting from overharvesting and the incorrect implementation of the selective method. Overall, the failure of this forest management initiative—one of the oldest single-selection method projects in the Hyrcanian forests of Iran—was attributed to several factors, including administrative issues, exploitation rates exceeding the growth capacity of the forest stands, the recruitment of unqualified labor, the profiteering of project implementers, and a lack of proper supervision over the execution of the forest utilization plan.

Keywords: Forest Sustainability; Silvicultural Practice; Single-Tree Selection; Uneven-Aged Forests; Lorrey's Mean Tree Height.

CITATION LINKS

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Introduction

Forest management and silviculture have undergone significant development over the past few decades. Leading countries (e.g., Germany, Slovenia, Austria, Switzerland) have practiced scientifically based forest management for more than two centuries [1,2], applying methods from traditional exploitation and clear-cutting to shelterwood and selection systems [3]. They continually refine these approaches through rigorous assessments, increasingly embracing close-to-nature forestry as a foundational and advanced strategy for mixed broadleaf forests [4–6].

Selecting appropriate forestry methods is crucial for maintaining ecosystem stability and advancing towards sustainable forest management objectives [5,7,8]. Today, close-to-nature forestry is recognized as a method that minimizes intervention in the overstory, supports natural regeneration, conserves native species, preserves landscapes and habitats, and maintains a higher number of mature trees in the forest [5, 9, 10]. Unlike conventional methods, the given forestry method leads to increased heterogeneity on forest surfaces and maintains biodiversity in forests by introducing varied environmental conditions [5,8]. The selection method (both single and group selection), as a close-to-nature approach, has been identified in numerous studies as an effective management technique for preserving diversity and plant composition in uneven-aged high forests by selectively harvesting individual trees or small groups of trees [4,11]. Tree harvest via the selection method partially opens up the forest's canopy, providing conditions for the establishment of new generations. In contrast, the canopy remains closed in other parts, ensuring the survival of species that are not resistant to the destruction and changes caused by utilization. The objective behind this forestry method is to maintain and establish mixed uneven-aged forests [11,12]. To execute this method, trees marked for cutting are harvested from different diameters, stories, and species, ensuring that the forest structure and its initial biomass remain constant by harvesting volumes identical to the annual increment rate of the relative stand [4]. Although many studies suggest that selective cutting can promote the conservation and sustainability of forest resources while improving environmental stability and quality [13], some research highlights potential drawbacks. The results of Lotfi et al. [14] in the Aldan Forests of Sari showed that in managed stands using the selection method, the number of trees per hectare was high; however, their small size resulted in a relatively low volume stock. In natural stands where no management interventions were applied, the number of trees per hectare was lower, but the volume of stock was comparatively high. Results of Karamdost et al. [15] in Asalem Nav mixed beech forests indicated that harvest intensity had a significant effect on stand volume growth. High-intensity harvested parcels (18 $m^3.ha^{-1}$) had the lowest stand volume growth, at 4.8 $m^3.ha^{-1}.y^{-1}$ than low-intensity harvested and protected parcels. Anissi et al. [16] reported that the forest type in managed forests has shifted from beech-hornbeam to hornbeam-beech. In terms of species diversity and standing timber quality, the managed forest performed worse than the unmanaged forest. Compared with the unmanaged compartment, hornbeam lost advantage in diameter-class density, following beech. The results also indicated a difference in stock volume between beech and hornbeam across the two compartments. Selective harvesting, if poorly executed, can lead to fragmentation, negatively impacting the remaining trees and the overall ecosystem [8, 15, 16]. This adverse impact is often linked to intensive harvesting practices and the failure to implement proper selective cutting techniques, which can result in rapid forest degradation. Moreover, project implementers often do not favor selective harvesting due to uncertainties related to the secondary succession of forests and its unsuitability for large-scale operations, as it tends to be labor-intensive and more expensive than clear-cutting methods [8, 11, 12]. Hyrcanian forests are the only commercial forests in Iran, covering an area of approximately 1.9 million hectares and extending from the southern coasts of the Caspian Sea to the northern hillside elevations of the Alborz Mountain range [18,19,20]. The Caspian beech communities (*Fagetum hyrcanum*) are considered the most valuable forest communities in the Hyrcanian regions. The Hyrcanian beech (*Fagus orientalis* L.) is the dominant species in these communities, holding substantial economic value [17, 21, 22]. The Natural Resources and Watershed Management Organization of Iran currently oversees the management of the Hyrcanian forests in Iran. The scientific exploitation of the mentioned forests was primarily implemented via the shelterwood method in 1961 and continued until 1995, when the single selection method, as a conventional and ongoing silvicultural method for managing the Hyrcanian forests, was replaced [23]. Eventually, in response to the detrimental effects of forestry management practices in the Hyrcanian region, the Forests Organization of Iran instituted a "rest or restoration period" for the forests in 2016. By 2019, all forest exploiters had been systematically removed, and active management projects had been terminated. Despite facing significant opposition and challenges, this restoration period was initiated to last for 10 years.

In 1995, the Galandroud forestry project was initiated as the first single-selection forestry project in Mazandaran Province, under the auspices of the West Mazandaran-Noshahr Natural Resources Headquarters. This study addresses the implementation impact of selection logging using data collected at the start and end of a 10-year harvesting period within a district encompassed by the Galandroud forestry plan. To assess the effects of selective cutting, we quantified several silvicultural parameters, including: (i) the frequency of dominant tree species per unit area, (ii) the distribution of trees across 5 cm diameter classes, (iii) the mean height of dominant trees within the stand, (iv) the timber quality of standing trees, (v) the abundance of regeneration for the main tree species, and (vi) adherence to reforestation and afforestation obligations throughout the harvesting period. Changes in these parameters were subsequently analyzed as indicators of the effectiveness of the selection method implemented in the study area. This paper concludes with a discussion of the challenges and issues related to managing forestry plans within the Hyrcanian ecosystem of Iran, particularly as they pertain to selection harvesting methods.

Materials & Methods

Study Area

Spanning 14 districts, the Galandroud forestry plan is situated in the watershed basin No. 48 of the Hyrcanian forests in Mazandaran province, Nour county, Iran. The present study was conducted in Bandbon District No. 14 of the given plan, located at 36° 28′ 30′′ to 36° 30′ 03′′ latitudes and 51° 53′ 30′′ to 51° 50′ 30′′ longitudes. The first independent forestry plan, provided and implemented in District No. 14 of the Galandroud forests, was conducted by the Headquarters of Natural Resources in 1995. The utilization and implementation were assigned to the Iran-Choob Co. in the same year using a 10-year contract [24].

