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Distribution of *Quercus* spp. and *Pinus nigra* mixed stands in semiarid northern Central Anatolia

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Abstract: Central Anatolia has semiarid ecological conditions that limit tree growth. In addition, long-term human activity has resulted in degradation of existing forests lands. Current forest cover mainly includes oak, juniper, and pine species. In this study, the distribution and present state of *Pinus nigra* L. and *Quercus* spp. (*Quercus cerris* L. and *Quercus pubescens* L.) mixed stands, and the relationship between different environmental factors and abundance of oaks and pines were analyzed. The results indicate that interactions of environmental variables and human disturbance may have influenced the frequency and abundance of species in the region.

Key words: Central Anatolia, semiarid, human disturbance, degradation, oak–pine mixed stand, forest relict

1. Introduction

One of the best examples of drought-prone regions after the last ice age is Central Anatolia, where vegetation, especially forests, is affected by the natural environmental conditions. In addition, since the advent of human settlements, the environment of central Anatolia has been changing rapidly. Although the Central Anatolian region has a surface of 15.1 million ha, woodlands cover a small, heavily degraded area. The woodlands are composed of different types of forest and tree species such as *Quercus* spp. (*Quercus cerris* L. and *Quercus pubescens* L.), black pine (*Pinus nigra* L.), junipers (*Juniperus* spp.), and other woody shrubs, but oak species are dominant (Woldring and Cappers, 2001). Ecologically valuable *Pinus nigra* and *Quercus* spp. mixed woody communities are concentrated mainly in northern Central Anatolia.

Human activity has had a significant impact on natural resources since the Neolithic period. In particular, the forest resources have been frequently exploited, as observed around the Mediterranean region (Naveh, 1990). The ancient capital city of the Hittite Empire lies in the middle of the research site, which was inhabited by approximately 40,000–50,000 people around 1400 BCE (Mikaeili, 2015). The daily activities of ancient people, such as grazing animals, collecting firewood, and shifting cultivations, brought about changes in the forest structure and forest ecosystem (Kahveci, 1998). Today, the main anthropogenic activities that affect the forest resources at the research site are overexploitation and overgrazing. Exploitation of the forest resources by the state has affected the natural mix of *Pinus nigra*–*Quercus* spp. stands, because the management strategy involved a range of management methods. While *Pinus nigra* was exploited by selective cutting, *Quercus* spp. were managed using a simple coppice system (FMP Sungurlu, 2006).

Relict forests are very important for ecological restoration in such degraded semiarid regions (Kahveci, 1998). Moreover, the presence of mixed stands in these fragile ecosystems should be seen as an opportunity for restoring the forests to their previous state (Scarascia-Mugnozza et al., 2000), because a larger number of species in these stands are possibly vital for maintaining the stability of ecosystem processes in changing environments (Loreau, 2001). Losses in species diversity typically affect species of low relative abundance in communities (Grime, 1998). Increase in tree diversity is most commonly associated with an increase in wood production (Vila et al., 2007). Therefore, mixed stands can play a key part in ecological restoration in the region.

The present study analyzed the distribution and present state of *Pinus nigra* and *Quercus* spp. mixed stands, and the associations between different environmental factors and abundance of oak and pine species in northern Central Anatolia. The data presented in this study are the most recent data under prevailing conditions, since the General Directorate of Forestry changed its management method 5 years ago and began converting the coppice into high forest.

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2. Methods

2.1. Location, study area, and land use history

The study was carried out in Sungurlu District in Çorum Province, located in the northern part of Central Anatolia, where oak–pine mixed stands are mainly found (Figure 1). The Sungurlu Forest District consists of two subdistricts: Yıldız, with 107,050.5 ha of forestland, including 23,005 ha of forest, and Eşme, with 138,816.5 ha of forestland, including 34,247 ha of forest. Both subdistricts have 1151 forest stands in total, 90 of which are oak–pine mixed stands found on 2912.6 ha of forested area (FMP Sungurlu, 2006).

