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The study of parent-regeneration relationships for wild cherry (*Prunus avium* L.) in Hyrcanian forests

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Abstract: The regeneration of forest trees is affected by the presence, dispersion pattern and specifications of parent trees. These effects were investigated and modelled in hardwood forests in the north of Iran. To do so, at first, fifty plots, each with a total area of 0.1 ha, were identified. Four subplots with a radius of two meters were then stabilized in each plot. The height and the root collar diameter of all the cherry seedlings were measured. Likewise, the diameter, basal area, and distance from the plot centre were appraised in the parent trees. The correlation and regression analyses were performed to evaluate the effects and to construct the models, respectively. The results showed that there was a positive and significant relationship between the presence, abundance, mean diameter, and total basal area of parent trees and the presence and abundance of seedlings. The logistic regression showed that the models based on the mean diameter of parent trees and abundance of parent trees could significantly predict the presence of regeneration. Only in 10% of the sample plots was the regeneration recorded without the presence of a parent tree. Due to the small number of established seedlings, while maintaining the existing parent trees, especially large trees, it is necessary to consider the proper management methods to promote and protect their regeneration. We recommend completing the natural regeneration of wild cherry by artificial regeneration and creating well-dimensioned canopy gaps.

Keywords: abundance; dispersion pattern; seedling recruitment; topography

The wild cherry (*Prunus avium* L.) is a native species which can be found at altitudes ranging from 900 to 2 800 meters above sea level throughout the northern forests of Iran (Shirazi et al. 2013). The wild cherries do not form any dominant trees. Rather, they are commonly accompanied by dominant trees, both broadleaves and conifers. The wild cherries spread over almost all parts of central Europe, parts of southern Europe and the Caucasus. It is also distributed in northwestern Africa, Crimea, northern Turkey, and, to a lesser extent, the Mediterranean areas (Shiranpour 2008; Narandžić 2018).

Among the studies done on the relationships between regeneration and mother trees, Mirschel et al. (2011) carried out a study in the northeastern forests of Germany. Their results showed a positive correlation between regeneration abundance and proximity to the parent trees in the beech and oak stands. Shirazi et al. (2013) showed that elevation, landform, aspect, and slope had significant effects on the dispersion pattern of the wild cherry, so that the seedlings were mostly concentrated in the eastern parts. Breitbach et al. (2012) studied the transport distance of the wild cherry seeds carried away by the birds in Germany. Their results showed that large amounts of seeds fell onto the ground, where the birds could feed on. The findings from the study by Long and Ristau (2017) showed that stand age may not be a factor reducing seed production of *Prunus serotina* (Ehrh.). There are likely also other factors such as poor pollination, a significant decrease in atmospheric nitrate inputs, and erratic

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weather that could affect seed production. Höltken and Gregorius (2006) stated that local establishment of wild cherry is highly affected by the forest management method. Sexual recruitment as the first local generation was followed by the second asexual generation in both coppice and high forest systems, whereas in the coppice system there was evidence for an additional clonal generation. Pairon et al. (2006) studied regeneration traits of black cherry (*Prunus serotina* Ehrh.). They found that production variability between individuals was not correlated with plant size variables. High mortality among young seedlings was observed and 95.3% of the fruits failed to give 4-year-old saplings. Only saplings older than 4 years presented a high survival rate (86%) during 2004–2005. Nyssen et al. (2016) provided some management guidelines for black cherry on sandy soils where the aim is timber production. They suggested regenerating under light shelter or in gaps with a minimum width of 10 m and a maximum width of 1.5 times the height of the surrounding trees.

The wild cherry seedlings have always been of interest to local people due to the domestic production of fruits. Today, mature trees of the wild cherry are rare as they grow only in the protected forests of Iran. Therefore, devoting attention to this pioneer tree species and studying its regeneration are vital (Mollashahi et al. 2009). Although a wide range of planting and propagation activities have been done in Iran, the wild cherry is not completely immune to degradation.

