

Article

Fuelwood Harvest and No Harvest Effects on Forest Composition, Structure, and Diversity of Arasbaran Forests—A Case Study

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Abstract: The impact of fuelwood harvesting on forest structure and composition is not clear, especially on the understudied and scarce Arasbaran forests in Iran. This research compared woody species density, species diversity, forest composition, and regeneration status in areas of continuous and ceased fuelwood harvesting in Arasbaran forests. We expected fuelwood harvesting to decrease stem density, species diversity, tree size (diameter at the breast height (DBH) and height), and shift composition away from preferred fuelwood species. We measured woody species size and frequency and identified species in three fuelwood harvest and three no harvest sites, with six sample plots (100 m × 50 m) per site. Results tended to show differences in composition, diversity, woody species height, and density. *Carpinus orientalis*, a preferred fuelwood species, tended to be more dominant in no harvest (importance values index (IVI) = 173.4) than harvest areas (IVI = 4.4). The diversity or richness of woody species tended to be higher in harvest (20 ± 1 species per ha) than in no harvest (14 ± 2 species per ha) areas, and other measures of diversity supported this trend as well. Harvest areas tended to also be characterized by shorter tree height and lower density of trees, a higher density of regeneration, and fewer small pole-sized trees than no harvest areas. Ongoing fuelwood harvests may further shift composition and structure away from no harvest area, compromising future fuelwood availability, but further detailed research is needed. Close to nature practices may be useful in sustaining fuelwood harvest areas and diversifying areas where fuelwood harvesting has ceased.



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Keywords: forest stocking; diameter distribution; height development; *Acer campestre*; tree recruitment; species composition; fuelwood collection

1. Introduction

Over three billion people in the world live in rural areas with an inadequate supply of energy for cooking, lighting, heating, and other purposes [1]. Wood and wood-derived fuels as fuelwood are primary energy sources for many domestic households in developing countries [2]. Fuelwood collection comprises 55% of global forest harvesting [3]. In Iran, about nine million rural people (10.7% of the total population) depend on fuelwood for providing energy [4]. This ratio is varied in different regions of the world, as 70% of people in Nigeria [5], 70% in India [1], and 73% in Bangladesh depend on fuelwood as a main source of energy [6].

Harvesting of deadwood and dead tree branches as fuelwood may cause minimal adverse impacts on the residual forest structure and composition, particularly in cases where a high density of deadwood is found in the forest stands [7–9]. High dependency on fuelwood as a main source of energy may lead to more detrimental activities, such as harvesting of live trees and charcoal production, leading to deforestation [3]. The impacts of the harvesting of fuelwood and other forest products on forest structure and composition rise with increased access to and harvesting pressure on forests [3]. For example, some

researchers showed that tree density, basal area, and tree diversity were lower at sites with small-scale fuelwood harvest than sites without harvest, because harvesters targeted small size classes and particular species in harvested sites [10]. In contrast, tree diversity and density were higher in the harvested than unharvested sites, because the harvesting activities created canopy openings and higher light conditions in the understory to support a greater range of tree species and numbers in Zimbabwe [11]. Also, there has been reported changing composition, or discordance among understory sapling and overstory tree composition, in the mangrove forest in southwest Madagascar due to small-scale harvesting by local communities [12]. Overall, the impacts of harvesting fuelwood on forest structure, composition, and diversity have had mixed results.

While the factors of deforestation range from overgrazing and timber clear-cutting to conversion of forests to agricultural land [13,14], the harvest of fuelwood is one of the main deforestation factors in Iranian forests [15]. Only 4.5% of Iran's land (approximately 7.3 million ha) is covered with forest, and, according to the FAO reports, Iran is classified among 56 low-forest-cover countries (comprising less than 10% of their area). The annual rate of deforestation in Iran is 2.3% in the northern part of the country and 1.1% in other regions [13]. Fuelwood harvesting has been mentioned in the different forest regions of Iran [16,17]. Rural communities usually harvest *Quercus macranthera*, *Carpinus orientalis*, and *Acer campestre* as fuelwood sources due to the high density of these species in the Arasbaran forest region [18]. These species are common and compose the main forest composition of the Arasbaran forest region [19,20].

The main species of Arasbaran forests vary in characteristics. The *Carpinus orientalis*, commonly known as oriental hornbeam, distribution range reaches through the Black Sea to the Caucasus region and northern west part of Iran. It commonly occurs at lower altitudes or on southern slopes up to 1300 m in Europe, but growing up to 2500 m in the Caucasus mountains [21]. This deciduous species can eventually reach a height of six to eight (15 max.) m, depending on the site and climate conditions, and prefers part shade to full shade. It will tolerate the full sun and is known to colonize open and degraded areas by seed. The species also regenerates prolifically through root suckers. Therefore, this species is often managed in coppice stands for fuel production as firewood or charcoal, and small tools and household items. Another species, *Q. macranthera*, or Caucasian oaks or Persian oaks, are long-lived, deciduous trees from southwest Asia (Iran and Turkey) and can eventually reach a height of 20–25 (30 max.) m, depending on the site and climate conditions. This species can be found at altitudes up to 2400 m [22]. *Q. macranthera* is a very cold-hardy tree, tolerating temperatures down to around -25°C when dormant. This species regenerates from seed (acorns) and vegetatively through stump sprouts. It grows well in moderately moist rich soil or dry sandy soil and is intolerant to shade. Oak wood has been used as hardwood timber for thousands of years, yet it takes up to 150 years before the wood from an oak tree can be used for construction. Modern uses for oak wood include household items, flooring, wine barrels, and fuelwood. *Acer campestre*, or field maple, is another valuable species in Arasbaran forests. Its elevation distribution limit is between 1100 m and 2600 m [22]. *Acer campestre* is an intermediate species in the ecological succession of disturbed areas and is very shade tolerant. It typically regenerates by seed under the existing vegetation cover. It exhibits rapid growth initially but is eventually overtaken and replaced by other trees as the forest matures. It has a value for ecosystem services for bees (honey plants) and butterflies. Thus, understanding the impacts of fuelwood harvest on the forests of Iran is important to sustaining the limited forestland and communities in the Arasbaran region.

Replacing fuelwood with another energy source can prevent deforestation. Mahmoudi and Eshaghi (2019) assessed the role of solar water heaters in reducing fuelwood consumption for forest dwellers in Central Zagros, Iran. They showed that this program has decreased the average annual fuelwood consumption from 19.17 to 2.72 cubic meters per household [23]. Fuelwood harvesting is common in forested parts of the Arasbaran forest. The average fuelwood used per household in spring and summer was 2522 Kg.