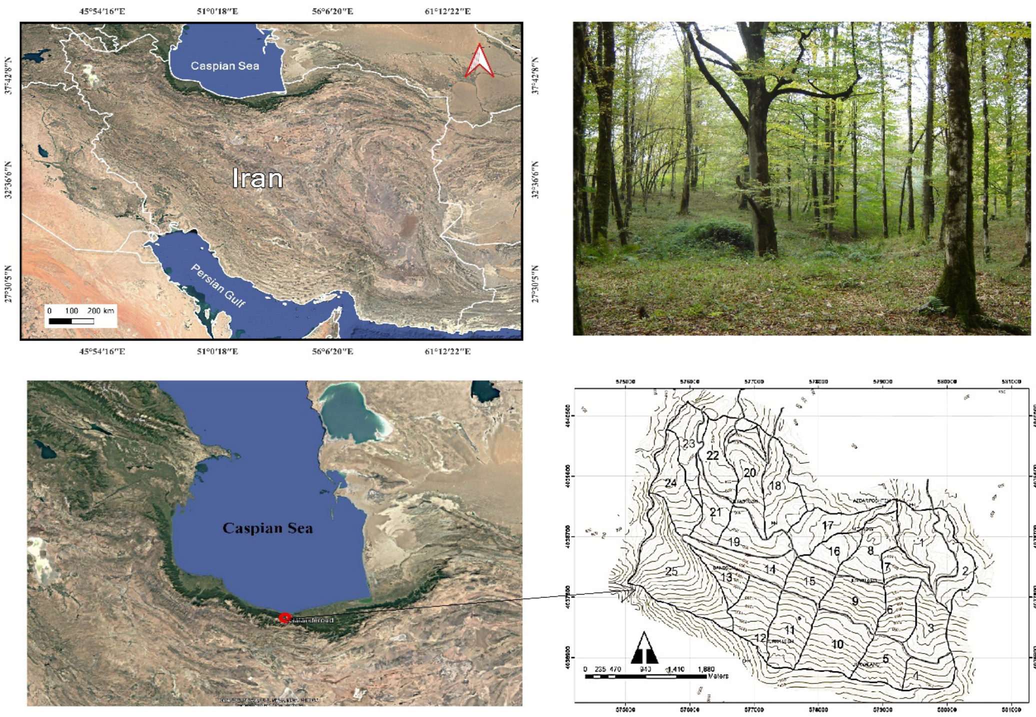

Figure 1) Location, topographical map, and forest type (*Fageto-Carpinetum*) of the study area (District 14, Galandroud Forestry plan, Mazandaran Province, Nour County, Iran).

By the end of 2005, the first revision plan was implemented by the Headquarters of Natural Resources. The findings relate to data gathered during the district's second decade of management, using the single-selection method. Table 1 and Figure 1 illustrate the overall specifications and the district's topographic map, respectively.

Sampling Plan

The data for this study were acquired from the project managers and provided the foundation for conducting inventory assessments and determining harvest volumes and quantities. All the factors measured and calculated in this study, including height, diameter, volume, and timber quality grading of standing trees, as well as the regeneration of the main tree species, are based on the guidelines established by the Iranian Forests Organization.

The silvicultural method employed for managing the study district was single selection, implemented over a 10-year harvesting period from 2005 to 2015. Forest inventory was conducted at the beginning and end of the period using a random systematic method with 1000 m² circular sample plots (Figure 2). The inventory grid, measuring 150×200 m, covered the entire district [25, 26, 27].

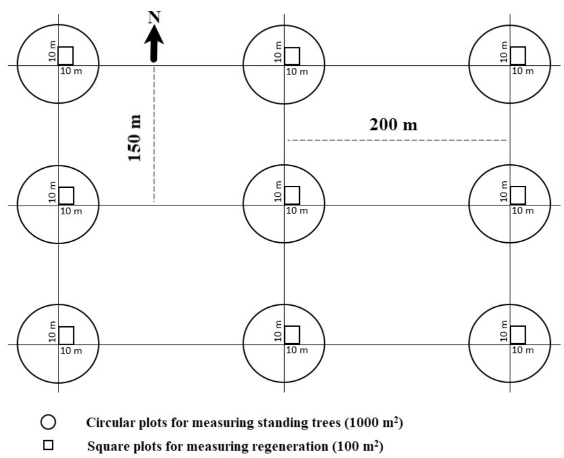

Figure 2) Inventory method to prepare forestry plans in the Hyrcanian forests based on the guidelines of Forests, Range and Watershed Management Organization of Iran [28].

Table 1) General specifications of district no. 14 in the exploitation period of 2005 to 2015 (information extracted from the forestry management plan booklet)

Area of Study District	1330 ha
Area of Utilized Forests	850 ha
Area of Protected Forests	480 ha
Number of Compartments in the Study District	25
Minimum and Maximum Area of Compartments	22-145 ha
Road Length in District	18.85 Km
Mean Road Density Per Hectare	14.2 $m.ha^{-1}$
10-Year Estimation of Allowable Cut before 2005	20000 m^3
Altitude of the District	450 –1700 meters from sea level
Mean Annual Precipitation	1085 mm (39 –211 $mm.month^{-1}$)
Mean Annual Temperature	16.2 °C (2.2 –29.4 °C)
Climate Type (Emberger Method)	Humid temperate
Soil Type	Brown forest soil
Forest Structure	High forest with mixed-uneven-aged structure
Silviculture Method	Single and group selection: second 10-year management period
Utilization System	Traditional (felling by chainsaw and wood extraction by mule) and hemi-mechanized (felling by chainsaw and wood extraction by rubber-tired skidder)
Dominant Forest Type (Stand Composition)	*Fageto-Carpinetum*
Forest Types of Protected Areas	*Carpino-Pareto-Quercetum*
Main Species	*Fagus orientalis*, *Carpinus betulus*
Industrial Species	*Alnus subcordata*, *Acer cappadocicum*, *Prunus avium*, *Pterocarya fraxinifolia*
Fuel Wood Species	*Parrotia persica*, *Diospyros lotus*, *Celtis australis*, *Gleditschia caspica*

According to the guidelines of the Forests, Range, and Watershed Management Organization of Iran, tree species, DBH, the height of the thickest and closest tree to the plot center, regeneration abundance, and trees' quality grading were registered in each sample plot. The diameter of the trees at breast height (130 cm from the ground) was measured using a caliper with an accuracy of 1 cm. All trees were then classified into 5 cm diameter categories, starting at a diameter of 7.5 cm. The quality of standing trees has been graded as follows [29]:

Grade 1: The first 10 meters of the trunk are straight, free from branches, knots, twisting, and decay (suitable for the veneer industry).