The regeneration of forest trees can guarantee their survival in the forests. However, regeneration is strongly influenced by the abundance, location, and dispersion of parent trees. In this research, the distribution pattern and characteristics of wild cherry seedlings and the relationship between their presence and the presence, abundance, and characteristics of parent trees were investigated. The objective of this research was to contribute to understanding of the dynamics of regeneration of the wild cherries, which can help develop restoration guidelines aiming at restoration and maintenance of this valuable species under the study site conditions.

MATERIAL AND METHODS

Study site. This research was carried out in a forested area located 10 km from Rezvanshahr city, northern Iran (longitude of 49°2'40"E to 49°7'10"E and latitude of 37°1'20"N to 37°30'8"N), covering an

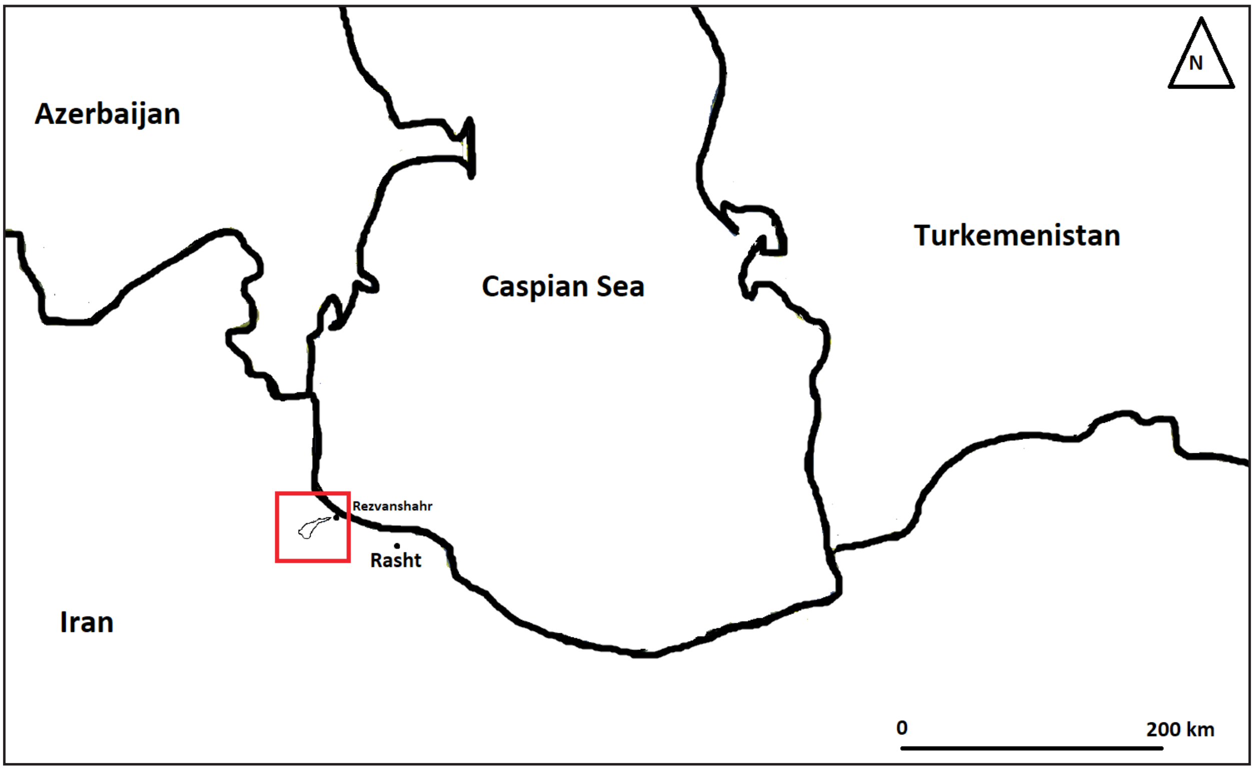

Figure 1. Location of the study area in the north of Iran

area of 1 500 ha (Figure 1). Based on the 30-year data set (1987–2017), the average annual temperature is 15.5 °C in this basin; the average annual rainfall totals 1 268 mm, and the climate of the region based on Emberger's method is humid (Arkian et al. 2018). This area is one of the most important habitats of wild cherry in Iran. The other main tree species include hornbeam (*Carpinus betulus* L.), Persian ironwood (*Parrotia persica* C.A. Meyer), chestnut-leaved oak (*Quercus castaneifolia* C.A. Meyer), Caucasian alder (*Alnus subcordata* C.A. Meyer), Caucasian wingnut (*Pterocarya fraxinifolia* Lam.), Caspian locust (*Gleditsia caspica* Desf.), Caucasian persimmon (*Diospyrus lotus* L.) and spreading plum (*Prunus divaricata* Ledeb.) (Anonymous 2003).