The average annual precipitation (for the years between 1930 and 2002) is 423 mm, the majority of which is experienced during the winter months. The summer months have less than 60 mm rainfall and low air humidity (30.4%– 41.7%). The average annual temperature is 10.7 °C and ranges from approximately 21.9 °C in July to –0.5 °C in January (FMP Sungurlu, 2006). The primary soil types are brown forest soil, gray-brown and chestnut-brown soil, and reddish prairie soils (Oakes, 1958).

The vegetation includes large-grass steppe in the plains and woodlands, including forest relicts with pure and mixed stands in the mountain area (Kahveci, 1998). The first forest trees were found at over 700 m above sea level and were usually single-standing *Quercus cerris* and *Quercus pubescens* or degraded oak coppices. *Pinus nigra*–*Quercus* spp. mixed stands occurred between 1040 and 1520 m. Over the study period, the following woody plants were recorded, in 42 plots: *Quercus cerris*, *Quercus pubescens*, *Pinus nigra*, *Juniperus oxycedrus*, *Juniperus excelsa*, *Juniperus sabina*, *Pyrus elaeagnifolia*, *Rosa canina*, *Cotoneaster nummularia*, and *Berberis crataegina*.

2.2. Sampling method

The sampling methodology was designed specifically for this study. Owing to the semiarid conditions and long-term human disturbance, the stands have been fragmented and are excessively degraded (Figure 2). It is common for stands in this region to comprise a few developed trees or no growing trees at all; such areas are called forest lands in the forest management plans and are protected for possible restoration. Therefore, sampling could be

