



Demography of *Juniperus phoenicea* L. and *Juniperus procera* Hochst. ex Endl. populations at Sarrawat Mountains, Southwest of Saudi Arabia

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Background: The present study aims to identify the pattern and size of *Juniperus* species (*Juniperus phoenicea* and *J. procera*) in the natural forests in terms of tree dimension, size structure and density, discussing the existing both species in Sarrawat Mountains for suggesting the preservation, conservation, and sustainable development. For achieving this, the height and mean crown diameter of each individual was measured based on 2–4 diameter measurements per ind. (506 ind. for *J. phoenicea* and 322 ind. for *J. procera*).

Results: The size index of both species was classified into 7 classes: the first (< 100 cm) and the second (100–200 cm) classes were chosen to represent the juvenile stage. The total mean of the *J. phoenicea* population increased with the increase of altitude, while the whole population decreased after altitude of 2,000 m. The total mean of the *J. procera* population increased with the increase of altitude till altitude of 2,000–2,100 m.

Conclusions: The present study indicated that both of species grow at low altitudes, they only grow at altitude above 1,700 m above sea level. The present study indicated that the study area has the two *Juniperus* spp. (*J. phoenicea* and *J. procera*) associated together all over the area. The results were discussed and compared with other related studies.

Keywords: conservation, ecological range, *Juniperus*, population, size structure

Introduction

Studies the processes determining geographic range patterns address fundamental questions on the distribution and abundance of *Juniperus phoenicea* and *Juniperus procera* species. *Juniperus phoenicea* is listed as Least Concern and threatened species according to International Union for Conservation of Nature (IUCN) Red List Category. It is native to the Canary Islands, coastal Mediterranean Sea from Portugal to Palestine, Turkey, North Africa (Algeria and Morocco), Saudi Arabia, Sinai, Egypt near the Red Sea, and Croatia (Farjon 2013). In North Africa, it occurs on hills, dunes, and arid mountain regions ascending to 2,200 m, while in European area of the Mediterranean it grows up to 1,200 m elevation (Vidakovic 1991). The climate is Mediterranean, with dry and hot summers. This species is rarely taken into cultivation in Mediterranean countries and only a few cultivars have been named of it. The wood is used in Algeria and Tunisia for construction, fence posts and firewood. It is of little economic value in most other

areas. The reddish and succulent cones (berries) can be used in cooking and alcoholic beverages. No specific threats have been identified for this species.

Juniperus procera is listed as Least Concern according to IUCN Red List Category. It is native to Congo, Djibouti, Eritrea Ethiopia, Kenya, Malawi, Saudi Arabia, Somalia, Sudan, Tanzania, Uganda, Yemen (North Yemen), and Zimbabwe (Farjon 2013). It spreads naturally in the highlands above 1,800 m a.s.l. but can occurs in a broader range of 1,000–3,500 m a.s.l., with an average annual temperature range from 5°C to 20°C (Couralet and Bakamwesiga 2007). Its climate is tropical montane, with a prolonged dry season. The larger trees of this species are prized for timber, having good, workable, and decay-resistant wood. It is also used for fence posts and shingles on roofs, for construction, furniture, cabinet making, and the manufacture of pencils.

The juniper populations have a high ecological value, mainly, in relation to the soil retaining ability, as well as the association flora and funa (Al-Sodany et al. 2014;



Moller et al. 1992). However, despite the increasing protected of junipers habitats, population sizes have continued to decline, very often due to the deficiency of regeneration (Verheyen et al. 2005). Two factors that are often mentioned as responsible for the insufficient regeneration of junipers are the absence of microsites suitable for seed germination and establishment (Ward 1982) and limited seed viability (García et al. 2000). The juniper woodlands occur only on the limited areas of upper slopes of Asir Mountains. The woodlands are not only important in biodiversity, but also might be directly and indirectly contributing to the maintenance of ecosystem of the wider vegetation types (e.g., *Olea*, *Acacia*, and other woody species). Therefore, the juniper woodlands should be regarded as an important natural resource which that need to be conserved and managed adequately.