Methodology. After stabilization of the first sample plot, the north-south orientation was selected for inventory lines. A total of 50 circular plots (500 × 600 m grid) with an area of 1 000 m^2 and 200 subplots with an area of 2 m^2 were taken systematically. In each sample plot, all the existing cherry trees were recorded and their distance and azimuth from the plot centre were measured. One subplot in the centre and three subplots in the azimuths of 0, 120, and 240 degrees, each with a radius of two meters, were taken, and all the cherry seedlings present within the subplot circle were counted and both their heights (to the nearest 0.5 cm) and the root collar diameters (to the nearest 0.5 mm) were measured (Figure 2).

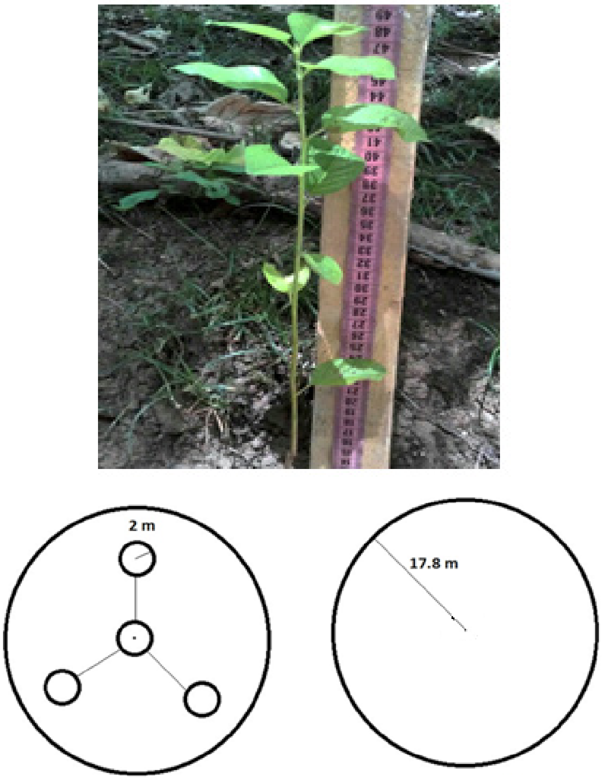

Figure 2. An approach to measure the height of large seedlings using a wooden rod with a tailor's tape measure (top); subplot patterns and their layout in the main plot (bottom)

The frequency of seedlings in height classes was calculated in accordance with the United States classification system (McWilliams et al. 2002), as shown in Table 1. In this system, greater weight and importance are assigned to the larger seedlings.

The relationships between the number and basal area of parent trees in the sample plot and the regeneration abundance were obtained from the Pearson test, and in the case of non-normally distributed data, the Spearman test was used to determine the given relationships. Eta correlation test was used to investigate the effect of geographic direction of the plot on the abundance and quantitative characteristics of seedlings. The relationships between the presence of parent trees and the presence of regeneration were also investigated by Phi and Cramer's tests.