The average fuelwood used per household in autumn and winter was 6968 Kg. Most households used oak and hornbeam as fuelwood [18]. We could not find a study of tree sizes harvested for fuelwood but, based on our observations, the typical size is larger than 5 cm in diameter. As forest cover is limited in Iran, the Arasbaran forest is an important vegetation region in Iran to promote biodiversity and sustainable use by nearby villagers and nomads [24]. For countries with low forest cover and with other fuel resources available such as Iran, using other fuel resources such as fossil fuels and clean energies can reduce the pressure on forest resources. Fuel switching, or the fuel source change from one source to another source, followed by improved management and conservation may dampen deforestation and detrimental effects on limited forest resources. Reducing the dependency of rural people on fuelwood has been considered by planners and policymakers in most rural areas of the world [25,26].

In 2001, Iranian policymakers established a strategic 20-year plan consisting of four 5-year plans of economic, social, and cultural development. Elements of the national program are aimed to conserve and protect forested regions of Iran and meet the socio-economic needs of rural communities. Part of the forest conservation and protection strategies involve fuel switching, or replacement of fuelwood with fossil fuel in all forest regions of Iran, including the Arasbaran forest area. Based on our knowledge, once fossil fuel was supplied to a village, fuelwood harvesting ceased. In recent years, management plans of the Arasbaran forests emphasize the importance of providing fossil fuels and clean energies such as solar panels to replace fuelwood and meet the needs of villagers [18]. Reducing dependence on fuelwood resources through appropriate alternative sources can decrease deforestation and provide opportunities to try close to nature forestry [23]. The effects of switching from fuelwood to another energy source on forests has been studied elsewhere, but it has not been studied in Arasbaran forests. Research is needed to establish baseline information on how the fuelwood harvest and no harvest affect forest composition, diversity, and structure so that more detailed studies can follow.

With the implementation of a strategic plan in Iran, portions of the Arasbaran forest were available for the first case study of forests near villages that have switched to fossil fuels and villages that continue to harvest fuelwood. In this research, we compared woody species density, species diversity, forest composition, and regeneration status in forest stands, where fuelwood harvesting continues ('harvest') and where it has ceased ('no harvest'). We hypothesized that stem density and species diversity would be higher in sites where fuelwood harvesting has ceased than where it continues. In addition, we assumed that the composition of dominant species harvested as fuelwood sources, such as *Acer campestre*, *Q. macranthera*, and *Carpinus orientalis*, would be lower in harvest than no harvest sites. We expected fuelwood harvesting to decrease stem density, species diversity, decrease mean DBH and height of large woody species (trees and shrubs) size, and shift composition away from preferred fuelwood species. Lastly, we expected that small woody species would be higher in areas affected by fuelwood harvesting.

2. Materials and Methods

2.1. Case Study Area

The research was conducted in the Arasbaran forests in northwest Iran at the border of Armenia and Azerbaijan (Figure 1, Table 1). Forest types are natural-origin, mixed broad-leaved, deciduous forests with an area of about 153,000 ha. The climate is semi-humid, with an average annual temperature of 14 °C and an average rainfall of 400 mm per year. One of the most important human disturbances over the centuries has been fuelwood harvesting [27]. The main species in these forests are Caucasian oak (*Quercus macranthera* Fisch. & C.A.Mey. ex Hohen.), common hornbeam (*Carpinus orientalis* Mill.), field maple (*Acer campestre* L.), common yew (*Taxus baccata* L.), wayfaring tree (*Viburnum lantana* L.), reddish-black berry or rock red currant (*Ribes petraeum* Wulfen. Synonym. = *Ribes biebersteinii*), and Persian walnut (*Juglans regia* L.) [19]. The main forest type or potential natural vegetation is a mixed forest type of *Quercus macranthera*, *Carpinus orientalis*, and

Acer campestre. The occupations of the local people in the target watersheds are primarily based on combinations of animal husbandry, farming, carpet-weaving, beekeeping, and cultivation or extraction of forest products [28,29].

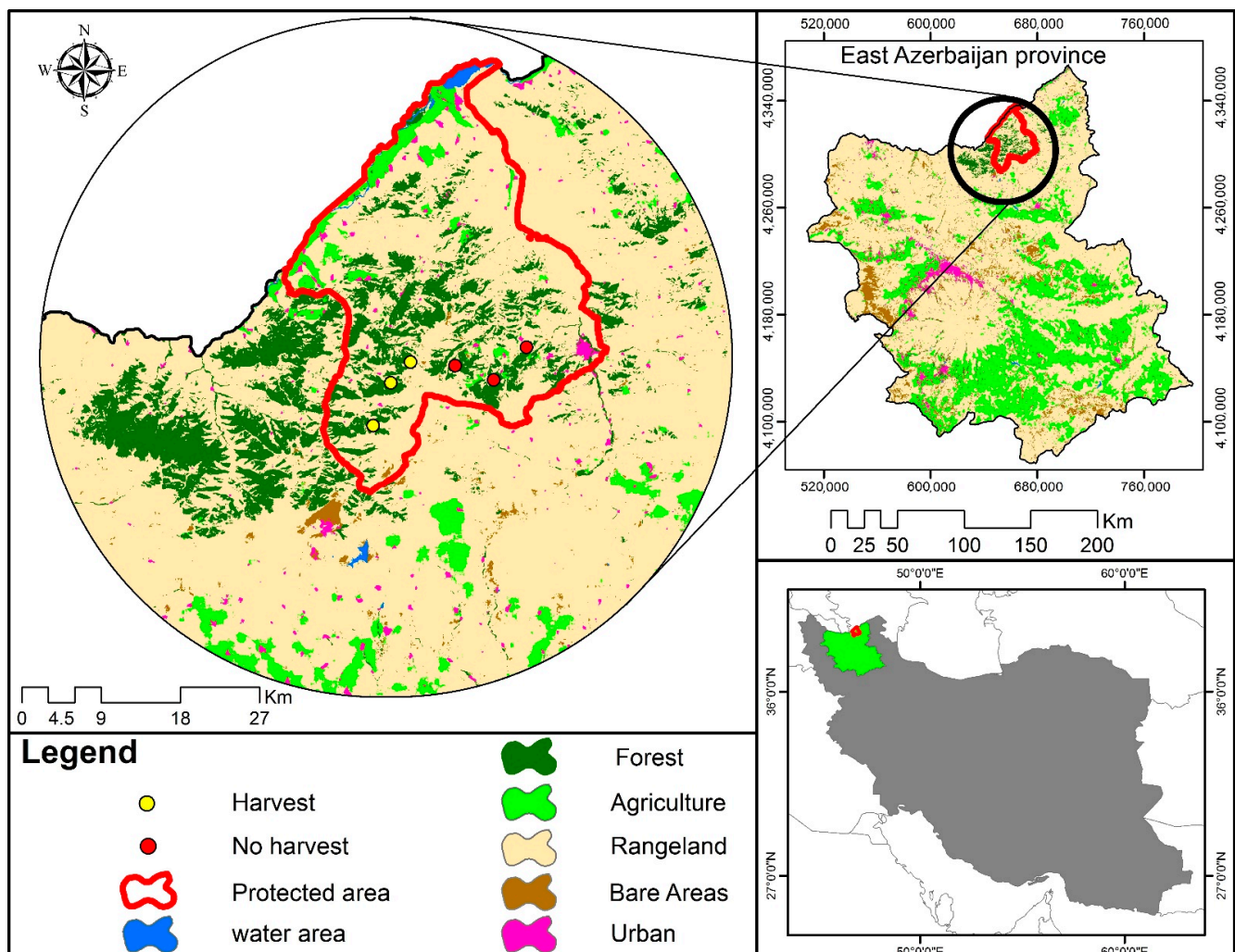


Figure 1. The location of the case study in Arasbaran forests, northwest Iran.