Die-off and die-back phenomena exhibited by these junipers appear one of the main problems facing forest ecosystems in Saudi Arabia (El-Juhany 2015; Warrag et al. 2019), although the conditions vary considerably depending on the location and elevation. Where these phenomena affect *J. phoenicea* in Hijaz Mountains north of Taif they appear to be less severe than in the areas of *J. procera* in Asir Mountains. However, a serious die-off and die-back affecting junipers has been observed in large areas of juniper woodlands in Asir Mountains from about fifteen years ago. National Commission for Wildlife Conservation and Development (NCWCD) undertook to clarify the cause and to take counter measures to care for the wildlife of the juniper woodlands in cooperation with other related authorities, especially the Ministry of Agriculture. Recently, Warrag et al. (2019) showed that > 80% of *J. procera* trees within the natural stands had symptoms of dieback but > 65% was not severely affected. Tree recovery signs of new lateral shoots, leaves, sprouts, and flowering were evidently observed even among the severely affected trees.

In the last ten years, NCWCD has carried out various projects on wildlife around the country, but in particular implemented the project on the “Joint Study Project for the Conservation of Juniper Woodlands” (1999–2002) in cooperation with the Japan International Cooperation Agency (JICA), in which NCWCD has clarified the structure and dynamics of juniper woodlands, including the die-off and die-back, studied their ecological features and biodiversity and suggested the basic points on the management plan. They are in a corridor between three continents and have preserved many wildlife life species as areas of refuge in the long process of climatic change on earth, including ice ages. It is thought that these juniper woodlands grew over a more extensive area and in denser forest stands in the distant past compared to the present. However, these woodlands have declined mainly due to human activities, such as tree felling, overgrazing, road, and housing construction, and so on. In addition, the die-off and die-back

have become obvious in juniper woodlands since the beginning of the 1990s and are a quite serious problem from the viewpoint of the conservation of biodiversity as well as the landscape of the Asir Mountains, and many studies and surveys have therefore been carried out to clarify these phenomena, their ecological aspects, and so on.

As it reveals species' growth, survival, and reproduction, the size and age structure of species populations indicate their regeneration and current status (Baker and Wilson 2003; de Kroon et al. 1986; Lusk 2003; Primack 1995; Witt 2004). To discuss conservation and sustainable use, the present study aims to analyze the elevational pattern of size structure (dimensions, size structure, and density) of natural forests of *J. phoenicea* and *J. procera* forests in Sarawat Mountains, discussing the existing both species of juniper for suggesting the preservation, conservation, and sustainable development.

Study area

Saudi Arabia extends over approximately 16° N, from 16° 22' N at the borders with Yemen in the south; to 32° 14' N at the Jordanian border in the north, and between 34° 29'E and 55° 40'E longitude. The western region of Saudi Arabia is rich in vegetation when compared with the central and eastern region. The southwestern Mountains (Sarawat Mountains) are floristically richer than the northwestern Mountains which affinities to the Mediterranean and North African floristic regions. However, the entire southwestern region is the richest in terms of species diversity and contains the highest concentration of endemism, even though these high-altitude areas are heavily populated with human settlements dating to ancient times (Shimono et al. 2010). Taif region is situated in the central foothills of the western Mountains at an altitude of an approximately 2,500 m above sea level). It is an important place for the people due to its scenic views and fertile valleys which support the growth of several fruits and vegetables (Fig. 1).

Climate of the study area is tropical. The monthly mean of climatic recodes in Taif meteorological station (1997–2009) indicated that the monthly average of minimum and maximum ambient temperatures ranged from 7.9°C ± 1.2°C to 23.4°C ± 0.8°C and 22.9°C ± 1.1°C to 36.3°C ± 0.8°C, respectively with a total monthly mean of 23.2°C ± 5.1°C. During the same period, mean monthly humidity ranged from approximately 19.6% ± 4.2% to 60.0% ± 6.0%. The data from last 10 years shows considerable inter-annual variation in the monthly amount (range 4.3 ± 5.7–294.1 ± 383.8 mm mo⁻¹) and timing of rainfall. The yearly amount of rainfall ranges from 83.3 mm yr⁻¹ in 2007 to 3,312 mm yr⁻¹ in 2001. The mean maximum temperature (± standard deviation [SD]) between 2006 and 2008 was 36.33°C ± 1.15°C, while average values for the period between 1991 and 2005 were 33.60°C ± 3.03°C (Fig. 2).