The quantitative characteristics of regeneration in different geographic directions were compared using the Kruskal-Wallis test. To model the relationships between the abundance and the characteristics of parent trees and the abundance of regeneration, a stepwise regression analysis was used. Durbin-Watson test was used to ensure the independence of regression residuals. In order to model the relationship between the presence and the characteristics of parent trees and the presence of regeneration, a binomial logistic regression analysis was used. Five quadrat indices were used to determine the dispersion pattern of wild cherry seedlings (Table 2). It also specifies how the values of the indices are used to estimate the dispersion pattern.

Table 1. Height classification of regeneration for forest trees (McWilliams et al. 2002)

Height class (cm)	Weighted frequency
5.1–14.7	1
14.7–30	1
30–90	2
90–150	20
150–310	50
> 310	50

Table 2. Quadrat indices to evaluate the dispersion pattern of wild cherry seedlings (Krebs 2014)

Index	Equation	Statistic	Pattern
Green	$GI = \frac{\left(\frac{S^2}{\bar{X}}\right)-1}{n-1}$	$GI = 0$ $GI > 0$ $GI < 0$	random clumped dispersed
Morisita	$MI = \frac{\sum X_i^2 - N}{N \times (N-1)}$	$MI = 1$ $MI > 1$ $MI < 1$	random clumped dispersed
Standardized Morisita	$Mu = \frac{\chi^2_{0.975} - n + \sum X_i}{\left(\sum X_i\right) - 1}$ $Mc = \frac{\chi^2_{0.025} - n + \sum X_i}{\left(\sum X_i\right) - 1}$	$IP = 0$	random
	If $ID > Mc < 1$ then $IP = 0.5 + 0.5\,[(ID - Mc)/(n - Mc)]$ If $Mc > ID < 1$ then $IP = 0.5\,[(ID - 1)/(Mc - 1)]$ If $1 > ID < Mu$ then $IP = -0.5\,[(ID - 1)/(Mu - 1)]$	$IP > 0$	clumped
	If $1 > Mu < ID$ then $IP = -0.5 + 0.5\,[(ID - Mu)/(Mu)]$	$IP < 0$	dispersed
Index of dispersion	$ID = \frac{S^2}{\bar{X}}$	$ID = 1$ $ID > 1$ $ID = 0$	random clumped dispersed
Lyoid	$LI = \frac{\bar{X} + \left(\frac{s^2}{\bar{X}} - 1\right)}{\bar{X}}$	$LI = 1$ $LI > 1$ $LI < 1$	random clumped dispersed

$\bar{X}$ – mean abundance; S^2 – variance between the subplots; n – number of subplots, X_i – number of seedlings in each subplot; N – total number of seedlings in the subplots; $\chi^2_{0.975}$ – value of the Chi-square table for df = $n - 1$ and $\alpha = 0.975$; $\chi^2_{0.0.025}$ – value of the Chi-square table for df = $n - 1$ and $\alpha = 0.025$; *GI* – Green index; *MI* – Morisita index; *ID* – index of dispersion; *LI* – Lyoid index

An important factor for *Prunus avium* is its ability to develop large numbers of root suckers that result in the clonal propagation of trees. So we checked whether the observed saplings were indeed seedlings (produced from seeds) or root suckers (developed from the root system of adult trees). This was verified by excavation of the measured seedlings.

RESULTS

Table 3 shows the descriptive statistics of the variables. All the seedlings with the height lower than 1.3 m were measured. As this forest is managed by the selection method, it was not possible to determine the exact age of seedlings. Our investigations showed that no measured tree was of root sucker origin.

Figure 3 shows the results of calculating the abundance of regeneration in different height classes at the subplot level. As can be seen, the highest frequency was observed in the height class of 5.1–14.7 cm. The higher the height classes, the higher the value of the seedling.