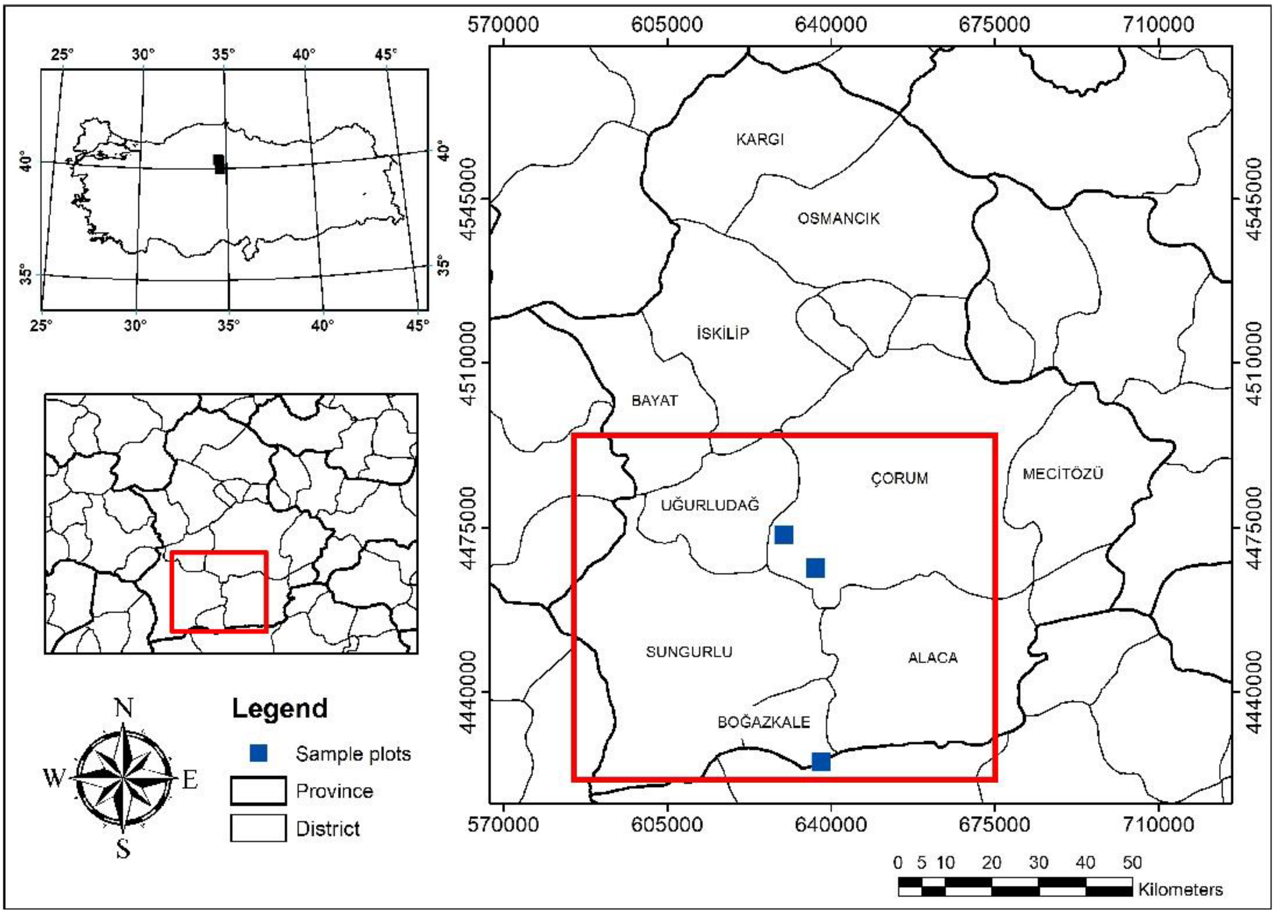

Figure 1. Location map of research site – Sungurlu (WGS 84 UTM 36N).

Figure 2. General view of degraded stands on the research site.

conducted only in forest relict areas. The initial selection of oak–pine mixed stands was carried out with the help of the Forest Management Plan of Sungurlu Forest District. The sampling was conducted in suitable areas of the selected stands using the following criteria: oak–pine mixed stand, with seedling, including vegetation of different heights and compositions, close to settlements and far from settlements, and containing different soil groups.

A sampling plot was defined as a region of oak–pine mixed stands of approximately 25 m × 20 m area. According to the above-specified criteria, 42 plots in 28 different oak–pine mixed stands were sampled in the Sungurlu Forest District. The distribution of the sample plots in the field was as follows: 12 sample plots from the Boğazkale region (coordinates: 40:02:52:49N 34:61:36:03E), 14 sample plots from the Esme area, Evci village (coordinates: 40:06:83:93N 34:83:07:49E), and 16 sample plots from the Uğurludağ area (coordinates: 40:44:51:61N 34:45:18:77E). The following data were recorded for each sample plot: coordinates, altitude (m), exposure (8 wind directions), slope (%), soil depth (cm), soil type, forest litter thickness (cm), erosion level (ERH, 2016), pressure on the forest resources in the past and present (Samojilik et al., 2013), woody plant cover according to the cover abundance scale (Domin, 1928), tree and scrub species, height (m), diameter at breast height 1.37 m (DBH) (cm), and crown class in the case of DBH > 5 cm. All trees with a DBH under 5 cm were defined as seedlings and recorded by counting. Definitions of measurement properties for each variable are presented in the Appendix. For obtaining visual information on the status of stands (Svaboda et al., 2010), stand maps of the sample plots were designed manually in the field. Sampling was performed in the autumn of 2012 and 2013.

2.3. Data analysis

A summary of all collected data, graphical presentations, and stand maps (using AutoCAD software) was performed. To determine the relationship between environmental variables and presence of species, Pearson correlation analysis was performed (using SAS statistical software package). Four variables associated with each genus (number of trees of *Pinus* [NTP], number of trees of *Quercus* [NTQ], number of seedlings of *Pinus* [NSP], and number of seedlings of *Quercus* [NSQ]) and nine variables associated with the environment (altitude [AL], exposure [EX], slope [SL], soil depth [SD], soil type [ST], forest litter [FL], erosion [ER], human impact [HI], and woody plant coverage [WPC]) were calculated.

3. Results

3.1. Distribution and present state of *Pinus nigra*–*Quercus* spp. mixed forest

Sampled *Pinus nigra*–*Quercus* spp. in the 42 plots covered an area of 21 ha. The total number of all measured trees (DBH > 5 cm) was 623 (Appendix). The mean density was approximately 29 trees/ha. The number of trees in the plots close to the village and the southern exposed plots generally decreased, but the number of oak trees increased in comparison with pine in the same stands. The total number of seedlings in the 21-ha extent was 2465 (1619 *Quercus* spp. and 946 *Pinus nigra*). The mean density of seedlings was nearly 117/ha. While pine had an abundant number of seedlings in north- and northwest-exposed slopes, oak had a high abundance in south- and southwest-exposed slopes (Appendix).

