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ORIGINAL PAPER

Dynamics of the natural regeneration of a natural zeen oak (*Quercus canariensis* Willd.) forests in Kroumirie, north-western Tunisia

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Abstract

The present work focuses on determining the state of the *Quercus canariensis* (zeenaie) forest in Kroumirie. Then, we have studied the influence of the distances of the closest human settlements on the diametric structure of *Quercus canariensis*. Finally, we have identified the relationship between the different diameter classes and natural regeneration by seed. The result following the examination of 80 studied files showed that the structure of *Quercus canariensis* in Kroumirie is essentially represented by the classes of seedlings (72.5%) and seeds (23.9%). The intermediate classes are less represented, with the diameter classes oscillate between C2 (7.8%), C3 (10.3%), and C4 (23.9%). The Pearson correlation matrix result reveals the significant effect of the distance from the nearest human settlements on the density and diametric structure of *Quercus canariensis* in Kroumirie. The most balanced stands are located in places furthest from human settlements forest populations. It is found that the diametric structure affected the natural regeneration by seed. Our founding allows us to develop new insight into the future of the *Quercus canariensis* forest and to practice large-scale artificial regeneration in well-protected areas.

Keywords Tunisia · *Quercus canariensis* · Forest dynamics · Natural regeneration · Anthropogenic factors

Introduction

The Quercus genus is one of the most species-rich forest genera. It brings together several hundred woody species from temperate and Mediterranean zones, among them there are some species of high economic importance (Benmahioul and Sarir 2017). In the Mediterranean region, forests are dominated by oak groves, Holm oak (*Quercus ilex*), Cork oak (*Quercus suber*), Pedunculate oak (*Quercus robur*), Kermes oak (*Quercus coccifera*), and Zeen oak (*Quercus canariensis*) (Brandle and Brandel 2001). Aissi et al. (2019) showed that the ecological habitat of *Quercus canariensis* in Algeria varies from 850 to 1700 m altitude in the supra-Mediterranean and mountain-Mediterranean level and under a semi-arid or sub-humid bioclimate.

Quercus canariensis is a deciduous oak, endemic to the western Mediterranean (Iberian Peninsula, Morocco, Algeria, and Tunisia). This species with its deciduous leaves is spread over the Mediterranean region and very remarkable in the Ibero Maghreb area. In North Africa, it occupies 102,000 ha, including 65,000 ha in Algeria (Messaoudène and Lucien 1991) and 17,000 ha in Morocco (Tafer 2000).

Quercus canariensis is an endemic species that grows in North Africa. In Tunisia, it grows in Kroumirie and it can be pure or mixed with *Quercus suber*. Zeen oak forests in the Kroumirie region (northwest Tunisia) have always been of great socioeconomic, hydrological, and ecological value, with their picturesque landscape and their rich flora and fauna (El Mokni et al. 2012).

The wood of the zeen oak is of great interest to North Africa region. The high quality of resistance and the high adhesion of these fibers are suitable for several uses (fine carpentry, furniture, and high-quality mechanical resistance jobs). They are also of great ecological, biological, aesthetic, landscape, and socioeconomic interest, as mentioned by Rabhi (2011).

In the Mediterranean basin and especially in Tunisia, zeen oak has always occupied a privileged place because of their economic and forestry importance (Hoenisch et al. 1970; Hasnaoui 12; Mechergui et al. 2022). Before colonization, the zeen oak occupied 100,000 ha

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in northwestern Tunisia. However, in 1970, this area decreased to 40,000 ha, of which 10,000 ha (Chakroun and Ben M'hamed 1994) were pure stands and 30,000 ha were mixed with Cork oak (Mechergui et al. 2022). At present, the area of zeen oak is estimated at 8332 ha in pure stand and 13,651 ha in mixture with cork oak (Mechergui et al. 2022). However, this forest undergoes a continual decline from year to year. The absence of silvicultural interventions, together with the action of anthropogenic, climatic, and topographical factors can generate an imbalance in age classes at the level of oak forests (Jdaidi et al. 2013). The combined action of these factors induced a gradual elimination of low strata and oak seedlings and leads to major difficulties in natural regeneration and structural modifications of forest stands (Hasnaoui 1992).

In general, Tunisian forests are fragile and under pressure from many external factors as well as human intervention. It ravaged by repeated fires, clearing, prolonged drought, overgrazing, and tree cutting. Many factors, such as environmental factors, competition, and human disturbance could influence the distribution of seedlings in this forest. Here, we present the current stem distribution by diameter class of the zeen oak forest in the Kroumirie region, Tunisia. We also determine the models of the evolution of the diameter classes of zeen oak according to the remoteness of human settlements and study the influence of different diameter classes on the natural regeneration by seed of zeen oak forest.