Table 3. Descriptive statistics of the studied variables regarding wild cherry regeneration

Variable	Mean	SD	Min	Max
Abundance (individual·ha^{-1})	959.4	1 080.6	0.00	5 573.2
Height (cm)	16.2	20.56	5	128.5
Collar diameter (mm)	3	3.3	1	21
Crown width (cm)	7.6	8.9	4.5	45.5

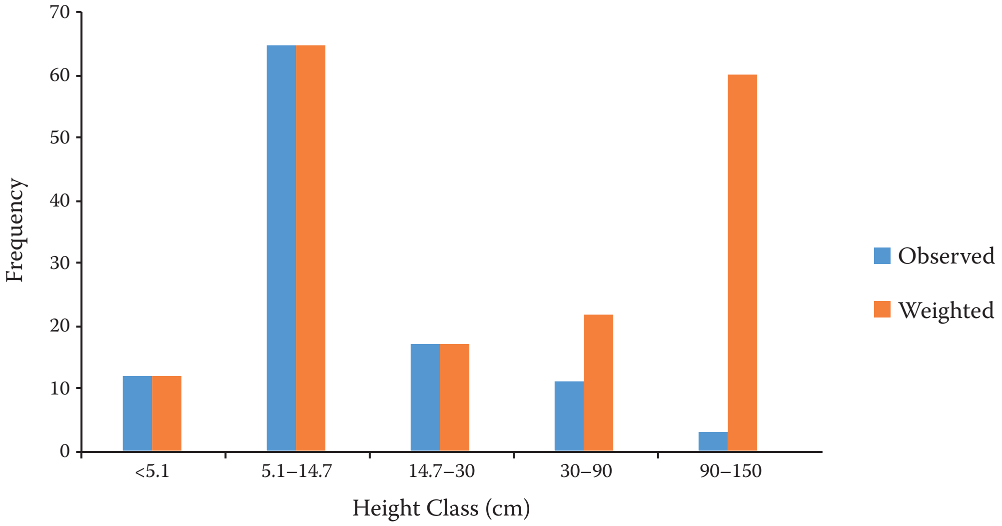

Figure 3. Observed and weighted abundance of wild cherry seedlings in the height classes

Examining the relationship between the regeneration characteristics and the topographic variables showed that there was no significant correlation between the geographic direction and the seedling characteristics, including abundance and root collar diameter. Only the seedling height was significantly correlated with the direction at a 5% significance level. As the elevation increased, the abundance per unit area of the wild cherry regeneration increased whereas seedling height decreased. These correlations were significant at a 5% level maybe due to the large sample size, however the correlation coefficients were quite low (Table 4).

A comparison between the quantitative characteristics of regeneration in different geographic directions showed that there was a significant difference between geographic directions in the height of seedlings. The results of the Mann-Whitney test in the pairwise comparison of the groups showed that the average height of seedlings was the lowest in the east and had a significant difference from the other directions. In the south, west, and north, however, the height of seedlings did not significantly differ. The largest root collar diameter and the highest crown size of regeneration were observed in the south, while the highest regeneration abundance was observed in the east, although the differences were not statistically significant (Table 5). It should be noted that this comparison was made at the forest level, not at the plot level. In fact, the basis of the work was the location of the plots on northern, southern, western and eastern slopes of the forest.

Investigating the relationship between the presence of parent trees and the presence of regeneration using Phi and Cramer's test showed that there was a positive and significant relationship between these two variables in the sample plots (Table 6).

The results showed that the number of wild cherry parent trees was on average 12.6 per ha. Also, mean diameter at breast height and total basal

Table 4. Relationships between topographic variables and wild cherry regeneration characteristics

		Abundance	Collar diameter	Height
Direction	correlation coefficient	-0.01^{ns}	0.10^{ns}	0.21^{*}
	P–value	0.898	0.126	0.018
Elevation	correlation coefficient	0.14^{*}	0.08^{ns}	-0.19^{*}
	P–value	0.043	0.396	0.042

*significant in 0.05 α level; ns – non-significant

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Table 5. Comparison of regeneration characteristics in different geographic directions