Materials and Methods

One hundred stands were selected along Sarrawat Mountains from two locations (Hada and Shafa Mountains) in the study area to represent the environmental variations that associated with the distribution of *J. phoenicea* and *J. procera* (Fig. 1). The stand size was about 20 × 20 m. The population structure of these species was evaluated in terms of size distribution. For achieving this, the species dimensions in terms of height and diameter were measured. The height and mean crown diameter of each individual in the whole stand was measured based on 2–4 diameter measurements per ind. (506 ind. for *J. phoenicea*

and 322 ind. for *J. procera*) and its volume was calculated as a cylinder according to the following equation:

$$\text{Volume} = \pi r^2 H$$

where r is the radius and H is the height of the individual. The size index of each individual was calculated as the average of its height and diameter $\{(H + D) / 2\}$. The size index estimates were then used to classify population into 7 size classes: 1) < 100, 2) 100–200, 3) 200–300, 4) 300–400, 5) 400–500, 6) 500–600, and 7) > 600 cm. The first (< 100 cm) and second (100–200 cm) classes were chosen to represent the juvenile stage. The absolute and relative frequency of individuals in each size class were then determined (Al-Sodany et al. 2019; Shaltout and Ayyad 1988). Also, the mean height, diameter, size index, volume, and height to diameter ratio (H:D ratio) in terms of location vs. altitude, location vs. size classes, and altitude vs. size class for each species were assessed. The number of Juniperus individuals in each stand were counted, and then used to calculate its density in different locations and altitudes.

Means, SD, and three-way analysis of variance (ANOVA-3) were calculated for the means of the respective height, crown diameter, size index, volume, H:D ratio, and density in relation to locations, altitudes, and size classes. These techniques were according to IBM SPSS software ver. 20 (IBM Co., Armonk, NY, USA).

Results

Species dimensions

Regarding to *J. phoenicea*, the minimum height was 76.6 cm at 1,900–2,000 m a.s.l with a mean of 78.1 cm (Table 1), while the maximum was 826.0 cm at the same altitude with a maximum mean of 805.0 cm (Fig. 3). The minimum crown diameter was 65.7 cm at 2,000–2,100 m a.s.l. with a mini-

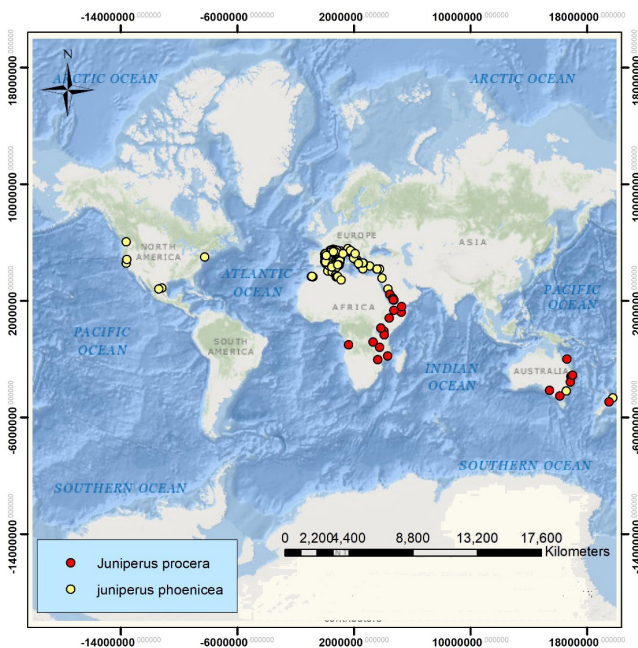


Fig. 1 The global spatial distribution of the two *Juniperus* spp. *Juniperus phoenicea* and *J. procera* (after Global Biodiversity Information Facility database: https://dendrome.ucdavis.edu/tree-genes/species/species_detail.php?id=356).