Material and methods

Study area

The study was carried out on about 8332 ha in different pure zeen oak forests in the northwest of Tunisia (DGF 2010). The *Quercus canariensis* at the level of our study area is located only in the coolest stations and well watered, in a humid bioclimate (Hoenisch et al. 1970). For annual average temperatures and precipitation, we used data from the Tabarka, Ain draham, and El Feidja weather stations for the period between 1980 and 2019, while making the altitude adjustments as follows:

- Increase in precipitation by 0.7 mm/m of altitude,
- Temperature decrease by 0.5 °C/100 m altitude.

The average annual rainfall in our study area is about 1300 mm/year and 1578 mm/year. The altitudinal distribution of our natural zeen oak forest varies from 580 to 880 m. Moreover, it takes its full development only at the north-western exposure, with slopes of 10 to 20% (Table 1).

In terms of edaphic conditions, all the stations visited for zeen oaks are in silty and clay formations. According to Boudy (1950), *Quercus canariensis* is only found in deep and permeable soils.

Northwest Tunisia is a well-watered region belonging to the humid, temperate, and cool bioclimatic stage. Hence, these favorable climatic conditions in addition to the nature of the soil, the altitude, and exposure factors (orographic factors) have an influence on the distribution and development of natural vegetation rich in tree taxa (*Quercus suber*; *Quercus canariensis*; *Quercus coccifera*; *Pinus pinaster*; *Olea europea*, etc.). Zeen oak and pure stands of cork presented more than half of the area of these forests. However, the rest are presented by a mixture of cork and zeen oak. It is also possible to find a stable and balanced mixture of cork oak and maritime pine (Hasnaoui 1992; Jdaidi 2009). The palynological studies carried out by Ben Tiba (1980) in the central region of Kroumirie seem to bring additional elements to the dynamics and distribution of the vegetation in this region. These studies reveal that Kroumirie had two types of vegetation: In particular, is an oak grove with *Quercus canariensis* (zeen oak) that existed before the Pleistocene. This association is relayed since the Holocene by an oak grove with *Quercus suber* (cork oak) which also coincides with the appearance of Ericaceae, notably *Erica arborea*, *Erica scoparia*, and *Arbutus unedo*.

Table 1 Ecological characteristics of study sites

	Oued Zeen	Ain Zana	Tabarka	El Feidja
Latitude (N)	N36°77′37″	N36°76′72″	N36°90′58″	N36°51′45″
Longitude (E)	E008°73′98″	E008°68′95″	E008°92′95″	E008°41′09″
Altitude (m)	750	880	580	805
Slopes (%)	15	10	20	15
Exposure	Northwest	Northwest	Northwest	Northwest
Bioclimate	Humid	Humid	Humid	Humid
Annual precipitation (mm/year)	1510	1578	1300	1550
Average annual temperature (°C)	10.1	10.1	12.6	10.3

Sampling

Considering the area of the Kroumirie region and the nature of the stand (pure zeen oak stand), we opted for the same sampling method adapted by Jdaidi and Hasnaoui (2014). Therefore, we used 500 m^2 circular plots based on the distance from the closest human settlements. Then, a total of 80 plots were placed in an equiprobable manner on four classes of distance of the stands from the closest human settlements: 20 plots (totaling 1 ha) for D1 (0–1000 m), 20 plots (totaling 1 ha) for D2 (1000–2000 m), 20 plots (totaling 1 ha) for D3 (2000–3000 m), and 20 plots (totaling 1 ha) for D4 (> 3000 m). The investigation field was carried out during the period from 10 November 2019 to 10 May 2020. The GPS (Global Position System) recorded the coordinates of the center of each plot. These geographic positions were subsequently plotted on a 1/40,000 map (Fig. 1).

When we investigate the area, we determine for each plot (plot) the individual dendrometric characteristics of the species studied (diameter in cm and height in m). At the level of each plot, we calculated the density of each diameter class per hectare of zeen oak: $Dp = \frac{ni}{s}$, with **Dp**: density of stems per hectare, **ni**: number of stems of *Quercus canariensis* for each class i, **s**: area of a plot in hectare (ha). While carrying out the surveys, we noted the main anthropogenic (action of humans and their livestock as a function of distance) and dendrometric (density of different diameter classes per hectare and height of seedlings). To study the overall average of the diametric structure of *Quercus canariensis* (the density of zeen oak stems by diameter class), we calculated the average densities observed by diameter class in hectare (the average of the number of zeen oak trees per class diameter) with the following formula: $Dmoy = \frac{ni}{np \times s}$, with $\mathbf{D_{moy}}$: average density observed in trees/ha of class i, **ni**: average number of trees counted for class i, **np**: total number of plots considered, S: Area of a circular plot in ha.