Table 1. The geographical position of three sites in the harvest and no harvest study areas.

Sites	Latitude/Longitude		Altitude from Sea Level (m)	
	Harvest	No Harvest	Harvest	No Harvest
A	38°51'47"/46°48'44"	38°50'59"/46°52'14"	2008	1878
B	38°49'59"/46°47'49"	38°49'38"/49°55'08"	2143	1825
C	38°47'16"/46°45'41"	38°51'36"/46°57'33"	2284	1864

Since 1976, UNESCO has registered 72,460 ha of Arasbaran area as a biosphere reserve. Fuelwood harvesting has been going on for many years. After 20 years of implementing the five-year strategic plans to replace fuelwood with fossil fuel, including LPG (Liquefied Petroleum Gas) and Kerosene, fuelwood harvesting has ceased, to our knowledge, in villages with access to fossil fuels. For this reason, we selected six forest sites available for research: three sites with ongoing fuelwood collection ('harvest' hereafter) and three sites without its collection for twenty years ('no harvest' hereafter). Selected sites were relatively similar in terms of distance from villages. Access to the forest was restricted, limiting site selection to villages in two watersheds. In one watershed, the villages were

at high elevations (Table 1) and had access to alternative fuels such that no harvest plots were established around these villages. The other watershed had villages at low elevations (Table 1) that continue to use fuelwood; harvest plots were established around these villages. Villages with the same altitude were not available. Therefore, for this case study, we assumed minor differences in composition and growth between the two watersheds, and elevations based on personal observation and experience in this forest type; main species that are found at both elevations; species richness in the altitudes <1400, 1400–1600, and >1800 m was not significantly different in a nearby study of Arasbaran forests, and another Iranian study showed human disturbance was more important to predicting forest structure than elevation [30,31]. Reference areas were not established, because forest areas that never had fuelwood harvests do not exist, to the best of our knowledge.

2.2. Data Collection and Analysis

In each site, we set up six sample plots (100 m × 50 m (0.5 ha)) in a systematic 800 m by 800 m grid. In total, 36 sample plots were surveyed with a total area of nine ha in harvest and no harvest conditions.

Data were collected in sample plots from May 2020 to May 2021 on trees and shrubs. Woody stems with height ≥ 1.3 m were categorized as mid-story and overstory woody vegetation that hereafter we called large woody species and those with height <1.3 m were defined as understory woody vegetation that we hereafter called small woody species [10,11]. At each sample plot, each stem was identified as to species and measured for DBH (diameter at the breast height = 1.3 m) and height class. The species identification was based on the Iranian flora books [32] and the expert botanical knowledge of researchers. Tree height was defined as the distance between the base and the top of a standing tree.

The six plots were averaged at each site such that site means $\pm$ standard errors (SE) are presented for harvest and no harvest areas ($n = 3$ for both areas). Large woody species data were summarized and scaled to a per hectare basis for density (stems/ha) and basal area (m^2/ha). To describe the distribution of DBH and height, large woody species were classified into <10, 10–15, 15–20, and >20 cm DBH classes and large woody species height was classified into 2-m intervals: <3, 3–5, 5–7, 7–9, 9–11, and >11 m height classes. Small woody species data were summarized for density (stems/ha). In addition, a suite of other common indices was calculated to describe large woody species contribution to stand structure and diversity in harvest and no harvest areas (Table 2). To describe the dominant species composition, we first calculated the importance values index (IVI) of species across all plots within harvest and no harvest areas. We then sorted the species according to these values and screened the most important woody species. The IVI of woody species was determined as the sum of relative frequency, relative density, and relative dominance [33] (Table 2).

Table 2. The equation of forest structure, diversity, and composition indices used in the analysis.

Equation Number	Index	Equation	Description & Reference
1	Relative density (RDe)	$RDe = \frac{\text{number of individuals of a species}}{\text{total number of individuals}} \times 100$	[33,34]
2	Species Richness (S)	$S = \frac{\text{Number of species}}{\text{quadrat}}$	[34,35]
3	Simpson index of Dominance (D)	$D = \sum (p_i)^2$	Where D = Simpson index of dominance; where p_i = the proportion of the important value of the i th species ($p_i = n_i/N$, n_i is the important value index of i th species and N is the important value index of all the species) [34,36]

Table 2. Cont.

Equation Number	Index	Equation	Description & Reference
4	Simpson's evenness (E)	$E = \frac{(\frac{1}{S})}{S}$	E: Simpson's evenness; S: species richness [34–36]
5	Shannon-Wiener's index of diversity (H)	$H = -\sum_{i=1}^s (p_i)(\ln p_i)$	Where $p_i = n_i/N$; n_i is the number of individual trees present for species i , and N is the total number of individuals [34–36]
6	Relative frequency (RF)	$RF = \frac{\text{Frequency of a species}}{\text{Sum of all frequencies}} \times 100$	[33,34]
7	Relative dominance (RDo)	$RDo = \frac{\text{Total basal area for a species}}{\text{Total basal area of all species}} \times 100$	[34]
8	The importance value index (IVI)	$IVI = RDo + RDe + RF$	[10,32,35]

3. Results

3.1. Species Composition and Structure

Results showed that 21 tree and shrub species were inventoried as large woody species across all sites. In the harvest areas, we identified 19 species, while 17 species were found in no harvest areas (Figure 2). Some of the species (*Carpinus orientalis*, *Quercus macranthera*, *Acer campestre*, *Pyrus syriaca*, *Sorbus aucuparia*, *Prunus avium*, *Malus orientalis*, *Mespilus germanica*, *Sorbus graeca*, and *Acer monspessulanum*) had tree form and some other (*Viburnum lantana*, *Cornus sanguinea*, *Prunus spinosa*, *Lonicera iberica*, *Crataegus orientalis*, *Euonymus latifolius*, *Juniperus excelsa*, *Berberis vulgaris*, *Cotoneaster hissaria*, *Ribes biebersteinii*, and *Rosa canina*) had shrub form. The most common species in the harvest areas tended to be *Q. macranthera*, *Viburnum lantana*, and *Lonicera iberica* (Figure 2). *C. orientalis*, *Q. macranthera*, and *A. campestre* tended to be the most common species in the no harvest areas. We found that the frequency percent for *Q. macranthera* tended to be higher in harvest than no harvest, but the trend was opposite of *C. orientalis*, while *A. campestre* tended to be similar between treatments.