Although individual oaks were found at elevations between 700 and 1600 m above sea level, the optimum location was observed between 1040 and 1520 m, in a mixture with *Pinus nigra*. However, almost all stands had gaps between trees and tree groups (Figures 2 and 3). *Pinus nigra* stands were found mainly between 1520 and 1700 m above sea level, and included more closed forest. Seedlings of both species were found in the best growing conditions between 1078 and 1110 m above sea level (Appendix). Seedlings of both genera were protected by mature trees or *Juniperus sabina* bushes (Figure 3).

Correlations between DBH and height for each genus are presented in Figure 4. Pine showed a maximum DBH of 60 cm and a mean DBH of 24.83 cm. The maximum height was 21 m and the mean height was 8.57 m (Figure 4a). Oak registered a maximum DBH of 25.5 cm, a mean DBH of 5.85 cm, a maximum height of 4.5 m, and a mean height of 3.03 m (Figure 4b).

3.2. Results of Pearson correlation analysis

The Pearson correlation coefficients (PCCs) are listed in the Table. The highest positive correlation (0.749) was observed between HI and NTQ. The next higher correlation (0.668) was between FL and NSP. The correlation (0.598) between FL and NSQ was fairly high. There was hardly any correlation between NTP and FL. AL, EX, SL, SD, and ST showed little correlation with any of the dependent variables, and some of them showed a negative correlation.