Variable	Direction	Mean*	df	Chi-square statistic	*P* value
Height (cm)	east	11.73^b	3	14.21	0.003
	south	23.85^a			
	west	22.23^a			
	north	23.38^a			
Collar diameter (mm)	east	2.57^a	3	3.39	0.334
	south	3.76^a			
	west	3.28^a			
	north	2.77^a			
Crown width (cm)	east	5.96^a	3	5.87	0.118
	south	9.73^a			
	west	8.19^a			
	north	8.78^a			
Abundance (individual·ha^{-1})	east	$1\,862.75^a$	3	1.48	0.687
	south	$1\,804.67^a$			
	west	$1\,642.11^a$			
	north	$1\,415.42^a$			

df – degree of freedom; *similar alphabetical letters show non-significant difference

area of the trees in sample plots were 34.67 cm and 0.16 m^2, respectively. There was a positive and significant correlation between the number of parent trees and the number of seedlings in the plot. The results also showed that there was a positive and significant correlation between the total basal area and the average diameter of parent trees and the number of seedlings in the plot. The distance of the parent trees from the centre of the plot was not correlated with regeneration abundance although there was a negative correlation between the two variables. Parent tree characteristics highly affected the presence of regeneration (Table 7).

Table 6. Phi and Cramer's correlation between the presence of parent trees and the presence of regeneration

Statistical teat	Correlation coefficient	*P*–value
Phi	0.544	0.018
Cramer	0.544	0.018

Modelling the relationship between the characteristics of parent trees and the abundance of regeneration showed that the total basal area (R^2 = 0.34) and the number (R^2 = 0.26) of parent trees were good predictors of the number of seedlings, while the presence of other variables related to the parent trees was not significant in the models. The parameters of the models are shown in Table 8. As can be seen, the presence of con-

Table 7. Pearson and Eta correlations between the characteristics of parent trees and regeneration abundance and presence

	The distance between the parent tree and the center of the sample plot	Average diameter of parent trees	Total basal area of parent trees	Abundance of parent trees
Regeneration Abundance	-0.194^{ns}	0.148^{*}	0.58^{**}	0.56^{**}
P–value	0.243	0.048	0.003	0.000
Regeneration presence	0.44^{ns}	0.86^{**}	0.86^{**}	0.64^{**}

*significant in 0.05 α level; **significant in 0.01 α level; ns – non-significant

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Table 8. Parameters of the fitted model for predicting regeneration abundance

Model parameter	Coefficient	Standard error	t	P–value
Constant	3.3	0.708	4.663	0.000
Basal area of parent trees	16.28	3.893	4.183	0.000
Constant	2.95	0.585	5.056	0.000
Number of parent trees	1.43	0.348	4.104	0.000

t – t-test statistic

stant values, the number and basal area of parent trees in the models were significant. The values of Durbin-Watson statistic were 2.5 and 2.3, respectively, indicating the independence of the errors. The normalized root mean square error (NRMSE) values were calculated to be 4.56% and 2.67%, respectively, representing precise models.

Calculating the probability of the presence of regeneration based on the characteristics of parent trees, with the help of logistic regression analysis, showed that the model which was based on the mean diameter of parent trees was significant ($R^2 = 0.29$). The equation was determined based on Equation (1).

$$Y = \frac{EXP\left(-5.4 + 0.29D\right)}{1 + \left(EXP\left(-5.4 + 0.29D\right)\right)} \tag{1}$$

where;

Y – probability of the presence of regeneration;

D – mean diameter of parent trees in the sample plot;

EXP – the exponentiation of the model coefficients.

The results showed that, for each centimetre, an increase in the diameter of parent trees in the plot increased the probability of the presence of regeneration by 33.9%. The above model could correctly categorize 96.4% of the data. The validity of the model was evaluated by drawing the receiver operating curve (ROC). The results showed that the area under the curve equalled 0.89, and statistically, the chance of random categorization of data by the model was less than 50% (P value = 0.04). The results also showed that the model which was based on the number of parent trees to predict the probability of the presence of regeneration was significant ($R^2 = 0.27$). The equation was determined based on Equation (2).

$$Y = \frac{EXP\left(0.17 + 1.58N\right)}{1 + \left(EXP\ \left(0.17 + 1.58N\right)\right)} \tag{2}$$

where:

N – number of parent trees in the sample plot.