Grade 2: The initial 10 meters of the trunk are straight, free from twisting and decay, but may contain a maximum of three knots or branches within this segment (industrial normal: suitable for producing Grade 1 timbers).

Grade 3: The trunk is twisted and exhibits a greater number of knots and branches within the first 10 meters (industrial defective: suitable for producing Grade 2 timbers).

Grade 4: The presence of rot and branches is significant enough that the trunk cannot be used to produce industrial wood (suitable for particle board industries and/or firewood).

Based on the mentioned guideline, two trees (i.e., the closest tree to the plot center and the thickest tree in each plot) were measured using a Suunto clinometer in each circular plot to determine the height of the stand trees. To do so, the diagram of the tree's height in different diameter classes was drawn for the studied stand. As the studied forest was uneven-aged, Lorey's mean tree height (Equation 1) was used to calculate the mean height of the stand trees. Lorey's mean tree height represents the mean height (in meters) of dominant and co-dominant trees of the main species in a forest stand, whereby individual trees are weighted with their basal area [30,31].

$$Hl = (\Sigma g_i \times h_i).G^{-1} \quad \text{Eq.(1)}$$

where Hl is Lorey's mean tree height (m), hi is tree height (m), gi is tree basal area (m^2), and G is total stand basal area (m^2).

The volume of standing trees is calculated according to established guidelines using two-variable (DBH and tree height) volume tables (tariff tables) that have been specified by the Natural Resources and Watershed Management Organization for each major tree species in each region. These tariff tables were developed based on accurate measurements of the volumes of a large number of standing trees that had previously been harvested and measured. To create these tables, a function was employed that yielded the highest correlation coefficient between the volumes of standing trees and the volumes of harvested trees that were subsequently measured with precision. Ultimately, the equation used to calculate the volume of standing trees in the aforementioned forestry plan, based on the best-fit value, was obtained as follows (Eq. 2).

$$V= 0.000009598 \times D^2 \times H + 0.001069422 \times D^2 - 0.0954 \quad \text{Eq. (2)}$$

where D is tree diameter at breast height (cm), H is tree height (m), and V is tree volume (m^3).

The mean standing volume and the number per hectare were calculated thereafter for all the stands as well as the main species [32].

Seedling inventory was conducted northwards via square plots (10m×10m) from the center of each circular plot (Figure 2). In each 100-m^2 plot, the regeneration of all tree species was counted according to the guidelines of the organization within the framework of the following four categories:

1- seedling height less than 1.30 m (the species has no diameter at breast height)
2- stem diameter at breast height between 0 and 2.5 cm
3- stem diameter at breast height between 2.5 and 7.5 cm
4- stem diameter at breast height between 7.5 and 12.5 cm

Data Analysis

After calculating the silvicultural characteristics for all sampling plots, a t-test analysis was conducted to compare the beginning (2005) and end (2015) of the period, investigating the impacts of forest management using the selection method [25, 26, 27, 33].

Considering the dimensions of the sampling grid (150 × 200 meters), a total of 443 circular plots, each with an area of 1,000 square meters, were established across the entire district [25, 26, 27, 33]. Of this total, 283 plots (covering an area of 850 hectares) were surveyed and measured for trees at both the beginning and end of the operational period. The remaining forest was designated as protected due to slopes exceeding 60% and the presence of forbidden-to-cut species, namely *Taxus baccata*, *Buxus hyrcana*, *Juglans regia*, and *Cupressus sempervirens* var. *horizontalis*.

The density, volume, and trunk quality of standing trees, as well as the abundance of regeneration per unit area, were calculated for each sampling plot and compared using a t-test for the before and after harvesting period (2005 and 2015) [25,33]. Comparisons were made pairwise across five groups of trees: *Fagus orientalis* and