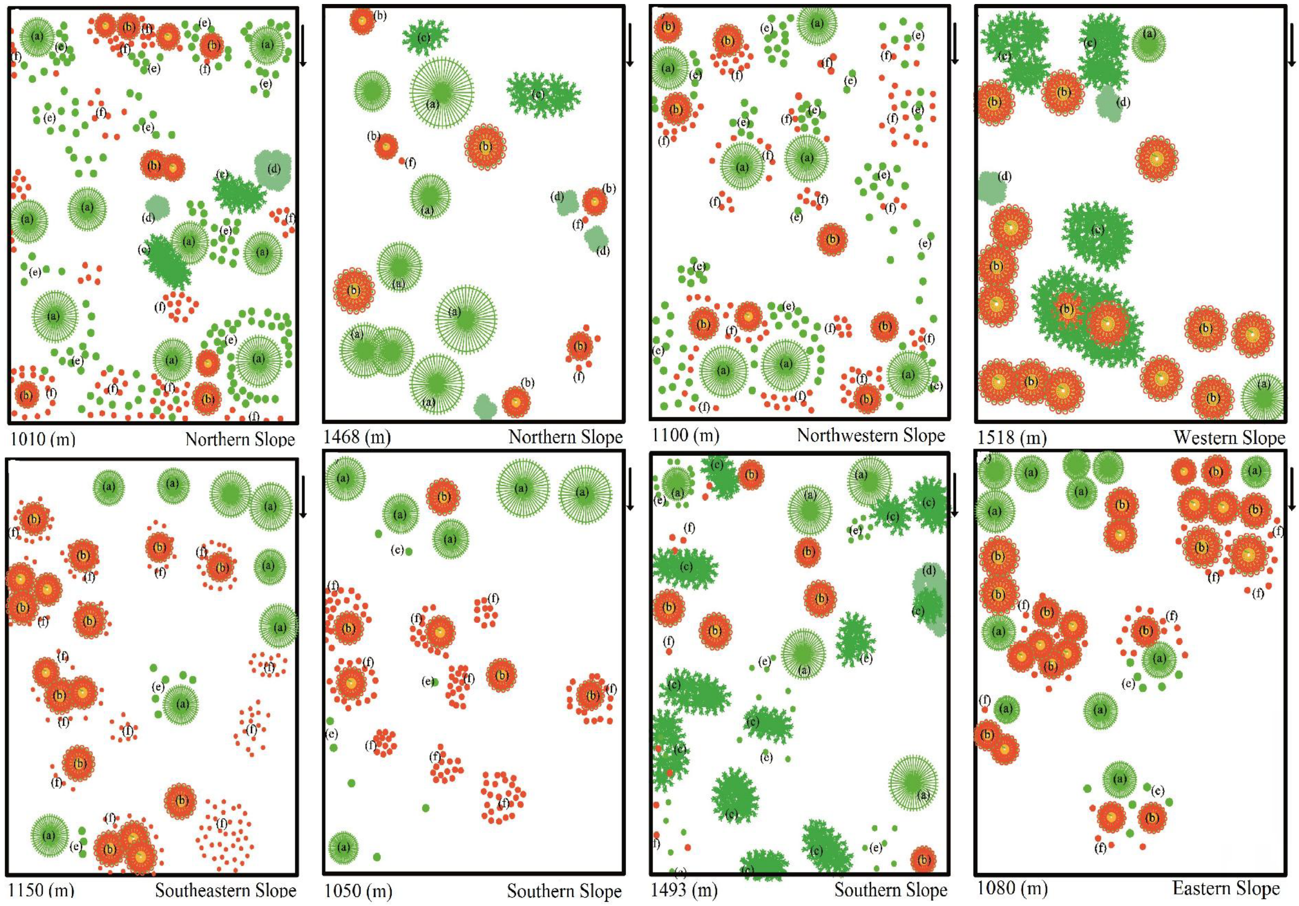

Figure 3. Stand maps of some sample plots in *Pinus nigra–Quercus spp*. mixed stands of the Sungurlu Region. In the maps (a) represents *Pinus nigra*, (b) represents *Quercus pubescens* or *Q. cerris*, (c) represents *Juniperus oxycedrus*, (d) represents *Juniperus sabina*, (e) represents *Pinus nigra* seedlings, and (f) represents *Quercus* spp. seedlings.

4. Discussion

The structure and composition of forest communities are influenced by climatic, edaphic, and physiographic factors (Roberts and Christensen, 1988). An average annual rainfall of approximately 423 mm and low air humidity are the main ecological factors limiting forest growth in pine–oak mixed stands in the research site. Tree vulnerability increases under water stress and growth can be used as a direct proxy for water stress (Suarez et al., 2004). In addition, low moisture availability reduces tree growth even if the tree is tolerant to drought (Gea-Izquierdo et al., 2014). Therefore, low rainfall and air humidity might be the reason for gaps in the stands at the research site (Baudena, 2015). Low moisture availability and rainfall may also be an explanation for the lower heights of *Pinus nigra* at the research site in comparison with humid regions (Balenović et al., 2015). However, pines may not need to grow much more due to the lack of light competition in stands with low tree densities (Kocher and Harris, 2007).

Oak and pine species are known to have drought tolerance in the northern hemisphere. However, pines behave as isohydric species, whereas oaks are unisohydric (Eilmann et al., 2009). Stomatal conductance and total water use decrease faster in trees tending toward isohydric behavior than in coexisting anisohydric trees (Klein et al., 2013). This might be the reason that *Quercus* spp. can occur at a lower altitude than *Pinus nigra*, because the lower altitudes are more arid than the higher altitudes (Kahveci, 1998).

Human-activity-related impacts, such as habitat destruction, deforestation, fragmentation, and overexploitation, have a significant effect on forest structure and composition (Hauck and Lkhakvadorj, 2013). Both effects were observed from the measurements taken from the 42 sampling plots of *Pinus nigra–Quercus* spp. mixed stands. There is a significant decrease in the number of trees in stands near villages and settlements (Appendix). In addition, the abundance of oak increases at places where human activity increases. The PCCs predicted that there was a relatively high correlation between human impact and the number of trees of *Quercus.* Oaks are best suited to tolerate this human impact (Johnson et al.,