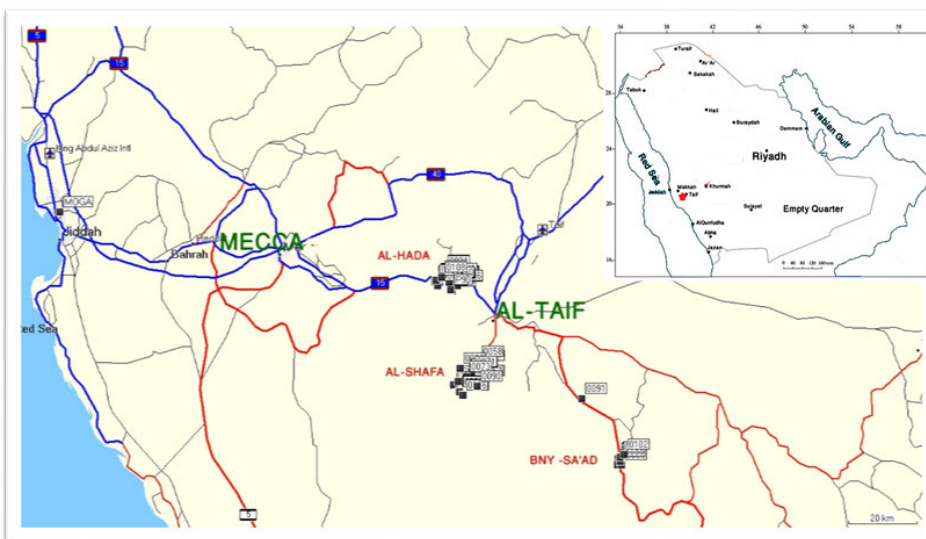


Fig. 2 Map of the study area (South-west of Saudi Arabia) illustrate the distribution of 100 stands along. By using their coordinates (GPS).

Table 1 F-value resulted from three-way analysis of variance (ANOVA-3) of *Juniperus* spp. (*J. phoenicea* and *J. procera*) dimensions in Sarrawat Mountains at Taif

Source	Height	Diameter	Size index	Volume	H:D	Density
<i>J. phoenicea</i>						
Location (loc)	0.35	0.22	0.81	0.33	3.37*	11.78***
Altitude (alt)	10.77***	49.27***	73.43***	22.24***	5.57***	3.57**
Class (cla)	399.15***	441.07***	1169.90***	608.82***	16.94***	-
Loc × alt	0.16	1.46	0.83	0.06	2.50	3.67**
Loc × cla	4.26***	6.81***	1.97	3.68**	6.73***	-
Alt × cla	1.46	2.01*	1.76*	3.66***	1.73*	-
Loc × alt × cla	6.34**	1.37	1.41	0.00	3.20	-
<i>J. procera</i>						
Location (loc)	142.25***	3.03	272.63***	70.17***	15.71	4.84**
Altitude (alt)	6.85***	4.68**	15.66***	3.89**	2.46	1.98
Class (cla)	188.66***	168.87***	1038.92***	274.40***	3.13	-
Loc × alt	2.32	3.38*	0.39	0.97	3.62	1.50
Loc × cla	3.96***	2.50*	2.02	0.80	2.37	-
Alt × cla	1.64	0.90	1.80*	2.05**	0.83	-
Loc × alt × cla	0.09	0.40	0.69	0.56	0.14	-

H: height; D: diameter; -: not applicable.
 * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

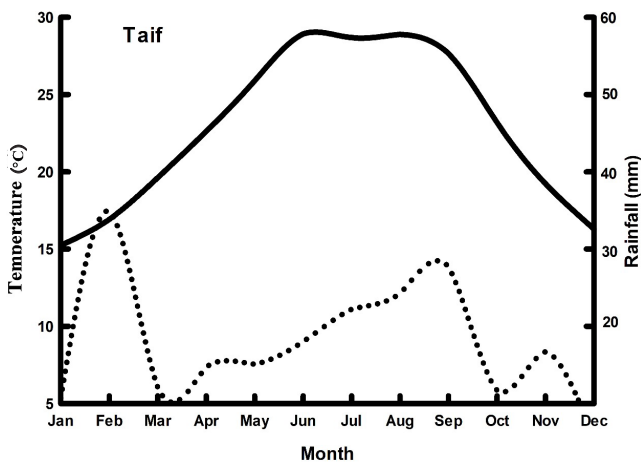


Fig. 3 Climatic diagram at Taif, Saudi Arabia. The data are long term averages (Climatological Normals for Saudi Arabia, 1970–2008).