As illustrated in Table.2, 5-diameter classes of *Quercus canariensis* (developmental stages) had chosen to describe the current diameter distribution of zeen oak trees (diametric structure) (Hasnaoui 1992; Jdaidi 2009; Jdaidi and Hasnaoui 2014).

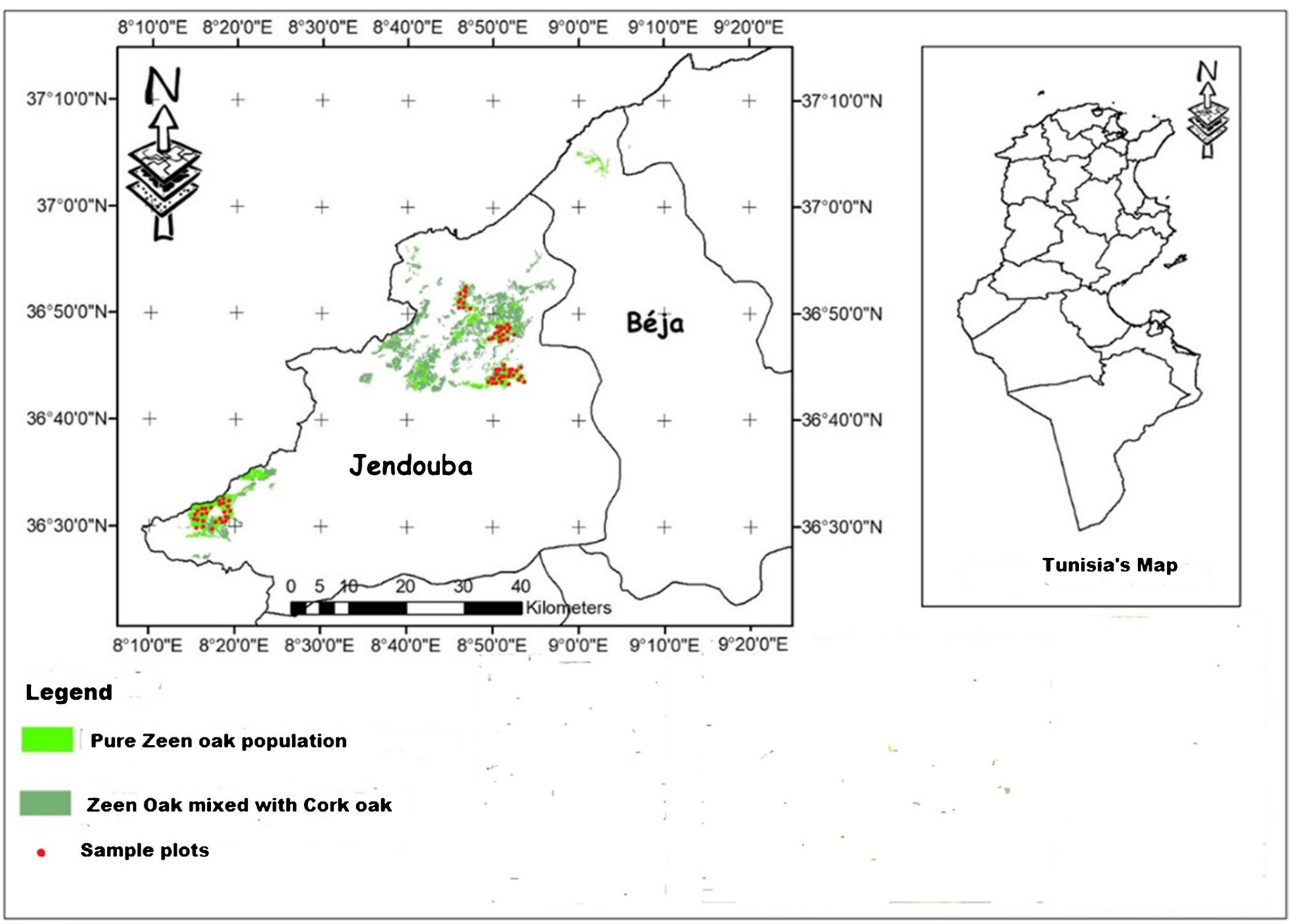

Fig. 1 Distribution of zeen oak in Tunisia (Mechergui et al. 2022) and sample plots