The results showed that, for each parent tree in the plot, the probability of the presence of regeneration increased 3.8 times (based on the EXP value). The above-mentioned model was able to correctly classify 82% of the data. The validity of the model was evaluated by drawing the receiver operating curve. The results showed that the area under the curve was 0.80, and statistically, the chance of random categorization of data by the model was less than 50% ($P = 0.004$). The results showed that the geographic direction, latitude, longitude, and elevation are not predictors of regeneration abundance. The values of Green index, Morisita index, standardized Morisita index, index of dispersion and Lioyd's index were were 0.1, 1.68, 0.506, 6.09 and 1.67, respectively, which show a clumped dispersion pattern of wild cherry seedlings according to Table 2.

DISCUSSION

The regeneration abundance of the wild cherry in this study was 960 individuals·ha^{-1} on average. In contrast, Sheykh-Aleslami (2001) reported that the regeneration abundance varied from 1 000 to 10 000 seedlings·ha^{-1} in different habitats. In the present study, a positive and significant relationship was found between the presence of parent trees and the presence of regeneration in the sample plots. There was at least one parent tree in 76% of the sample plots, where the regeneration was recorded. Only in 10% of the sample plots was the regeneration recorded without the presence of a parent tree. In this case, it should be noted that the registration of parent trees was done in a radius of 17.8 m, and if the parent tree was not inside the plot, it would not be registered.

The results showed a positive and significant correlation between the number of parent trees and their basal area and the number of seedlings in the plot. So, maintaining a sufficient number of parent trees, having proper dispersion over the forest, is essential. Moreover, large trees play an important role in the regeneration of wild cherries. However, Pairon et al. (2006) found that fruit production variability between black cherry individuals was not correlated with the plant size. In the coastal areas of China, Mao et al. (2014) showed that the abundance of parent trees had a positive effect on the growth of *Pinus thunbergii* seedlings and their cylindrical form. They stated that the age of the parent tree affects the growth and biomass of seedlings.

The results of the modelling carried out to predict the presence of regeneration in the sample plots showed that the probability of the presence of regeneration increased by 33.9% for every one-centimetre increase in the diameter of parent trees, and for each parent tree in the plot, the number of seedlings increased 3.8 times. Hence, it can be said that the presence of a large number of parent trees plays an important role in the regeneration of wild cherries and it should be taken into account in the forest management practices. This also highlights the importance of maintaining a sufficient number of parent trees to enhance the regeneration of the wild cherry. However, no study has been done to find out how many seedlings per unit area are essential for the wild cherry.

In the present study, it was found that the distance between the parent trees and the centre of the plot had no significant effects on the regeneration abundance. This might be attributed to the fact that the wild cherry seeds were displaced by birds, thereby negating the effects of the seed weight or the distance from the parent trees. Based on Reinhart et al. (2003) results, the soil community that develops near black cherry trees affects plant abundance. They found that the soil community inhibits the establishment of neighbouring conspecifics and reduces seedling performance in native habitats whereas in the non-native range, black cherry readily establishes in close proximity to conspecifics. So, studying soil specifications, especially soil organisms around parent trees of wild cherry may be helpful to describe parent-regeneration spacing.

The wild cherries cannot regenerate under the closed canopy and they can only grow in the canopy gaps because they are essentially light-demanding trees. These gaps are created by the shelterwood method, where the groups of selected trees are cut. Höltken and Gregorius (2006) stated that local establishment of wild cherry is highly affected by a forest management method. As the shelterwood method is currently set aside in northern Iran, we need to maintain a sufficient number of parent trees to guarantee the regeneration in the naturally occurring openings. Breitbach et al. (2012) studied the distances of wild cherry seeds transported by birds. The results showed that large amounts of fruits fell onto the ground, where the birds could feed on. The study also found that the viability and abundance of the seeds released in the natural forests were higher than those released in the areas where humans interfered. This highlights the need to maintain a sufficient amount of natural forests to support the regeneration of the wild cherry.