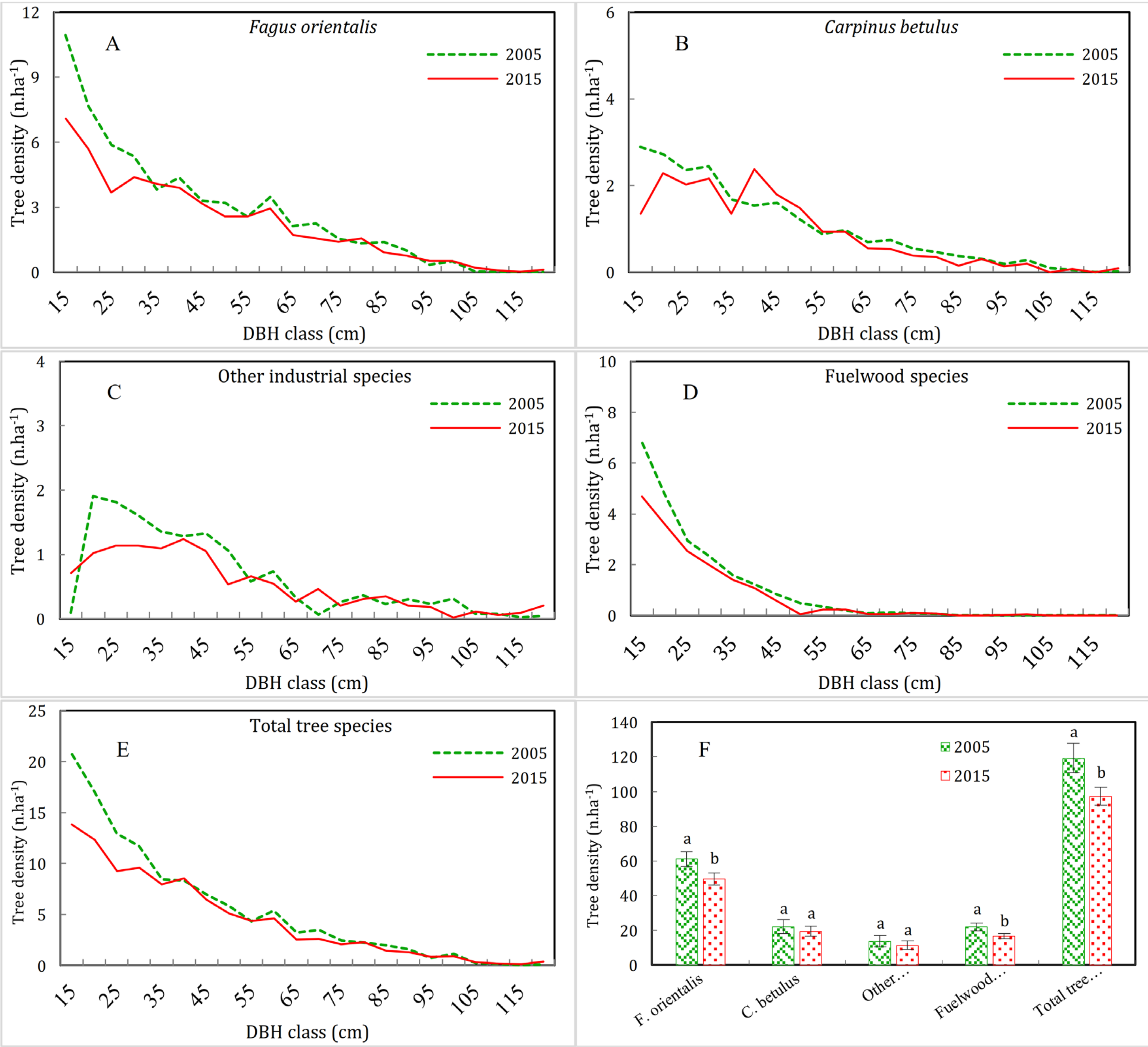

Figure 3) Distribution of standing volume per hectare in different DBH categories at the beginning (2005) and end (2015) of the harvesting period: A) *F. orientalis*; B) *C. betulus*; C) other industrial trees (*Quercus castaneifolia, Alnus subcordata, Acer velutinum, Acer cappadocicum, Tilia begonifolia, Pterocarya fraxinifolia,…*); D) fuelwood (*Parrotia persica, Diospyros lotus, Gleditsia caspica, Celtis australis,…*); E) total species. F) statistical mean comparison of tree density between the two years for the five groups using the Student's t-test (different letters {a and b} on each paired column indicating a significant statistical difference at the 95% level.

Carpinus betulus (the dominant species of the forest, comprising over 70% of the standing trees), other industrial trees (including *Alnus subcordata*, *Acer velutinum*, *Acer cappadocicum*, *Tilia begonifolia*, and *Pterocarya fraxinifolia*), fuelwood trees (such as *Parrotia persica*, *Diospyros lotus*, *Gleditsia caspica*, and *Celtis australis*), and total tree species, utilizing the Student's t-test for the specified years.

Findings

The harvest potential from the Galandroud district, No. 14, including harvest from districts, road construction, and rural consumption, was predicted to be 20,000 m^3 (19 $m^3.ha^{-1}$ on average) for the first harvesting period from 1995 to 2005. This number was expected to be 8500 m^3 (8 $m^3.ha^{-1}$ on average) for the second harvesting period from 2005 to 2015.

Table 2 presents the percentages of volume and the number of marked trees on the district surface over the 10 years. This table represents the trend of programming for the exploitation of the species on the district surface. Among the species, *F. orientalis* holds the largest share of volume and number of marked trees due to its highest occurrence in these forests.

Table 2) Percentages of volume and number of marked trees during the period

Species Name	Percentages of Marked Trees	Standing Volume of Marked Trees
Fagus orientalis	50.3%	56.3%
Carpinus betulus	18.2%	20.6%
Other industrial species *	13.4%	17.0%
Fuel species **	18.1%	6.1%
Total tree species	100%	100%

* *Quercus castaneifolia, Alnus subcordata, Acer velutinum, Acer cappadocicum, Tilia begonifolia, Pterocarya fraxinifolia.*
** *Parrotia persica, Diospyros lotus, Gleditsia caspica, Celtis australis.*

A statistical comparison of tree density and standing volume was conducted between the beginning and end of the harvesting period for the five main categories of trees using the Student's t-test (Table 3).

Table 3) Mean comparison of standing volume and tree density at the beginning and end (2005 and 2015) of the harvesting period using the Student's t-test

Industrial Tree Groups	Tree Density		Standing Volume	
	df	t	df	t
Fagus orientalis	282	−5.11 **	282	−4.73 **
Carpinus betulus	282	−1.03 ns	282	−2.97 **
Other Industrial Species	282	−0.84 ns	282	−3.30 **
Fuelwood Species	282	−2.23 **	282	−2.01 *
Total Tree Species	282	−6.60 **	282	−7.02 **

** and *: Significant statistical difference between the two groups at the 99% and 95% confidence level, respectively; ns: No significant statistical difference between the two groups.

The fluctuations in standing volume and tree density for the entire district were calculated and presented for the main categories of trees (Figures 3 and 4), and according to the inventory data of District 14, the standing volume and tree density declined by 5,366.5 m^3 and 18,623 individuals (including industrial and fuelwood trees), respectively, during the 10-year management period.

As observed (Figure 3E), except for diameter classes 40, 80, and >95 cm, the number of trees has declined in the remaining classes across the district. The given decline is by far larger in diameter classes less than 35 cm.

Based on the information about the beginning (2005) and end (2015) of the period, the diagram of standing volume distribution in the DBH categories of the whole dominant trees and industrial woody species (including fuelwood species) was plotted for the study district (Figure 4). As Figure 4 displays, the volume of the dominant and industrial trees has declined drastically, up to a diameter class of 105 cm, at the end of the period compared to its beginning. In other words, it indicates the decrease in the standing volume of total exploitable species in 18 diameter classes (Figure 4E). The volume per hectare of species in very thick diameter classes (>105 cm) has increased compared to that of 10 years ago.

Table 4 shows the variations in standing volume and tree density resulting from the implementation of the selection method during the harvesting period (2005-2015) for the main categories of trees throughout the whole district.