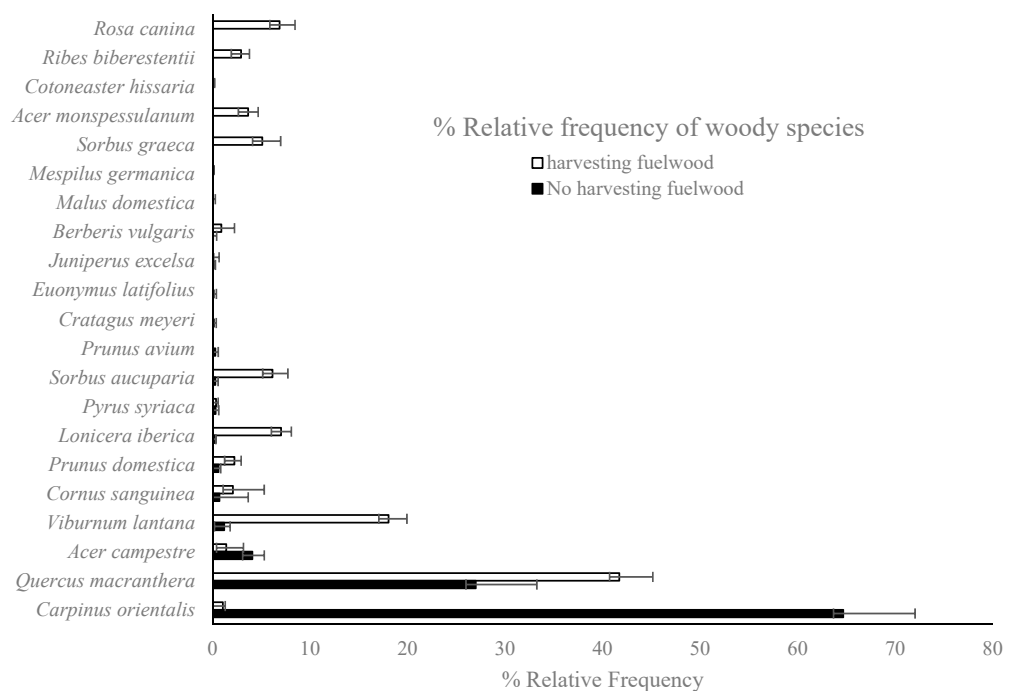


Figure 2. Mean $\pm$ SE of the relative frequency percent of all large (≥ 1.3 m tall) woody species in both harvests ($n = 3$) and no harvest ($n = 3$) fuelwood sites within the Arasbaran forests, northwest Iran.

The importance value index (IVI) showed marked differences between harvest and no harvest areas. In harvest areas, *Q. macranthera* tended to dominate with the highest IVI

followed by *Viburnum lantana* and *Sorbus graeca*. In contrast, in no harvest areas, *C. orientalis* tended to have the highest IVI as dominant woody species followed by *Q. macranthera* and *A. campestre* (Figure 3).

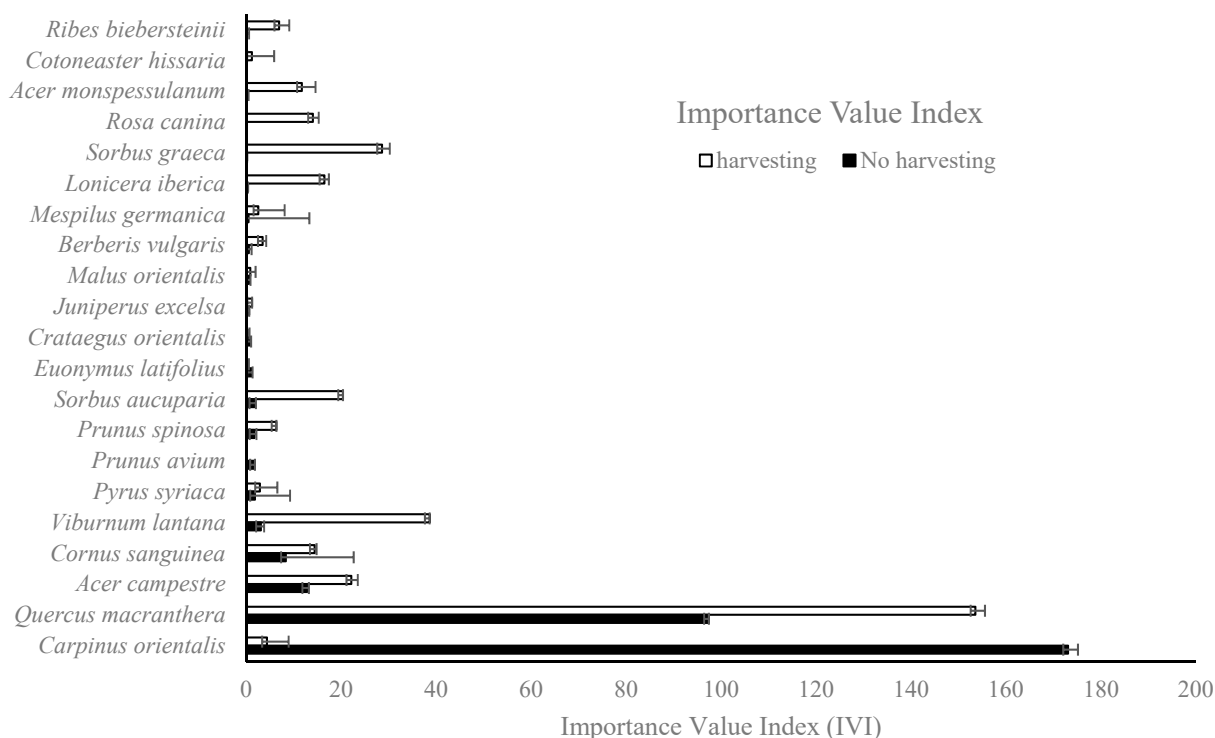


Figure 3. Mean $\pm$ SE of the Important Value Index of large (≥ 1.3 m tall) woody species in fuelwood harvest ($n = 3$) and no harvest ($n = 3$) sites within the Arasbaran forests, northwest Iran.