In this study, the wild cherry seedlings were found to have a clumped dispersion pattern, which could be attributed to the weight of wild cherry seeds. On the other hand, it can be said that the regeneration of the wild cherry relies on the presence of parent trees because the birds feed on the fruits when sitting on the parent trees or the trees close to them. Shahriari et al. (2007) stated that the reason for the low regeneration rate of the cherry could be attributed to the rodents' feeding on the fruit and seeds. Sheykholeslam et al. (2011) determined the dispersion patterns of the wild cherry trees, but so far no research has been done concerning the dispersion pattern of cherry seedlings.

In this research, it was found that the geographic orientation could only affect the height of the seedlings so that seedlings were shorter in the east direction. The abundance of regeneration was also higher in the east, while its difference from the other directions was not significant. Similarly, Shirazi et al. (2013) stated that the geographic direction had a significant effect on the dispersion of wild cherry seedlings, thus being mostly present in the east. Sheykh-Aleslami (2001) showed that parent trees were mostly abundant in the east. Zalnezhad et al. (2015) reported that the regeneration of cherries mostly occurred in the northeast, with a slope of 0–20% and at an elevation of 1 250–1 500 m. An increase in the elevation increased the abundance of seedlings, though the correlation coefficient was low.

This research showed that 60% of the cherry seedlings were located in the 5–15 cm height class. Based on the used height classification system (McWilliams et al. 2002), only 10.2% of the seedlings were located in the 90–30 cm class; 2.8% of them were placed in the 150–90 cm class, which were of great value for survival. Similarly, in Pairon et al. (2006) study, high mortality among young seedlings of black cherry was observed and 95.3% of the fruits failed to give 4-year-old saplings. Rainfalls in the summer period are the main limiting factors for wild cherry distribution. Also, soil texture, depth and groundwater availability play an important role for wild cherry growth and survival (Ducii et al. 2013). These are interesting topics to consider in the study area.

Field measurements in sample plots showed that the relative canopy across the area is between 40 to 60%, which represents enough radiation for the wild cherry seedlings. In excess of openings, large amounts of daneworts, raspberries and ferns grew, and wild cherry seedlings were not seen in these areas. Nyssen et al. (2016) suggested regenerating the black cherry under light shelter or in gaps with a minimum width of 10 m and a maximum width of 1.5 times the height of the surrounding trees. Also, Eşen et al. (2015) investigated the effects of the canopy gap size on the regeneration of wild cherry in Turkey. They concluded that large gaps (0.5 ha) are required to establish the natural or artificial regeneration of light-demanding broadleaved tree species including wild cherry in the mixed stands of Turkey. Hence, the effects of canopy opening and the presence of ground vegetation would be interesting topics in focus at the study site. Dyderski and Jagodziński (2019) stated that the survival of *Prunus serotina* seedlings mostly depended on intra- and inter-specific competition, germination year, precipitation seasonality and light availability. So studying the effect of competition on growth and survival of wild cherry seedlings can be interesting.

CONCLUSION

Wild cherry seedlings had a clumped dispersion pattern and based on the field observations, they were often found in small canopy openings. Hence, it is necessary to pay more attention to the naturally occurring canopy openings in management practices. Also, considering the group selection method as a silvicultural system and determining optimum canopy opening dimensions can be recommended in wild cherry habitats. The presence and dimensions of parent trees affected the regeneration of wild cherry positively. Due to the small number of established seedlings, while maintaining the existing parent trees, especially large trees, it is necessary to consider the proper management methods to promote and protect their regeneration. Although the wild cherry is a light-demanding species, excessive opening of the canopy will stimulate the growth of weeds such as daneworts and ferns, which are serious competitors for wild cherry seedlings. So, in order to protect seedlings, excessive opening of the canopy should be avoided in forest management operations. A crucial management objective in Hyrcanian forests is the reduction of browsing and grazing pressure. Without this reduction, fencing of the stands will be necessary for successful development of wild cherry natural regeneration. This can be completed by artificial regeneration and creating well-dimensioned canopy gaps.

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