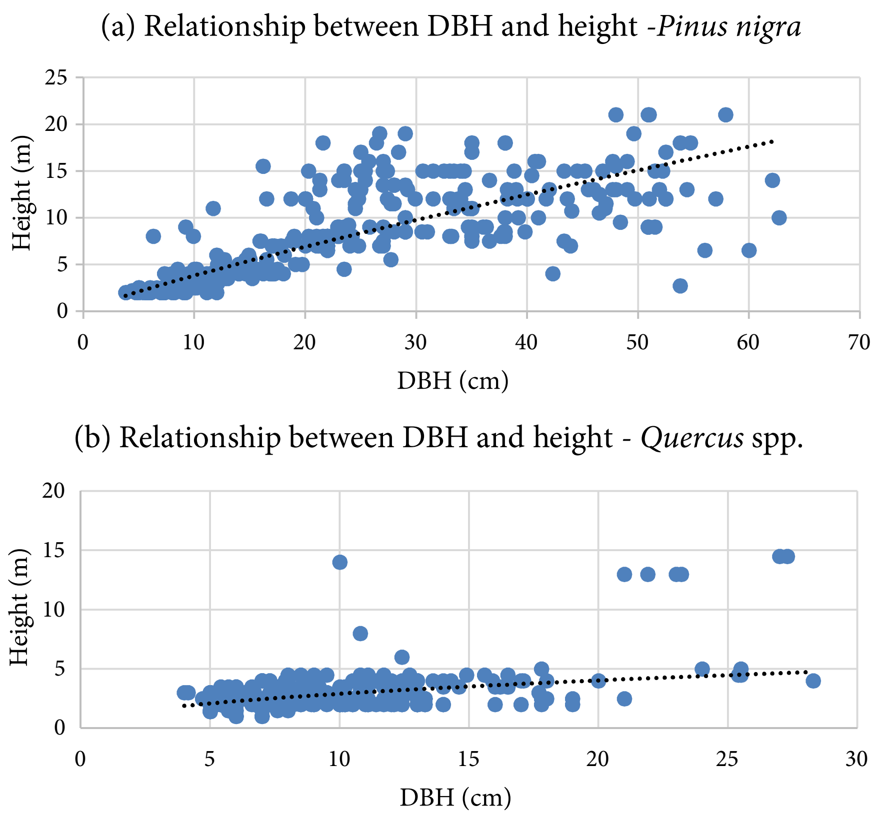

Figure 4. Graphical illustration about relationship between DBH and height; *Pinus nigra* (a), *Quercus* spp. (b).

Table. Pearson correlation coefficients. Altitude (AL), exposure (EX), slope (SL), soil depth (SD), soil type (ST), forest litter thickness (FT), erosion (ER), human impact (HI), woody plant covering (WPC), number of trees of *Pinus* (NTP), number of seedlings of *Pinus* (NSP), number of trees of *Quercus* (NTQ), number of seedlings of *Quercus* (NSQ).

	AL	EX	SL	SD	ST	FL	ER	HI	WPC
NTQ	−0.084	−0.008	0.023	−0.228	−0.065	−0.032	0.089	0.749	0.39
NSQ	−0.277	−0.119	−0.401	0.26	−0.07	0.598	−0.508	−0.175	0.299
NTP	−0.159	−0.051	0.238	−0.204	−0.146	0.001	0.058	0.548	0.5
NSP	−0.205	−0.18	−0.376	0.139	−0.279	0.668	−0.372	0.073	0.305

1992), because if their roots remain strong in the ground, the tree can persist against cutting and grazing. In fact, Ramirez and Diaz (2008) suggest establishing grazing for the promotion of oak regeneration. Bakker et al. (2013) characterize oak as an anthropogenic indicator species and suggest that if original species disappear, oaks can increase in abundance. These characteristics provide an advantage for *Quercus* spp. over *Pinus nigra* at the research site.

Human disturbance in arid regions makes the natural regeneration of trees especially difficult (Scarascia-Mugnozza et al., 2000). Both genera could regenerate in different ways at the research site. *Quercus* spp. have regenerated through stump sprouting. However, this reduces the capacity of oak as an overstory tree and provides an advantage to *Pinus nigra*. During the anemochoric dispersion of *Pinus nigra*, seeds are spread into beneficial ecological niches and into places devoid of human impact, where they are protected throughout their germination and growth. For instance, *Juniperus sabina* bushes often host *Pinus* seedlings. According to the PCCs, there is a negative and small correlation between human impact and the number of seedlings of *Quercus*. There is positive correlation between human impact and the number of *Pinus* seedlings, but the correlation coefficient is lower than that for *Quercus*.