Mid- to overstory forest structure and composition tended to vary across fuelwood treatments (Table 3). No harvest areas tended to be dominated in large woody species density and basal area by *C. orientalis* and *Q. macranthera*, while harvest areas tended to be dominated by *Q. macranthera*. The three important species in no harvest areas tended to be large in diameter and tall in height, while the three important species in harvest areas tended to vary in mean diameter and height.

Table 3. Mean $\pm$ SE of the three main large (≥ 1.3 m tall) woody species in fuelwood harvest ($n = 3$) and no harvest ($n = 3$) sites within the Arasbaran forests, northwest Iran.

Variable (Mean $\pm$ SE)	No Harvest			Harvest		
	<i>Acer campestre</i>	<i>Carpinus orientalis</i>	<i>Quercus macranthera</i>	<i>Quercus macranthera</i>	<i>Sorbus graeca</i>	<i>Viburnum lantana</i>
Stem ha ⁻¹	124 $\pm$ 66	1975 $\pm$ 975	824 $\pm$ 361	947 $\pm$ 204	136 $\pm$ 83	410 $\pm$ 95
DBH (cm)	10.3 $\pm$ 1.6	12.1 $\pm$ 2	14.3 $\pm$ 3	15.3 $\pm$ 1.6	10.9 $\pm$ 5.4	2.9 $\pm$ 0.08
Height (m)	6.2 $\pm$ 1.1	6.9 $\pm$ 0.8	6.9 $\pm$ 0.9	4.9 $\pm$ 0.7	3.3 $\pm$ 1.7	2.4 $\pm$ 0.1
Basal area (m ² ha ⁻¹)	1.1 $\pm$ 0.4	20.3 $\pm$ 7.8	15.4 $\pm$ 7.78	20.5 $\pm$ 7.4	3.5 $\pm$ 1.8	0.3 $\pm$ 0.09

The distribution of stem DBH and height of large woody species tended to vary between treatments (Figure 4). A greater density of large woody species tended to be in smaller than larger DBH classes in both harvest and no harvest areas. In the 10–15 cm DBH classes (>20 cm), density tended to be lower in the harvest than in no harvest areas. Height class distribution tended to be similar but tended to shift toward taller trees and shrubs in the no harvest and toward shorter trees and shrubs in the harvest areas. In general, no harvest areas tended to have large woody species in the five to seven m and taller classes, while harvest areas tended to have more large woody species in the <3 m tall category.

Also, canopy cover in the harvest areas (63%) tended to be lower than no harvest areas (75%) (Table 4).

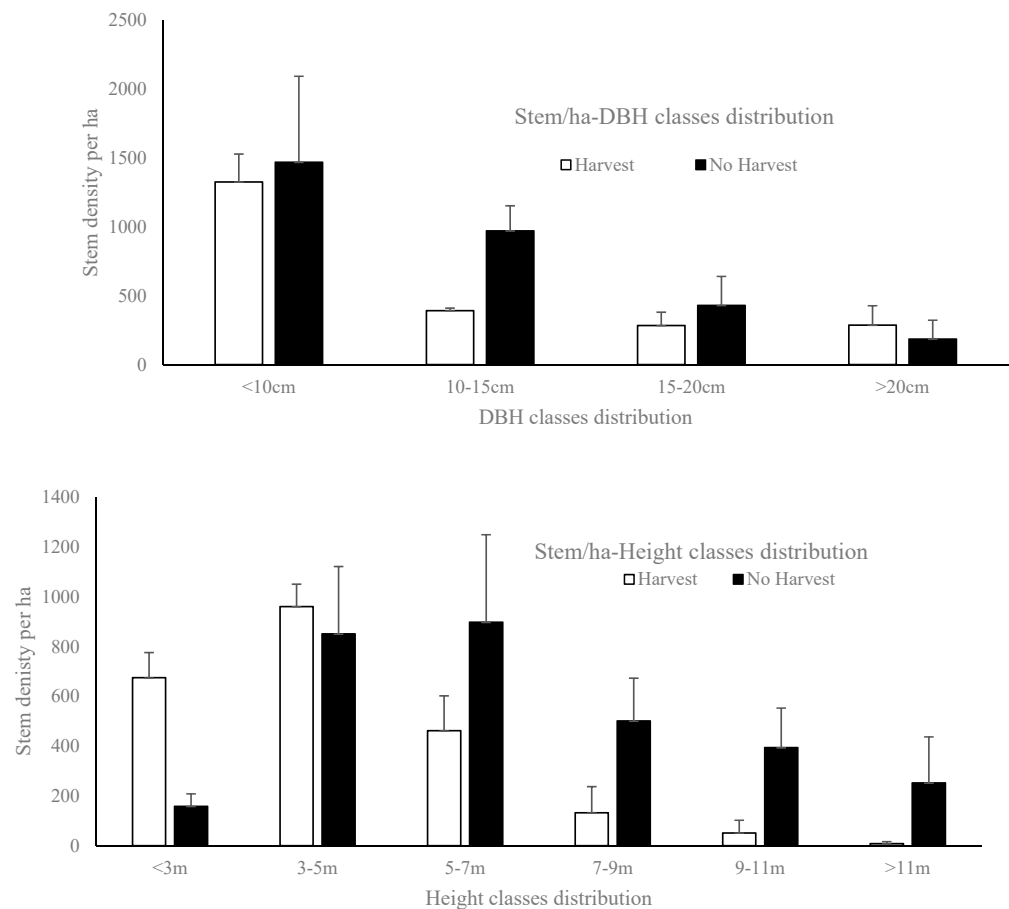


Figure 4. Mean $\pm$ SE of the DBH and height by class for large (≥ 1.3 m tall) woody species in areas of fuelwood harvest ($n = 3$) and no harvest ($n = 3$) sites within the Arasbaran forests, northwest Iran.

Table 4. Mean $\pm$ SE of large (> 1.3 m) woody species structure and diversity variables in fuelwood harvest ($n = 3$) and no harvest ($n = 3$) sites within the Arasbaran forests, northwest Iran.

Variable	All Species	
	Harvest	No Harvest
Stem ha ⁻¹	2271 (430)	3043 (599)
DBH (cm)	12.6 (1.2)	12.5 (2.3)
Height (m)	4.3 (0.5)	6.6 (0.8)
Basal area (m ² ha ⁻¹)	27.8 (9.0)	38 (12.2)
Canopy cover (%)	63 (4)	75 (1.3)
Species richness (ha ⁻¹)	20 (1)	14 (2)
Simpson evenness	0.32 (0.03)	0.33 (0.04)
Simpson index of dominance	0.33 (0.02)	0.53 (0.08)
Shannon-Wiener's index of diversity	1.66 (0.05)	0.77 (0.21)

3.2. Large Woody Species Diversity

Large woody species diversity tended to vary between fuelwood harvest and no harvest areas (Figure 5, Table 4). For most variables, diversity tended to be higher in harvest than in no harvest areas, but there was variability among sites. For species richness, there tended to be a pattern across sites where richness tended to be higher in the harvest than in no harvest areas. We found that species richness in the harvest areas tended to be higher than no harvest areas despite lower stem density per ha in the harvest than no

harvest sites (2271: 20 and 3043:14 stem density ha^{-1} : species richness ha^{-1} in the harvest and no harvest areas, respectively).