Table 2 Diameter classes used to represent the diametric structure of *Quercus canariensis*

Zeen oak diameter class	Zeen oak categories and stages of growth
C1	Seedlings (Ø < 1 cm): Young plants grown from acorns of zeen oak (height less than 40 cm). These are unbranched or sparsely branched stems
C2	Gaulis (1 < Ø < 10 cm): Young stems of low heights (3 to 8 m) and diameters (1 to 10 cm)
C3	Low perch (10 < Ø < 20 cm): Trees with a diameter of 10 to 20 cm (circumference of 30 to 60 cm) and height greater than 8 m
C4	High perch (20 < Ø < 3 0 cm): Trees with a diameter of 20 to 30 cm (circumference 60 to 90 cm) and a height of 15 m
C5	Seed or adult (Ø > 30 cm): Trees with diameters greater than 30 cm and height between 15 to 20 m

In order to study the influence of edaphic factors on the evolution of the zeen oak forest, a soil profile per station was carried out. In total, 4 profiles were excavated, and two samples with two depths of 20 cm and 60 cm for each site, i.e., 8 soil samples. The soil analysis covered 10 parameters: total pH H_2O, total fine silt (FSi), total coarse silt (CSi), total fine sand (FS), total coarse sand (CS), total clay (C), total organic matter (MO), total nitrogen (NT), total C/N ratio, and total carbon (CT) (as shown in Table 3).

Statistical analysis

To study the evolution dynamics of different diameter classes of our *Quercus canariensis* forest, we carried out a linear regression using the XLSTAT 2020 software. First, the linear regression of the different classes of zeen oak diameters was determined according to the distances closest to human settlements, then the influence of different zeen oak diameters on natural regeneration by seedling.

Results and discussions

The overall Average structure of Quercus canariensis stems by diameter classes

According to data collected from all the plots in accordance with class distance, the average distribution of the diameter classes of zeen oak stands in the northwest of Tunisia was dominated by two classes C1 (seedlings) and C5 (seed trees). Regarding individuals belonging to each intermediate classes C2, C3, and C4, the average numbers of individuals are very low for all the distance classes (Fig. 2). In the present study, several cuts of zeen oak trees and shrub layer for the harvest of fuel wood were observed in the study area. Therefore, as to approach the human visited settlement, the cleaning surfaces were increased. The anthropogenic factors, which represented here by the human presence and the livestock (distance from the forest compared to the human settlements), are expressed not only by overgrazing and its

Table 3 Soil sample analysis at the study area level

El Feidja	pH H_2O	Grain size fractions (%)					NT (%)	CT (%)	C/N	MO (%)
		CS	FS	CSi	FSi	C				
S1(to 20 cm)	6.15	29.00	33.00	8.00	9.00	21.00	0.801	11.3	14.10	5.41
S2 (to 60 cm)	4.84	23.01	6.00	2.00	8.00	68.00	0.570	8.70	10.52	2.32
Oued Zeen	pH H_2O	Grain size fractions (%)					NT (%)	CT (%)	C/N	MO (%)
		CS	FS	CSi	FSi	C				
S1(to 20 cm)	6.2	11.2	48.8	12.0	10.2	19.5	0.904	12.33	13.60	5.65
S2 (to 60 cm)	6.0	22.6	39.4	11.6	8.3	24	0.650	7.62	11.72	3.43
Ain Zana	pH H_2O	Grain size fractions (%)					NT (%)	CT (%)	C/N	MO (%)
		CS	FS	CSi	FSi	C				
S1(to 20 cm)	7.05	12.4	23.7	22.6	28.44	10.5	0.98	12.8	14.38	6.56
S2 (to 60 cm)	6.3	17.5	10	20.33	15.3	23.9	0.45	6.4	14.22	4.5
Tabarka	pH H_2O	Grain size fractions (%)					NT (%)	CT (%)	C/N	MO (%)
		CS	FS	CSi	FSi	C				
S1(to 20 cm)	5.78	33.5	42.5	7.03	8.06	24.3	0.54	9.5	17.59	6.6
S2 (to 60 cm)	4.56	27.2	9.05	3.12	5.33	54.4	0.31	4.6	14.83	4.3

S, sample; *CS*, coarse sand; *FS*, fine sand; *CSi*, coarse silt; *FSi*, fine silt; *C*, clay; *NT*, total nitrogen; *CT*, total carbon; *C/N*, nitrogen carbon ratio; *MO*, organic matter