The PCCs show that altitude, exposure, slope, soil depth, and soil type had little influence on the abundance of the trees and seedlings. In semiarid regions, the effect of water stress normally increases on the southern slopes, because they receive sunlight for a longer period than other slopes, and are thus more affected by drought. Therefore, the southern slopes are predisposed to degradation. Human impact increases this effect by increasing surface flow and decreasing the soil depth, resulting in a reduction in the number of trees and seedlings (Kahveci, 1998). Ten of the 42 sample plots are located on southern slopes, where the number of trees, especially of *Pinus nigra*, and seedlings decreased (Appendix). Essentially, altitude is an important growth parameter of species in semiarid regions (Scarascia-Mugnozza et al., 2000; Jin et al., 2008). All samplings in this study were taken at the altitudes where pine–oak mixed stands are mainly found, and thus Pearson correlation analysis may have not recognized the effect of altitude. Observations during the field surveys support the results from the correlation analysis that slope, soil depth, and soil type had little influence on tree and seedling occurrence.

Forest litter thickness, erosion, and woody plant covering are related to human activity, resulting in reduced number of trees, diminished understory vegetation, reduced local biodiversity, and a decreased regeneration rate (Bugalho et al., 2011). The PCCs essentially confirm this. While the numbers of seedlings for both genera increase with a rise in forest litter thickness, the number of trees of both genera has a low relation with forest litter. The effects of erosion on tree growth and distribution of trees do not need to be fully assessed because there are numerous reports regarding the on-site effects of erosion (Lal, 1998). However, at the research site, an increase in erosion had a negative effect on the number of seedlings of both genera. Woody plant coverage had a positive correlation with the number of trees and seedlings for both genera.

The planned aim of the General Directorate of Forestry about the conversion of coppice would also be applied to *Pinus nigra*–*Quercus* spp. mixed stands. The new management method is bound to change certain aspects in the oak–pine mixed stands. It is a reasonable assumption that *Quercus* spp. would be forced to become overstory trees and regenerate via seeds, because years of coppice management restricted overstory tree reproduction by seeds (Brudvig and Asbjornsen, 2008). A key question to ask then is if the oaks become overstory trees and produce enough seeds, could they regenerate to the same extent? It is also possible that oak species regenerate, favored under the canopy of pine (Urbita et al., 2011). Such changes in management are progressive but it takes years to see their results (Oskorbin and Bugaeva, 2013).

In conclusion, *Pinus nigra* and *Quercus* spp. mixed stands were distributed mainly between 1050 and 1440 m above sea level at the research site. Although both genera are resistant to extreme climatic conditions, none of them covered the ground completely. Despite these conditions, both genera have regenerated in the region and developed mixed stands. During the field survey, *Quercus* spp. were found to be better suited for regeneration under human intervention because they can regenerate through the stump sprout. *Pinus nigra* could also utilize its advantage of spreading seeds in sheltered places. However, this might reverse in the future owing to changes in the management strategy of the General Directorate of Forestry. This study suggests that *Quercus* spp. and *Pinus nigra* mixed stands should be observed and sampled using different methods and different points of view every 10 years for possible transformation and improvement.