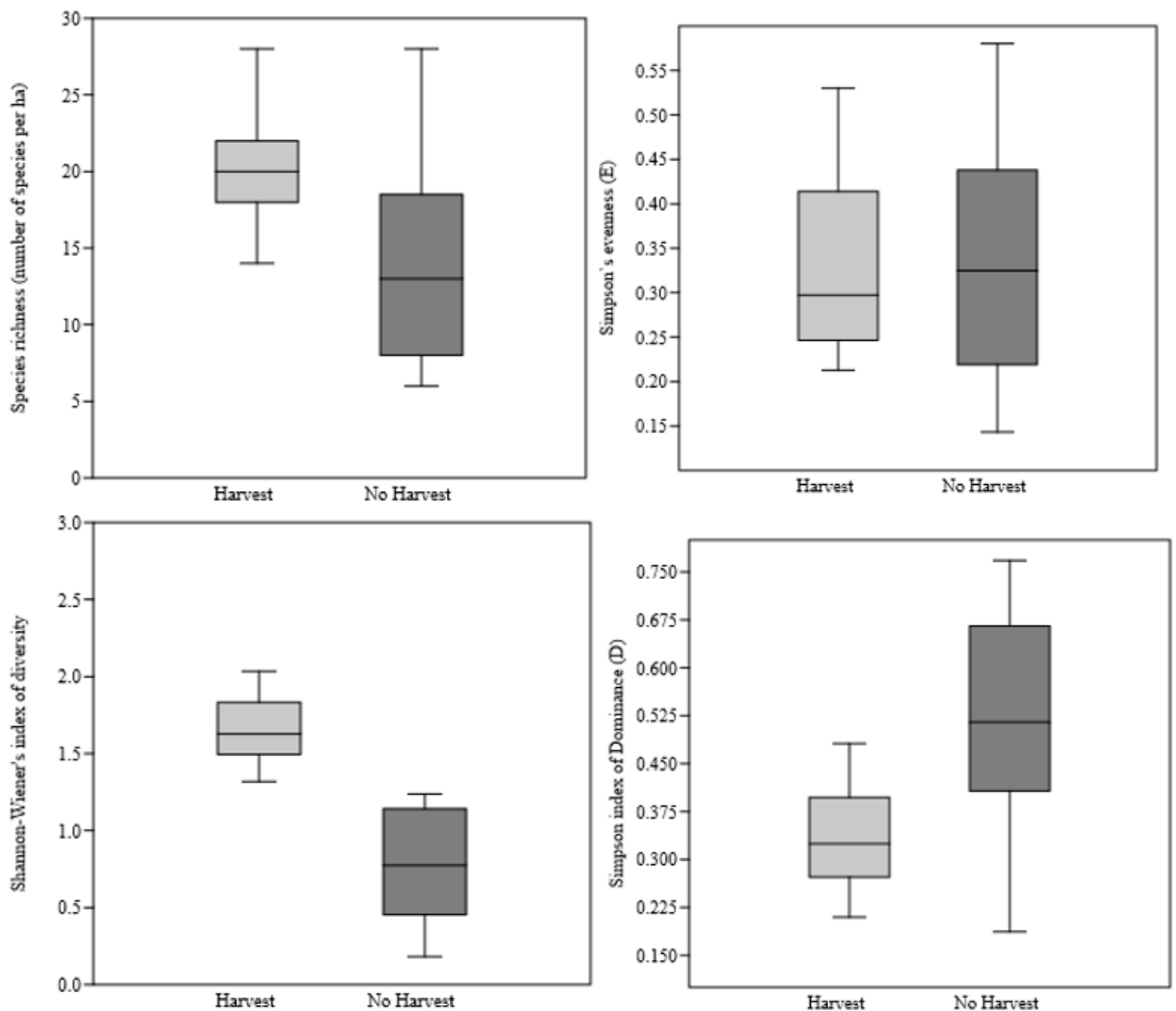


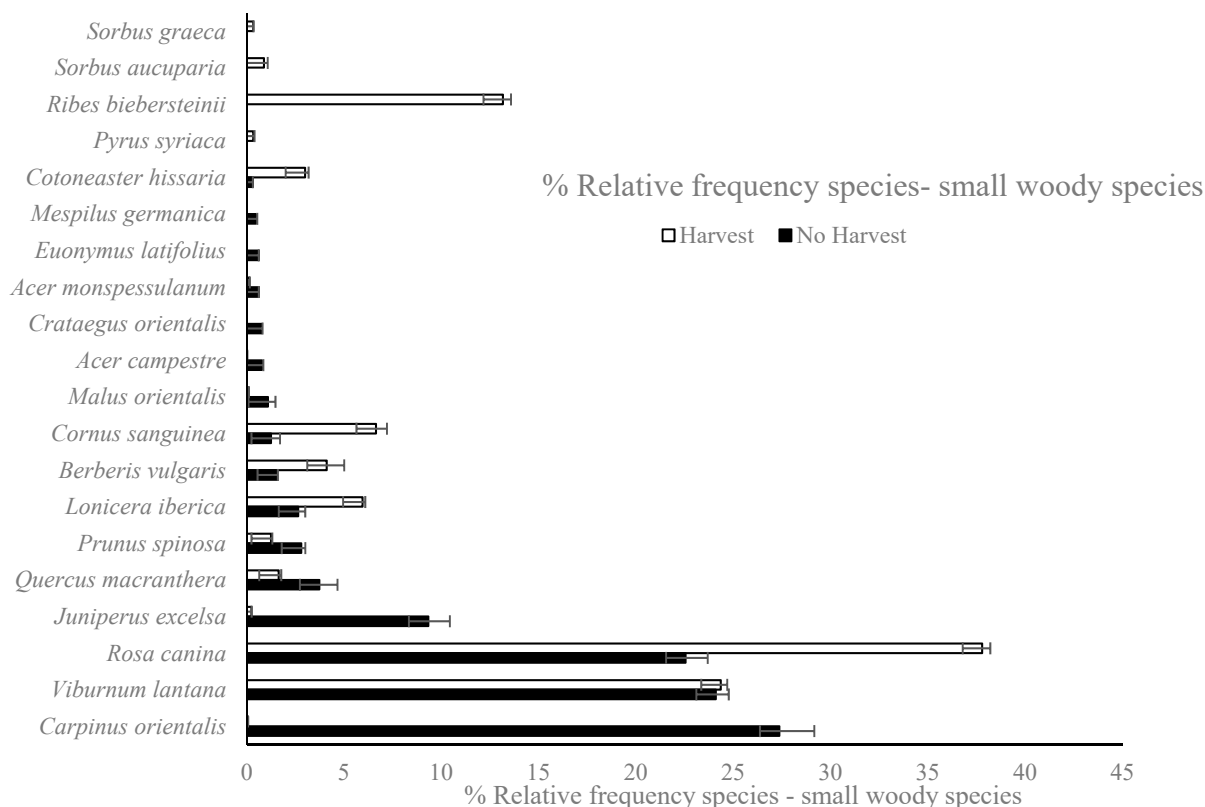
Figure 5. Box plots of large (>1.3 m tall) woody species diversity indices in fuelwood harvest ($n = 3$) and no harvest ($n = 3$) sites within the Arasbaran forests, northwest Iran.