The mean standing volume at the beginning and end of the plan was 249.9 $m^3.ha^{-1}$ and 186.6 $m^3.ha^{-1}$, respectively. Thus, the standing volume of the whole trees has declined on average by 63.13 $m^3.ha^{-1}$ (25.3%) during the 10-year study period. Additionally, the mean number of individuals in the entire standing

Table 4) Changes in standing volume and tree density resulting from the implementation of the selection method (2005-2015) across the main tree categories in the entire district

	Standing Volume		Variations of Standing Volume in the Whole District		Tree Density		Variations of the Standing Trees in the Entire District	
	2005	2015	m^3	%	2005	2015	no.	%
Fagus orientalis	55.1%	59.7%	−22,193.5	−19.0 %	51.2%	50.9%	−9,809	−18.9%
Carpinus betulus	20.6%	19.7%	−12,486.5	−28.6%	18.5%	20.0%	−2,252	−12.0%
Quercus castaneifolia	0.5%	1.2%	+705.5	62.0%+	0.4%	0.4%	−76.5	−19.6%
Other industrial species	16.5%	13.4%	−13,795.5	−39.4%	11.5%	11.7%	−2,227	−19.5%
Fuelwood species	6.1%	5.5%	−4,182	−32.3%	18.4%	17.1%	−4,513	−24.2%
Total	100%	100%	−53,660.5	−25.3%	100%	100%	−18,623	18.4%−

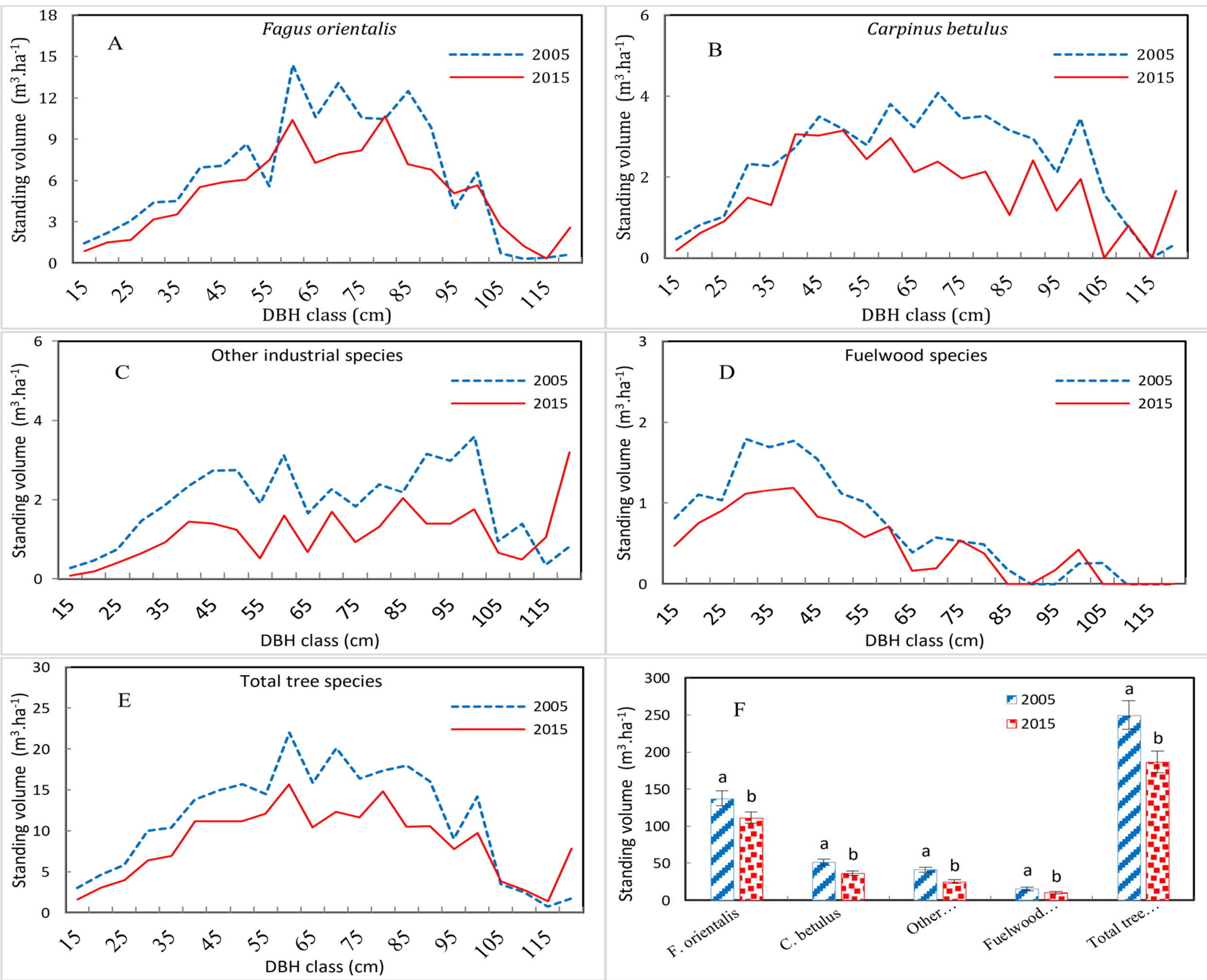

Figure 4) Distribution of standing volume per hectare in different DBH categories at the beginning (2005) and end (2015) of the harvesting period: A) *F. orientalis*; B) *C. betulus*; C) other industrial trees (*Alnus subcordata, Acer velutinum, Acer cappadocicum, Tilia begonifolia, Pterocarya fraxinifolia,…*); D) fuelwood (*Parrotia persica, Diospyros lotus, Gleditsia caspica, Celtis australis,…*); E) total species. F) statistical comparison of standing volume between the two years for the five groups using the Student's t-test (different letters {a and b} on each paired column indicating a significant statistical difference at the 95% level.

Table 5) Comparison of regeneration abundance of tree species existing in Bandbon district no. 4 (number per hectare) in the beginning and end of the period using the t-student test