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Appendix

Plot no.	Stand no.	Altitude (m)	Exposure (N, S, E, W)	Slope (%)	Soil depth (cm)	ST *	Fores litter (cm)	ER (1–5) **	HI (1–5) ***	WPC ****	*Quercus* sp.		*Pinus nigra*		*Juniperus* spp.		Legend
											Number of trees	Number of seedlings	Number of trees	Number of seedlings	Number of trees	Number of seedlings	
1	1143	1468	N	70	>100	1	1	1	2	8	7	7	8	1	3		*= Soil type (ST)
2	1143	1390	N	62	>100	1	3	1	2	8	9	6	6	5	1		(Oakes, 1958)
3	1148	1370	W	85	>100	2	1	2	2	9	8	26	15	17	1		1 = Brown forest soil
4	1148	1302	NW	60	>100	2	1	2	2	8	13	30	8	14	1		2 = Gray-brown soil
5	1143	1518	W	75	80	3	1	2	4	7	15	5	3	4	2		3 = Reddish prairie soil
6	1151	1480	S	80	80	1	0	2	3	6	5	6	4	5			4 = Chestnut-brown soil
7	1152	1479	S	80	75	1	0	2	3	5	2	33	4	27	1		** Erosion (ER)
8	1152	1466	W	90	70	2	0	2	4	6	1	37	7	8	1		(ERH, 2016)
9	1149	1400	S	70	>100	1	0	2	3	7	6	25	5	6	1		1 = Rare erosion, 25% of
10	1149	1492	S	75	>100	1	0	2	3	7	6	17	5	45	1	4	upper soil lost
11	1148	1406	N	75	>100	1	1	2	3	6	4	15	4	18			2 = Medial erosion, 25%–75%
12	1146	1200	SE	80	80	1	0	2	4	5	3	13	4	8			of upper soil lost
13	829	1070	NW	80	>100	1	1	1	3	8	4	27	12	38			3 = Heavy erosion, upper
14	829	1080	NW	75	>100	1	0	2	3	7	5	14	6	17			and 25% of subsoil lost
15	828	1080	E	85	60	1	0	1	3	8	22	40	12	12			4 = Very heavy erosion,
16	827	1085	SW	70	>100	3	0	2	3	7	10	25	7	13			more than 75% of subsoil lost
17	831	1078	W	50	>100	3	0	2	3	9	12	52	9	24			*** Human impact (HI)
18	830	1072	SW	80	>100	3	1	2	2	9	4	14	9	30			(Somajilik et al., 2014)
19	830	1090	NE	80	90	3	1	1	2	9	4	38	21	7			0 = No impact,
20	830	1110	S	90	80	1	2	1	2	7	2	35	17	11			1 = Ancient and early
21	779	1150	SE	60	>100	3	1	0	2	8	16	65	8	12			medieval impact
22	779	1162	S	58	90	3	1	0	2	7	10	25	4	4			2 = Cutting trees
23	781	1060	SW	60	>100	3	1	1	2	9	7	41	4	5			3 = Commercial using,
24	781	1100	S	65	>100	3	3	0	2	8	7	80	4	12			fire, beekeeping
25	890	1190	N	70	90	3	2	0	2	7	6	56	7	10			4 = Destruction of the
26	784	1210	SE	65	>100	3	3	1	2	6	4	18	6	7			forest
27	332	1100	NW	60	>100	1	5	0	2	8	8	106	7	115			5 = Complete destruction
28	333	1100	E	85	>100	1	1	1	2	7	5	33	5	35			of forest
29	333	1180	SW	60	90	1	1	1	2	6	7	14	4	9			**** Woody plant cover
30	421	1050	S	95	>100	2	0	2	2	7	6	106	6	9			(WPC)
31	420	1100	SE	90	>100	1	3	1	2	8	7	64	5	34			(Domin, 1928)
32	420	1200	S	90	80	1		1	2	8	9	62	6	44			+ = Single tree
33	418	1010	N	58	90	1	6	0	2	8	9	114	9	128	2		1 = 1-2 tree
34	419	1130	SW	60	90	2		1	2	7	10	28	8	12			2 = 1% <covering
35	419	1026	S	68	100	2	0	2	2	7	6	80	18	29		1	3 = Covering 1%–4%
36	515	1030	SE	58	80	3	0	2	2	6	7	25	8	2			4 = Covering 4%–10%
37	560	1100	N	40	>100	1	5	0	3	9	8	112	7	142			5 = Covering 11%–25%
38	561	1040	SE	80	>100	4	0	2	3	7	8	55	6	6			6 = Covering 26%–33%
39	562	1003	W	90	>100	4	0	2	3	6	9	23	8	1			7 = Covering 51%–75%
40	108	1180	NE	75	>100	4	2	2	2	5	8	12	4				8 = Covering 76%–90%
41	172	1260	NW	80	90	4	1,5	2	3	6	7	14	7	8			9 = Covering 76%–90%
42	173	1300	S	90	90	4	1	2	3	5	6	21	4	12			10 = Covering 91%–100%