3.3. Small Woody Species Status

The number of small woody species tended to vary across harvest and no harvest areas (Table 5). The small woody species density tended to be higher in harvest than in no harvest areas. Composition tended to be different between harvest and no harvest areas (Figure 6); *Rosa canina* tended to have the highest density ($227 \pm 38 \text{ Ind. ha}^{-1}$), followed by *Viburnum lantana* ($137 \pm 30 \text{ Ind. ha}^{-1}$) in harvest areas, while, in no harvest areas, *R. canina* ($45 \pm 18 \text{ Ind. ha}^{-1}$) and *Viburnum lantana* ($34 \pm 14 \text{ Ind. ha}^{-1}$) tended to be dominant. Based on density, species richness tended to be higher in harvest than in no harvest areas (501:11 and 76:10 stem density ha^{-1} : species richness ha^{-1} in the harvest and no harvest areas, respectively).

Table 5. Mean $\pm$ SE of the density and richness of small (<1.3 m tall) woody species in fuelwood harvest (n = 3) and no harvest (n = 3) sites within the Arasbaran forests, northwest Iran.

Variable ($\pm$ SE)	All Species	
	Harvest	No Harvest
Stem ha ⁻¹	501 (154)	71 (3)
Species richness (ha ⁻¹)	11 (1)	10 (3)

**Figure 6.** Mean ($\pm$ SE) of the relative frequency percent of small (<1.3 m tall) woody species by species in both fuelwood harvest (n = 3) and no harvest (n = 3) sites within the Arasbaran forests, northwest Iran.

4. Discussion

The harvest of fuelwood is one of the main deforestation factors in Iranian forests [27,37]. Policy changes in northwestern Iran have increased access of villages to fossil fuels and fuelwood harvesting in adjacent forests has ceased for 20 years. This case study provides initial data on the woody species density, species diversity, and forest composition among areas of fuelwood harvest and no harvest in the understudied and scarce forests of northwest Iran. While similar research has been conducted in different parts of the world such as Europe [38,39] and America [40–42], this is the first case study on this topic in Arasbaran forests that we are aware of. The study findings supported our hypotheses, in part; two of three of the preferred fuelwood species (*C. orientalis* and *Q. macranthera*) tended to be higher in large woody species IVI and of greater density in the no harvest area than harvest areas, and all small woody species tended to be higher in harvest than no harvest areas. In contrast to our expectations, diversity measures tended to be lower in no harvest than harvest areas.

Fuelwood harvesting may be species-specific, because some species may be more preferred fuelwood sources than others. *Q. macranthera*, *C. orientalis*, and *A. campestre* have been mentioned as the three most important species for fuelwood uses by rural people of Iran due to high relative frequency and suitable burning qualities [18]. The wood of *C. orientalis* has a high calorific value as it burns slowly, making it excellent fuel wood, and

charcoal [21] and *Q. macranthera* and *A. campestre* have similar qualities (calorific values: *Q. macranthera* = 17.4 MJ/kg, *C. orientalis* = 16. MJ/kg, *A. campestre* = 17.1 MJ/kg) [43,44].

Based on this case study, the relative frequency of *A. campestre* and *C. orientalis* tended to be higher in no harvest than harvest areas, suggesting fuelwood harvesting has decreased their presence in areas of fuelwood harvest. Notably, the relative frequency of *C. orientalis* tended to be high (64%) in no harvest and low (1%) in harvest areas. *C. orientalis* is one of the dominant species of Arasbaran forests [19], and these results suggest the tentative need for conservation to sustain this species around villages that use fuelwood. *C. orientalis* favors deep moist and well-drained soils from sub-acid to calcareous, although it can tolerate wet heavy clay to light dry sandy soils, but never acid. It grows in full to partial sunny conditions and it is also one of the few strongly shade-tolerant native trees. For this reason, this species can play roles both as a secondary species and as an understory tree and also as a colonizer on bare and disturbed soils. [21,45]. The practice of selective species harvesting has already been reported, and shows that the preference of fuelwood gathering is *Pinus wallichiana* because it easily catches fire [46], and *Quercus* spp. due to its burning and heating quality [18,46]. Selective harvest of *C. orientalis* may be occurring in the case study areas. Therefore, developing new harvesting practices to maintain a minimum residual number of stems across a range of size classes, including seed-bearing trees and dead trees, would be important to sustaining the species in harvest areas. In modern silviculture, dead trees are retained to promote biodiversity in multi-use forest management [47,48]. However, more research is needed to establish detailed guidelines for Arasbaran forests.

On the other hand, some research shows that fuelwood collection is not species-selective [49], and composition shifts associated with fuelwood harvesting may be due to other factors. For instance, *R. canina* tended to be found in the fuelwood harvesting areas, while it tended to not occur in the no harvest areas. This species is usually observed in early succession. In a different study, the frequency of ruderal species such as *R. canina*, *Crataegus orientalis*, and *Prunus spinosa* increased with increasing human intervention and in highly degraded ecosystems [50]. In our case study, fuelwood harvesting likely changed forest structure and niches available such that ruderal species could establish. The compositional change of the high density of *R. canina* in harvest areas may be due to its life history traits being favored in harvested areas and not due to selective species harvest. Harvesting practices that create variability for both early and late-successional species would promote more even species abundance in composition. Close to nature practices that have micro stands of dispersed and clumped cutting and no cutting would create variable conditions for a range of life-history traits.