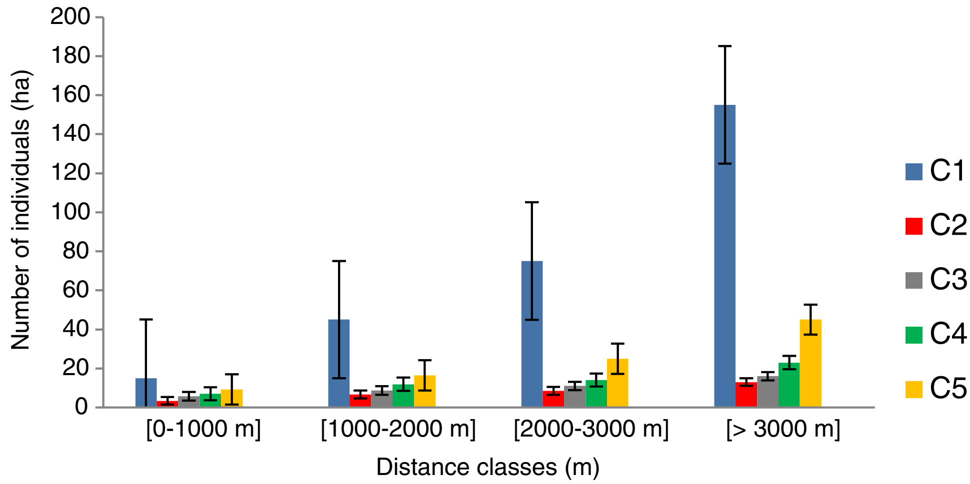

Fig. 2 Distribution of zeen oak stems by diameter classes as a function of distances from human settlements

impact on natural regeneration and on new shoots, but also by possible misdeed affecting, in particular, the saplings, perch, and adult stages of the species studied.

Indeed, the growth of the young shoots has been affected by continuous and excessive grazing, which challenges the natural regeneration of the zeen oak forests. However, the stations with no pressure allow seeing zeen oak feet of different diameter classes.

These results were similar to those found by Hasnaoui (1992); Jdaidi (2009); and Jdaidi and Hasnaoui (2014). In these previous studies, they reported that the distribution by diameter classes (diametric structure) of the populations of the different oaks present in Kroumirie showed a clear break in the growth of young seedlings from seedlings at the level of classes C2 (sapling), C3 (low perch), and C4 (high perch). As a consequence, an alarming future can rise concerning these oak groves.

Linear regression models of different diameter classes of Quercus canariensis

Various factors such as pastoralism, the extraction of firewood, the clearing, and overgrazing elicited disturbance to the zeen oak forest in northwest Tunisia where the populations furthest from the human settlements are the densest. It has shown that the most grazed and the less dense populations are the closest to the human settlements.

Regarding the density of seedlings (C1), as shown in the Fig. 3, it is significantly related to the distance from the human settlements ($P < 0.0001$; $R^2 = 0.88$). They are very important in terms of numbers and classes of zeen oak seedlings in the plots furthest from the human settlements compared to those with moderate close distance. By getting closer to human settlements, the growing number of livestock causes great pressure on the frequency of shrub species at the level of all the plots. In this regard, *Arbutus unedo*, *Phillyrea latifolia*, *Phillyrea angustifolia*, *Erica arborea*, and *Smilax aspera* are the most palatal species of sheep, cattle, and goats. Traces of delimbing and felling of zeen oak trees are observed in our study area. However, pastoral pressure has considerably increased in recent years due to consumed seedlings by livestock (sheep, cattle, and goats).

The relationship between the abundance of the other young (C2), low perchis (C3), high perchis (C4), and adult (C5) stages of the zeen oak and the distance of the populations to the nearest human settlements presents a coefficient of determination, respectively ($R^2 = 0.64$, $R^2 = 0.65$, $R^2 = 0.65$, and $R^2 = 0.74$).

It is clearly noted that the plots furthest from human settlements are the densest, as shown in Fig. 3, while the places closest to dwellings are the least dense. Furthermore, the action of stand distances from the nearest human settlements has an effect on the stability and structure of zeen oak stands.