Species Name	Height <1.30 m		DBH = 0–2.5 cm		DBH = 2.5–7.5 cm		DBH = 7.5–12.5 cm		Total		Total Changes in the Period (%)
	2005	2015	2005	2015	2005	2015	2005	2015	2005	2015	
Fagus orientalis Lipsky	1015.1 a	649.8 b	302.0 a	278.1 b	169.5 a	110.6 b	40.2 a	14.8 b	2302.1 a	1053.4 b	-54.2
Carpinus betulus L.	276.4 a	180.2 b	11.4 b	12.0 a	5.7 a	2.1 b	5.1 a	3.5 b	484.4 a	197.9 b	-59.2
Quercus castaneifolia C. A. Mey.	13.7 a	5.0 b	1.7 b	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	20.3 a	5.0 b	-75.7
Alnus subcordata C. A. Mey.	2.0 b	30.4 a	1.4 b	1.1 a	0.3 b	1.8 a	0.0 a	0.0 a	35.9 a	33.2 b	-7.3
Acer velutinum Boiss.	305.7 a	318.4 a	22.5 b	27.9 a	3.1 a	3.9 a	0.9 a	0.7 a	655.2 a	350.9 b	-46.4
Acer cappadocicum Gled.	388.0 a	214.1 b	11.7 b	15.9 a	3.7 a	0.7 b	1.7 a	0.7 a	620.7 a	231.5 b	-62.7
Tilia begonifolia Stev.	82.3 a	55.5 b	2.9 b	7.1 a	1.1 b	2.1 a	1.1 a	0.0 b	145.1 a	64.7 b	-55.4
Ulmus carpinifolia Borkh.	0.9 a	0.0 b	0.0 b	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.9 a	0.0 b	-100
Ulmus glabra Huds.	191.7 a	84.8 b	8.8 b	8.8 a	1.7 a	1.1 b	1.1 a	0.0 b	289.3 a	94.7 b	-67.3
Fraxinus excelsior L.	4.0 a	1.4 b	0.0 b	0.4 a	0.0 a	0.0 a	0.0 a	0.0 a	5.4 a	1.8 b	-67.4
Sorbus torminalis (L.) Crantz	14.0 a	1.1 b	0.3 b	0.0 a	1.1 a	0.0 b	2.0 a	0.0 b	18.4 a	1.1 b	-94.3
Prunus avium L.	5.4 a	1.8 b	0.0 b	0.4 a	0.0 a	0.0 a	0.0 a	0.0 a	7.2 a	2.1 b	-70.5
Diospyros lotus L.	29.9 b	71.0 a	22.8 b	36.4 a	10.5 b	12.0 a	8.3 a	3.5 b	158.1 a	123.0 b	-22.2
Buxus hyrcana Pojark.	2.0 a	0.0 b	6.3 b	0.0 a	5.4 a	0.0 b	1.4 a	0.0 b	15.1 a	0.0 b	-100
Taxus baccata L.	0.3 a	0.0 b	0.0 b	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.3 a	0.0 b	-100
Parrotia persica (DC.) C.A. Mey.	79.5 b	87.3 a	85.8 b	148.1 a	27.9 b	47.0 a	13.4 a	3.5 b	344.3 a	285.9 b	-17.0
Carpinus orientalis Mill.	1.7 a	0.0 b	0.0 b	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	1.7 a	0.0 b	-100
Gleditsia caspica Desf.	1.1 b	3.9 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	1.1 b	3.9 a	253.6
Other Species	1.4 a	0.0 b	0.6 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	2.0 a	0.0 b	-100
Total	2415.0 a	1704.6 b	478.0 b	536.0 a	230.2 a	181.3 b	75.2 a	26.9 b	5107.3 a	2448.7 b	-52.1%

Different letters (a and b) in two adjacent columns, comparing the means for the years 2005 and 2015, indicate a statistically significant difference between the two groups at the 95% confidence level.

tree density has declined from 119 to 97 per hectare (18.4%).

Regarding Table 4, a considerable decline in forest stock has occurred during the harvesting period (2005-2015) in terms of standing volume and tree density of the main tree categories.

After introducing the tree height of each diameter class in Lorrey's function, the height of trees was calculated in the given class at the beginning and end of the period. The height diagram was plotted for the trees of the entire district (Figure 5A). The mean stand heights (across all tree species) in 2005 and 2015 were 28.71 m and 23.92 m, respectively. This indicates that Lorrey's mean height for the trees of the district decreases by 16.7% after 10 years of management. The total height diagram of the stand trees (Figure 5) shows a decreasing trend in tree height across the district across the DBH classes (28 classes). This decreasing trend indicates that taller trees in each diameter class have been more heavily utilized.

The reforestation area across the entire district at the beginning (approximately during the former harvesting period) and at the end of the period is shown in Figure 5B. During these two periods, reforestation rates of only 0.53% and 0.82% of the district area were registered by the end of the periods in 2005 and 2015, respectively.

The timber quality grading of the standing trees has been compared between the beginning (2005) and the end (2015) of the harvesting period, as illustrated in Figure 5C. As observed, after implementing the selection method during these 10 years, the tree volume in qualitative grade 2 has increased (10.7%). In contrast, the given volumes have decreased in qualitative grades of 1, 3, and 4 by 70.5% ($t = 6.34$, $p < 0.0001$), 46.4% ($t = 4.69$, $p < 0.0001$), and 99% ($t = 8.76$, $p < 0.0001$), respectively. The variations in tree standing volume across the qualitative grades of 1 to 4 in the exploited districts of the whole district were -34.565, +9.848, -11.809, and -5.613 m^3, respectively. Among these, the most notable decline was observed in the grade 1 trees. This implies that the high-quality trees have been more markedly regarded for marking.

The natural regeneration of species across the district at the beginning and end of the study period is given in Table 5. The sum of regeneration abundance for almost all tree species decreased at the end of the period, demonstrating that the establishment conditions of 17 main tree species have been impaired. Only *Gleditsia caspica* has shown better regeneration after the implementation period of the plan (10 years). The abundance of tree species has decreased from 5,107 to 2,448 individuals per hectare (a 52% decrease after 10 years). However, the three main species existing in the studied forest volume composition (i.e., beech, hornbeam, and oak) showed a larger abundance in almost none of the regeneration classes at the end of the period, as compared to their beginning.

Discussion

Effective implementation of the selection method requires precise calculations of the standing stock at both the beginning and the end of the harvesting period. It also requires accurate assessments of the annual harvest volume for each management partition, which should be tailored to the forest's growth rates per unit area [8]. While the allowable cut of the district had been determined to be 8,500 m^3 at the beginning of the project, 6.3 times this amount of timber was cut from the forest during the harvesting period. During the harvesting period, the mean standing volume and tree density drastically decreased (Figures 3 and 4). These two main variables distinctively demonstrate the over-