Contrary to our expectations, we found that indices of species diversity tended to be higher in harvest than in no harvest sites. We had anticipated that selective species harvest would result in lower species diversity in the harvest than no harvest areas. However, the Shannon-Wiener's index of diversity and Simpson index of dominance suggest few commonly-dominant species in no-harvest areas, whereas harvest areas tended to have more species and better frequency distribution among the species than no harvest areas. Other researchers have also found higher diversity species in the harvest than no harvest sites [11,51]. It is likely that the fuelwood harvesting created a range of stand conditions that allowed a variety of species to coexist [52]. The no harvest areas have had minimal disturbance over the last 20 years and likely a narrower range of stand conditions, limiting species coexistence. On the contrary, in a research by [42] have been found that species richness for trees ≥ 15 cm DBH was greater in the control and low-intensity (74–75 species) than in the moderate-intensity (47 species) and clear-cut (26 species) treatment plots. Additional follow-up studies at our sites would be needed to test a longer timeframe (e.g., longer than the average tree life span or longer than the 20-year post fuel switch in this case study) of no fuelwood harvest and whether species diversity would eventually be greater in no harvest than harvest areas.

In line with our expectations, the density of woody species tended to be higher in no harvest than harvest areas. We anticipated that regular fuelwood harvest was unsustainable such that woody species numbers would be reduced compared to no harvest areas where natural processes influence stand development. A similar finding has been found by [42] in Amazonian forests. Small-scale disturbances through fuelwood harvesting have been shown to decrease basal area as well [10]. Based on the findings of [53], the basal area stocking decreased from $25 \text{ m}^2\text{ha}^{-1}$ to $10 \text{ m}^2\text{ha}^{-1}$ in no harvest to harvest in mangrove forests, respectively [10,53]. While a similar trend was observed at our sites, stocking was highly variable in both harvest and no harvest areas.

Several studies have shown that harvest areas had shorter trees compared to no harvest areas [11,51]. We similarly tended to find shorter trees in harvest than no harvest areas. This may be due to selective tree size harvest or the frequency of harvest being high, such that trees do not have enough time to attain similar heights as no harvest areas. More research would be needed to examine this idea.

In terms of tree diameter size, the mean size tended to be similar in harvest and no harvest areas, except in the 10–15 cm DBH range. Small pole-sized trees (10–15 cm DBH) were less frequent in harvest than in no harvest areas. People were typically harvesting relatively small-diameter tree stems and branches used for fuelwood uses [49]. Selective tree size harvest could create this pattern; alternatively, it could be a pattern created by a past disturbance. Additional research would be needed to clarify the cause. If fuelwood harvesting is the cause, then continued harvest in this size range could lead to future deficits in larger size classes. Future studies could detail guides for the sustainable harvest that leaves an alternative residual size class structure.

Fuelwood harvesting can create canopy gaps into forest stands. At our sites, canopy cover tended to be lower in harvest than in no harvest areas. Canopy gaps can facilitate suitable environmental conditions such as light availability for shade-intolerant species, enhancing recruitment and contributing to the maintenance of existing tree species [10]. Canopy gaps also provide a suitable condition for regeneration [49]. Other researchers also have found a strong correlation between canopy gaps and regeneration density [54,55]. We observed that harvest areas tended to have more small woody species density (about 6.5 times of density no harvest areas), which could partially be due to the presence of small gaps and lower canopy cover in harvest areas [10]. Also, in a research by [11] was reported that regeneration was higher in harvest than in no harvest sites. Regeneration may be negatively affected by fuelwood harvests due to a reduction in viable seed sources [1]. In our case study, regenerating *C. orientalis* tended to have low relative frequency and this may be due to its rare presence in the overstory and lack of seed source.

One important consideration for our case study is the altitudinal differences between the harvest and no harvest areas (Table 1). Villages located in similar altitudes with different fuelwood harvesting statuses were not available in the accessible forest area; therefore, altitude could explain some of the trends we observed (Not shown: classification analysis of species presence/absence indicate plot separation by harvest, elevation, or both, which, without further data, cannot be clarified empirically). In the literature, previous research has shown altitudinal differences in forest composition, structure, or diversity at low and high altitudes [56–58]. There was no correlation between tree density and basal area with topographical parameters including altitude in forests located between 1000 and 2000 m.a.s.l. in northern Iran, which has a similar altitudinal range to our case study [56]. However, some research has shown that altitude has significant impacts on species diversity [57,58]. For instance, in a study [57] has been shown that in three altitude classes (600–900, 900–1200, and 1200–1500), that diversity indices of ground-layer vegetation of Arasbaran forests were different. Understory plants are often more sensitive to environmental change than trees [59], and our case study focused on trees and shrubs. In a study in northern Iran, tree species richness was not different across elevations that were similar to our case study [31]. Based on our observations of the forests at the two altitudes and our general experience in these forests, forest conditions tended to be similar

in main species. As presented, our case study provides initial data for further inquiry into these harvest and elevation effects. Future research should include replicated factors of fuelwood treatments, altitude, and other variables so that statistical models can be used to analyze their individual and interactive effects on forest structure, composition, and diversity of Iranian forests.

5. Conclusions

Assessment of woody species diversity and structure is important for their sustainable utilization, management, and conservation. This case study in the Arasbaran forests detailed forest composition, structure, and diversity in fuelwood harvest and no harvest areas in two watersheds. In general, the results highlight an opportunity for sustainable forest management both in harvest and no harvest areas in these watersheds. For example, woody species density tended to be higher, tree height tended to be taller, and fuelwood preferred species tended to be more common in no harvest than harvest areas. These results suggest some recovery since alternative fuel availability and fuelwood harvest cessation 20 years ago. However, no harvest areas also tended to be low in diversity. When increasing species diversity is a goal in areas without fuelwood harvest, close to nature forestry practices could be used to create variability in stand structure to allow for more species to coexist and increase diversity. On the other hand, harvest areas tended to have shorter trees, greater species diversity, and greater dominance by ruderal species, and lower densities of small pole-sized trees compared to no harvest areas. To address areas with goals for fewer ruderal species and more tree size diversity, close to nature forestry practices that shift composition away from ruderal dominance and allow for the structural development of smaller tree sizes could promote sustainability of this ecosystem. Follow up silviculture studies in these watersheds would be necessary to develop guidelines.

Based on our case study of two watersheds and villages at two elevations, we suggest continued support for research in these and other watersheds and elevations to develop sustainable forest management for both fuelwood harvest and no harvest areas in the Arasbaran forests. Best practices would aim to modify subsistence fuelwood harvests and restore no harvest areas so that planned management can be implemented. Suggestions for planned management include close-to-nature practices such as (1) enrichment planting of species of concern, such as *C. orientalis*, in areas currently used for fuelwood harvest to increase density and provide a seed source, (2) creating canopy gaps in highly stocked no harvest areas to provide growing space for natural regeneration of a range of species, and, (3) where switching to alternative fuel sources is not possible, educating the villages about close to nature forestry approaches for fuelwood harvesting.

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