Our results showed that the best conserved zeen oak forests are those far from human settlements. Therefore, the condition of the places of *Quercus canariensis* closest to the forest dwellers is worrying (Fig. 4). Particularly, as in some studied plots, more than half of the trees were felled. Following this context, comparable results were obtained by Jdaidi and Hasnaoui (2014) and Jdaidi et al. (2017). They demonstrated that anthropogenic pressure was aggravated by the growth of population when it got closer to human settlements, which resulted in clearing, overgrazing, and collecting acorns. According to these results, the density decreases as it moves closer to the human settlements, yet the plots close to homes are very prevailed by domestic animals (cattle, sheep, goats, etc.).

The same results were obtained by Abdessemed (1985), Berrichi and Bouazzaoui (2015), and Aissi et al. (2019), who showed that the species is very threatened by increased anthropogenic action due to the intense grazing and pruning, which have the consequences of weakening trees and low natural regeneration average.

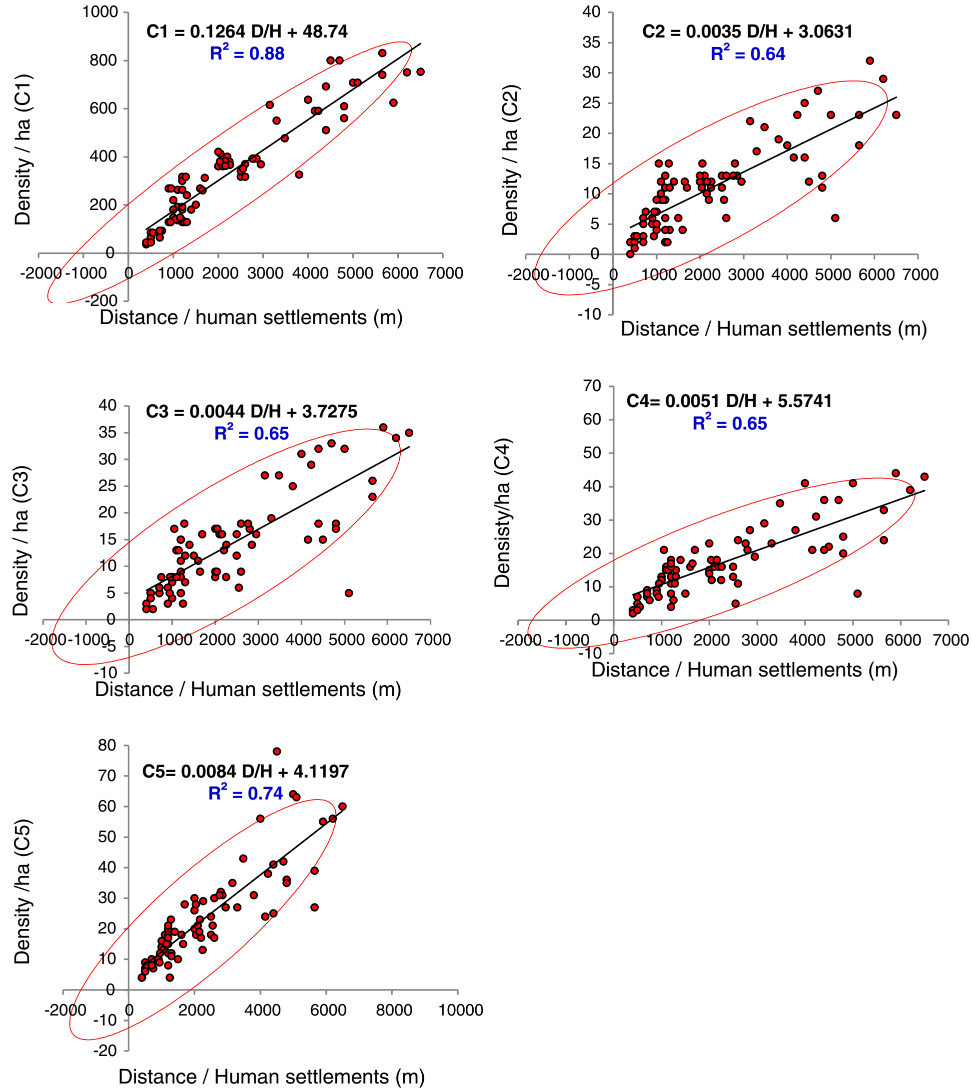

Fig. 3 The linear regression of different diameter classes of *Quercus canariensis* vis the distances from the nearest human settlements (D/H)

Several studies have shown that the natural dynamics of reconstituting oak ecosystems in Morocco are compromised by the almost complete collection of sweet and edible acorns, whose public and rights holders are wrongly and very accustomed (Bendaanoum 1998; Ezzahiri et al. 2001; Foundi et al. 2001; Ben Brahim et al. 2004). More importantly, Alfonso (1985) achieved the same results and noticed that the pastoral burden suffered by the zeen oak forests in Spain far exceeds the load of equilibrium and can reach up to four times the possibilities of the zeenaie.