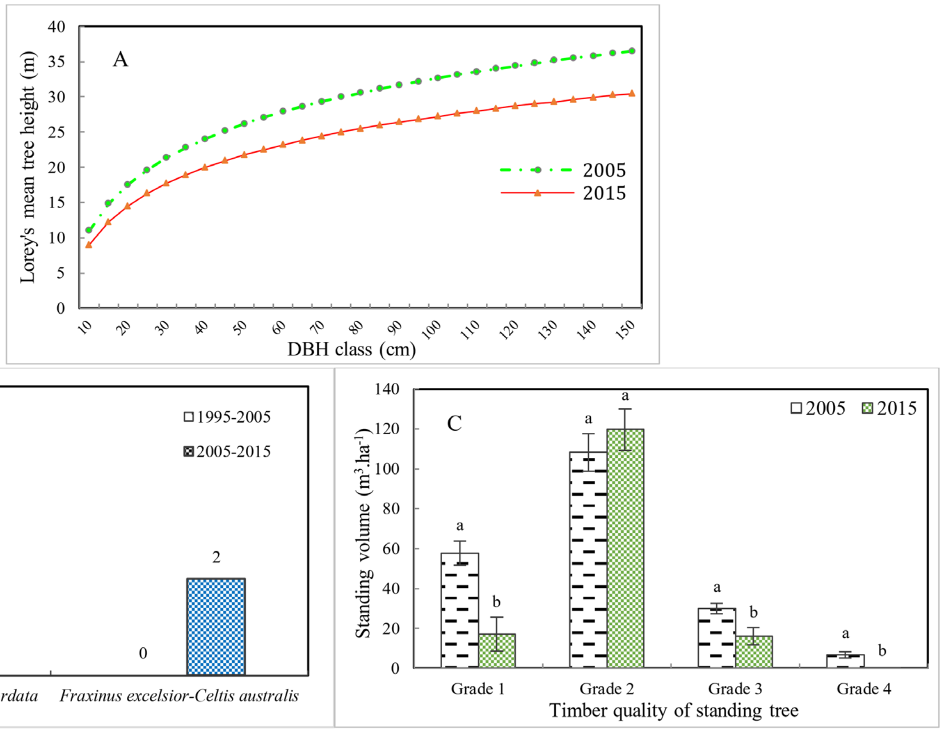

Figure 5) The height of the dominant tree species in the forest at the beginning and end of the harvesting period (A), the reforested area during the two consecutive harvesting periods (B), and the statistical comparison of the standing volume of trees in each of the four quality grades at the beginning and end of the harvesting period using the Student's t-test (C), where different letters (a and b) in the paired columns reflect a statistically significant difference at the 95% confidence level.

exploitation phenomenon in the studied forest. The decline in mean tree density per hectare of small diameter classes was more than that of the other classes (Figure 4). It is worth noting that the results of these two variables had a considerable distance from those of a typical Hyrcanian mixed beech forest (*vs.* identical forests) even at the beginning of the exploitation period. The results indicate that some of these adverse changes refer to the management conditions of the former exploitation period. A close examination of the results presented below clarifies the current poor state of these forests' stock. In this regard, Sagheb-Talebi et al. [34] studied the standing volume during the successional stages of the beech forest in Kalardasht. They reported 579, 585, and 488 m^3 of standing timber per hectare for the initial, climax, and decay stages, respectively. Amiri [35] reported that the mean standing volume and tree density were 472 m^3 and 287 individuals per hectare in an intact mixed beech stand located in District 1 of Shastkola Forest, Gorgan, Iran. Additionally, Karamdost Marian et al. [16] reported that the mean tree standing volume in a protected beech district located in Nav-Asalem forests was approximately 325 m^3 ha ^{1}, which increased from 218 m^3 to 256 m^3 per hectare via the single-selection method in the harvested district after 10 years. Bayat et al. [36] reported that no significant changes were observed following the implementation of the single-selection method in the Gorazbon district of Kheyroudkenar Forest (Noshahr, Iran), managed by the University of Tehran. At the start of the study period, the mean tree density and standing volume were 298 trees per hectare and 335 m^3.ha^{-1}, respectively. By the end of the study period, these values had slightly changed to 290 trees per hectare and 367 $m^3.ha^{-1}$, respectively. The diagram of volume distribution per hectare also shows reductions in all diameter classes except for very thick classes. The reason behind the volume increase in very thick classes is to reinforce marking restrictions on the given classes, to preserve the genetic reserve, and to produce seeds in the Hyrcanian forests. This is announced by the Natural Resources and Watershed Management Organization of Iran to private corporations as part of the close-to-nature regulations and principles required for the single-selection method. Thus, the preservation of very thick trees within the studied area is primarily due to stringent regulations in this regard.

The mean height of Lorey's trees in the studied district decreased significantly during the harvesting period. Since Lorey's mean height accounts for the contribution of trees to stand height based on their basal area, it is less sensitive to the harvest of smaller trees compared to an unweighted mean height. The findings presented in this section of the study are consistent with those reported by Hassanzad Navroodi and Hassannezhad Sadatmahaleh [25], who found that Lorey's mean height in forests managed through a single-selection method decreased by 23% compared to unmanaged forests. This reduction has been attributed to a decline in the basal area per unit of forest area, primarily due to the preferential harvesting of larger and taller trees.

The percentage ratio of Oriental beech individuals showed a significant reduction in all classes compared to the beginning of the study period. This was due to harvesting at a rate exceeding forest growth, the opening up of the canopy, inadequate seedling establishment, and overgrazing. Furthermore, a reduction in tree density and standing volume per hectare was observed in other species (i.e., fuelwood and non-industrial species) compared to the beginning of the period. This was attributed to the decrease in the main species' stock across the district, the reduction in tree quality during the period, the rise in fuelwood prices, and thus the enhanced profit of the project executor through harvesting the fuelwood species. This resulted in reduced standing individual and volume per area of fuelwood species at the end of the utilization period. The results of the present research reveal that the highest volume of marking was focused on quality grade 1 trees, resulting in a drastic decrease in the volume of the given trees by the end of the harvesting period. This implies that one of the most important objectives of forest management using the single selection method, which is the improvement of standing tree quality, has never been fully realized. That is, the health and structure of the stand have been endangered due to the harvest of high-quality trees and lack of protection from elite trees while marking (Figure 5C). Anissi et al. [15] compared the effects of single-selection cutting on forest quantitative and qualitative properties with the corresponding properties of a control forest in Golband district. They concluded that the conditions in the managed forest changed to the benefit of hornbeam species, such that even the forest type changed from *Fageto-Carpinetum* to *Carpino-Fagetum* in the mentioned forest. Additionally, the managed forest exhibited weaker conditions in terms of species diversity and the quality grades of the standing trees.