The area of zeen oak forest in Morocco experienced a significant extension during the period 1962 and 2017 (El Mazi et al. 2018). This regression is the result of human pressure exerted by the population in terms of clearing and roads, with cutting of wood from heating and construction. According to the same authors, the Moroccan forest domain is susceptible to strong anthropogenic pressure. The extent of population growth in forest and peri-forest areas has caused strong pressure and impact on the forest ecosystem. The grazing livestock consists above all of sheep and cattle in the stations of *Quercus canariensis* closest to the forest inhabitants.

Similarly, according to Nsibi et al. (2006), the rate of overgrazing in Tunisian oak forests varied from 77 to 83%. Previously, Jdaidi (2009) had shown that the geographical position of plots in relation to human settlements were seriously influenced the population density; the greater the distance, the higher the density. Regarding the acorn, several agents can intervene including man (collection of acorns whether by galling or after their natural fall), domestic animals (sheep, cattle, goats), wild boar, birds, and rodents. Furthermore, this destruction of oak forests causes very serious disturbances of natural ecosystems like an increase in the impact of certain disasters known to be natural, such as drought (Hasnaoui 1995). Recently, Aissi et al. (2019) showed that in Algeria, a large part of these populations

Fig. 4 Distribution of human activity (red circle) within the study area (Google earth source)

(*Quercus canariensis*) with its obsolete character had made this species precious and useful for humans to meet the needs of their livestock. In addition, a large quantity of acorns from this species in the region is consumed by wildlife, especially wild boar. Surprisingly, this combined action directly affected with negative impact the natural regeneration process, which seriously could threaten its sustainability.

Influence of the different diameter classes on the regeneration of Quercus canariensis (zeenaie) by seedling

From the data collected at the level of the plots, we determined the influence of the diametric structure on the density of seedlings (C1) of Zeen oak. As illustrated in Fig. 5, there is a significant effect ($P < 0.001$) of the different classes of diameters C2 ($R^2 = 0.64$), C3 ($R^2 = 0.63$), C4 ($R^2 = 0.63$), and C5 ($R^2 = 0.76$) on the density of seedlings (C1). On considering the result showed from the same figure, we can see that the number of seedlings increases at the same time with density of the other diameter classes (C2, C3, C4, and C5). However, the low densities of tree classes (C5) have caused a negative effect on the natural renewal by seedling of the forest of oaks zeen in Kroumerie by insufficiency of acorns (Fig. 5).

Obviously, the obtained results demonstrated that the best-preserved zeen oak forests are those located far from human settlements. The acorns of *Quercus canariensis* manage to germinate easily, but it is difficult to find trees of different diameters comprising, especially young plants in the different forests. Thus, a question rises about the future of these forests after the death of the old ones. As illustrated in Table 3, the evolution of the *Quercus canariensis* ecosystem is influenced by the edaphic factors such as the nature, the textures, and the pH of soil. Zeen oak is best installed at the level of fresh stations. This forest species prefers silty-clay soils for its optimal water-holding capacity and requires a good mineral wealth combined with a good water supply. In addition the pH fluctuates between 4.3 and 6.7.

In situ, we could see at the various stations visited, the collection of this litter by certain nurserymen prevents the development of the soil of the zeenaie and impoverishes the environment from its biodiversity. The litter is also the soil in which the zeen oak acorns can germinate once they have fallen to the ground. Its absence simply means the impossibility of regeneration of the forest.

The obtained results showed that the acorns of zeen oak cannot easily germinate, yet it is difficult to find trees of different diameters including the young plants (C2, C3, and C4), which justified the question concerning the future of these forests after the death of the old