The reforestation area during the studied period, and even in the previous period, was not substantial (Figure 5B). By the end of the harvesting period, only a few species were used, and these areas were monocultures. Unfortunately, in the Hyrcanian forests, project implementers often pay insufficient attention to landscape preservation commitments and fail to prevent significant canopy gaps through cutting. This lack of attention is mainly due to the considerable financial investment required for such operations, resulting in only minimal areas of the project sites being dedicated to planting seedlings. The Natural Resources and Watershed Management Organization must require oversight of implementers to prevent significant canopy gaps. Such gaps quickly become dominated by undesirable understory vegetation that hinders natural regeneration of the main tree species, such as raspberry and ferns [4].

The present research revealed that the regeneration of all species declined across the exploited districts. This is deemed another variable, which can, in itself, represent the damages incurred by overexploitation across the district [4,11]. This can be attributed to the increased distance among standing trees brought about by overexploitation and the excessive stand canopy opening up, which provides the conditions for the presence of opportunist and shade-intolerant species [4,11] such as *Sambucus ebulus*, *Rubus hyrcanus*, and *Pteridium aquilinum*. This undermined the competitiveness of the main species to establish themselves in these gaps. Sagheb Talebi et al. [34] demonstrated that the most suitable gap area for the regeneration and health of tree species in the Hyrcanian forests is 200 to 500 m^2, above which values can be troublesome and even detrimental for the quality, abundance, and future well-being of the given forest stands. The results of research conducted by Hassanzad Navroodi and Hassannezhad Sadatmahaleh [25] in a managed forest using a single selection method in Guilan Province of Iran showed that the mean standing volume in the managed and unmanaged stands was 453 and 612 m^3.ha^{-1} (26% decrease), respectively. The tree density in these two stands was 426 and 319 individuals per hectare (a 37% increase), respectively.

Amiri et al. [37] compared two stands managed by the single-selection method with an unmanaged stand located in Loveh forest, Gorgan. They reported that the natural and unmanaged stands had significantly higher values in DBH, basal area, density, total height, stem height, and canopy, as compared to the managed forest stands.

Navrodi et al. [26] stipulated that improper implementation of the single selection method in district 1 of Janbesara forest, Guilan province, led to impaired forest conditions in 1995-2005, where not only the quantitative and qualitative properties of trees and stands did not improve but also the parameters relative to forest standing volume underwent marked reductions at the end of the forestry plan.

Omidvar et al. [27] and Daliri et al. [38] postulated that the violation of marking principles and improper exploitation were the primary reasons behind the unsuccessful forestry projects managed by the single-selection method in the Hyrcanian forests.

The findings of Radaei and Habashi [39] indicate that applying harvesting intensities below 13.5% yields improvements in the characteristics of mixed hornbeam stands. This underscores the value of forest management interventions and highlights the positive impact of adopting a single-tree selection silvicultural approach on stand structure. Given that the structure at a moderate harvesting level (3.5–9.5%) closely resembles that of the control stand, this range is proposed as an optimal treatment for shaping the structure of mixed hornbeam stands in the eastern Hyrcanian forests.

The scope of the research presented in this paper references only a limited number of articles that discuss the decline in the value, quality, and quantity of the standing stock of managed forests (by selection method) compared to unmanaged ones. There exists considerably more research indicating that the management of Hyrcanian forests, even when a close-to-nature method, has not guaranteed the sustainability and health of the forest. In some areas, the extent of degradation is so severe that the forest has strayed significantly from its climax state. The data presented in this study pertains solely to a 10-year harvesting period. It is evident that, due to the lack of access to data from previous harvesting periods, it is impossible to estimate the extent of degradation in such forests accurately. Regrettably, the degradation has disproportionately impacted the rarest and most vulnerable species. Today, it is increasingly challenging to find stands in the Hyrcanian lowland forests that have not been significantly altered from their original species composition. Additionally, the percentage of thick trees has considerably decreased in many managed forests.

Although the present study cannot show the management condition of all the forestry projects executed on the watershed basins of the Hyrcanian forests, its results along with those of the other researches in this field infer the improper performance of single-selection method, exploitation much more than forest growth rate, harvest targeted more on high quality species and individuals, and lack of supervision on proper execution of some projects [26,27,38]. Such concerns are more pronounced in regions with more intense socio-economic problems, or those far from the main Natural Resources Offices, and even in regions where family and tribal cultures overshadow proper supervision by relevant authorities from forest organizations. In such regions, even halting the execution of forestry plans can lead to increased rates of wood smuggling, as local labor forces working on these projects are laid off. This, either directly or indirectly, highly intensifies the wood smuggling phenomenon unless forest protection measures are correctly implemented.

Over the past several decades, efforts have been made to adopt different forest management methods that align with natural processes, a history of which is discussed in the introduction. Therefore, the single-tree and group-selection silvicultural methods have served as the basis for inventory calculations, timber harvesting, and volume extraction amounts in these forests [35,40]. Now, the Hyrcanian forests have undergone approximately 30 years of management using single and group selection methods, and about 35 years using the shelterwood method (resulting in a total of about 65 years of scientific forest management experience). Excessive logging in some regions of the Hyrcanian forests has occurred due to a range of factors, including mismanagement, overexploitation by contractors, inaccurate inventorying, underreporting of forest stock at the start of projects, intentional discrepancies in initial and final inventory assessments, hiring of inexperienced and unskilled personnel (close relatives), bribery of supervisors, and other contributing factors. As a result of these overexploitation practices and the immense pressure placed on these forests, not only have they become degraded and sparse, but large portions of the forest have been fragmented, losing their original continuity and integrity [26,27,37,38]. The sustainability of these forests can only be accurately assessed through inventorying and comparing stand stock data at the beginning and end of harvesting periods. Consequently, rigorous monitoring is essential to ensure compliance with management practices and prevent further overexploitation, as any imbalance in forest stocks can result in significant forest degradation and drive ecosystems toward lower climax stages or disclimax conditions [8, 39].

Conclusion

The results of this study revealed that the condition of District 14 of Galandroud Forest, located in Mazandaran Province, Iran, was far from optimal at the end of the second exploitation period using the single-selection method (in 2015). At the end of the 10-year harvesting period, not only no improvement was observed in the main structural parameters of the studied stand including standing volume, tree density, qualitative condition of trees, total stand height, DBH, basal area at DBH, and natural regeneration establishment of tree species, but also the reduction of quantitative and qualitative properties of the studied stands was thoroughly evident. The most significant factors contributing to the severity of degradation observed during the implementation of the selection method included inadequate oversight by the Forestry Organization of Iran, the profit-driven motives of project implementers, and the exploitation exceeding the allowable cut established at the beginning of the harvesting period.

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