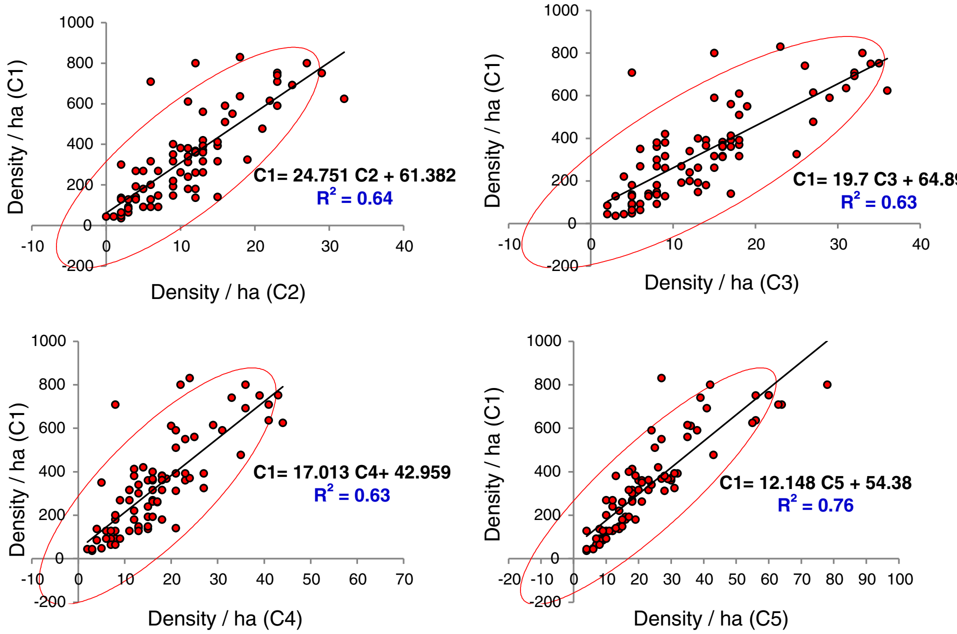

Fig. 5 Relationship between diameter classes and natural renewal by acorns of *Quercus canariensis*

feet. In fact, many factors influenced the natural regeneration of zeen oak. As illustrated in Fig. 6, the continuous and excessive grazing (cutting of scrub and trees for different uses; firewood, carbonization, agricultural land) at the level of the closest places to inhabitants did not let the young shoots continuing their growth in order to achieve natural regeneration of *Quercus canariensis* forests (Fig. 6).

Likewise, the collection of the litter formed by the nurserymen of the region prevents the development of the soil of *Quercus canariensis* (zeen oak) and the impossibility of natural regeneration of this forest. Indeed, the various plots studied are visited throughout the year by herds of different types (cattle, sheep and goats). Beltrain (2002) has claimed that cutting has been abusive. Excessive pruning is detrimental to the development of the tree

Fig. 6 The cuts of *Quercus canariensis* trees in Tabarka (**A**) and The clearing and cutting of trees in El Feidja (**B**) and the action of livestock on the natural regeneration of cork oak and zeen oak in Ain Zana (**C**) and natural regeneration of *Quercus canariensis* at the most remote areas of human settlements in Oued Zeen (**D**)

which makes it weak and more susceptible to drought and disease. In addition, the strong thinning of the crowns leads to an invasion of the understory by heliophilic species which degrade the cork grove. Bendaanoum (1998) reported that herds, by their selective action, eliminate the most palatable flora in favor of toxic and very poorly palatable taxa, which comprise an imbalance in the structures of the vegetation and a brake on the natural regeneration by sowing.

Importantly, the edaphic parameters also affect the zeen oak regeneration. This plant grows only on deep, permeable, silty, and clay soils (Boudy 1950). The suitable physical condition for zeen oak to settle is complete and deep soils. The thickness of this species is favored because of the supply of plant debris mainly comprising dead leaves (Benkaleat 2015).

Our results are consistent with those published by Aissi et al. (2019). It appears that certain soil parameters such as texture, nitrogen content, organic matter, and C/N ratio may also influence the distribution of *Quercus canariensis*. This species seems to prefer soil rich in silt and nitrogen.

Conclusion

The study of the current diameter structure of the zeen oak forest showed the dominant presence of two strata (seedling and tree). Indeed, individuals belonging to intermediate strata are very rare and sometimes non-existent in some plots. This current population structure reflects the lack of natural renewal dynamics of the zeen oak forest in Tunisia.

The study carried out showed the effects of anthropic action on the density of the different classes of zeen oak diameters, in particular the distance from the nearest human settlements. Importantly, the effect of overgrazing on the density of the different diameter classes is very noticeable in all the plots studied. It is the same for its effect on the natural regeneration of this species which is still totally absent.

The future of this ecosystem remains uncertain if the necessary measures are not taken to safeguard it.

Among these measures, natural regeneration by stump shoots is a highly sought-after solution. This approach, which can be undertaken within the framework of an appropriate zeen oak silviculture, can give satisfactory results provided that precautions are taken in a strict manner, such as the date of the cut, the setting aside, and the conduct of the rejections.

Declarations

Competing interests The authors declare no competing interests.

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