imum mean of 67.7 cm (Table 1), while the maximum was 541.2 cm at 2,000–2,100 m a.s.l. with a mean of 548.5 cm. The minimum size index was 72.6 ± 20.1 cm at 1,900–2,000 m a.s.l. with a minimum mean of 72.9 cm, while the maximum size index was 683.6 cm at the same altitude with a maximum mean of 676.8 cm. Generally, the H:D ratio of this species is approximate or less than unit in most locations and altitude gradients. The minimum H:D was 0.81 at 2,100–2,200 m a.s.l with a minimum mean of 0.90, while the maximum H:D was 1.53 at altitude > 2,200 m a.s.l. with a maximum mean of 1.50. The minimum volume of *J. phoenicea* was 0.6 ± 0.4 m³ at 2,000–2,100 m a.s.l. with a minimum mean of 0.7 m³, while the maximum volume was 385.9 m³ at 1,900–2,000 m a.s.l. with a maximum mean of 384.3 m³.

The dimensions of *J. phoenicea* is not differed in relation

to location (Hada and Shafa) and interaction of altitudes vs. location, while the variations in relation to altitudes and size classes are highly significant different ($p < 0.001$) (Table 2). Regarding the interaction between location vs. altitude vs. size, all dimensions of this species are differed significantly in relation to location vs. size class interaction ($p < 0.001$), except size index and altitude vs. size class ($p < 0.05$), except height. Regarding the interaction between the three factors, only height is differed significantly ($p < 0.01$). On the other hand, the dimensions of *J. procera* are differed significantly in relation to location, altitudes, and size classes ($p < 0.001$):diameter ratio. Regarding the interaction, the diameter is differed significantly in relation to location vs. altitude and location vs. size class interactions ($p < 0.05$); while the height is differed significantly in relation to location vs. size ($p < 0.001$), and both size index and volume are differed significantly in relation to altitude vs. size ($p < 0.05$ and 0.01, respectively).

Regarding to *J. procera*, there is no growth at altitude < 1,900 m a.s.l. The minimum height was 67.0 cm at 2,000–2,100 m a.s.l. with a minimum mean of 74.3 cm (Table 3), while the maximum height was 718.3 cm at 1,900–2,000 m a.s.l. with a mean of 695.0 cm (Fig. 4). The minimum crown diameter was 38.0 cm at 2,000–2,100 m a.s.l with a mean of 67.3 cm, while the maximum crown diameter was 612.1 cm at the same altitude with a mean of 585.5 cm. The minimum size index was 52.5 cm at 2,000–2,100 m a.s.l. with a minimum mean of 70.8 cm, while the maximum size index was 652.7 cm at the same altitude with a maximum mean of 640.2 ± 46.6 cm. Generally, the H:D ratio of *J. procera* exceeds one in most locations and altitude gradients. The minimum H:D was 0.80 at 2,100–2,200 m a.s.l with a mean of 0.95, while the maximum H:D was 1.60 at

Table 2 Altitude vs. size class variations in the mean ± standard deviation of *Juniperus phoenicea* dimensions in Sarawat Mountains

Altitude (m)	Size class (cm)	Height (cm)	Diameter (cm)	Size index (cm)	Volume (m ³)	H:D	
< 1,900	100–200	160.0 ± 28.3	151.3 ± 97.2	155.6 ± 62.8	7.6 ± 8.6	1.26 ± 0.62	
1,900–2,000	< 100	76.6 ± 21.7	68.7 ± 22.0	72.6 ± 20.1	0.7 ± 0.5	1.15 ± 0.27	
	100–200	161.4 ± 28.7	149.5 ± 42.4	155.5 ± 29.3	6.3 ± 3.7	1.15 ± 0.33	
	200–300	236.0 ± 45.9	272.8 ± 47.2	254.4 ± 27.7	27.8 ± 9.2	0.90 ± 0.28	
	300–400	318.7 ± 53.0	365.6 ± 47.6	342.2 ± 28.0	66.9 ± 17.1	0.90 ± 0.24	
	400–500	424.5 ± 61.9	466.2 ± 52.6	445.3 ± 29.2	144.4 ± 29.6	0.93 ± 0.22	
	500–600	616.7 ± 57.7	456.2 ± 49.3	536.4 ± 11.6	200.5 ± 26.1	1.37 ± 0.26	
	> 600	826.0 ± 154.5	541.2 ± 84.0	683.6 ± 84.9	385.9 ± 147.5	1.56 ± 0.38	
	Total	282.9 ± 142.8	302.9 ± 124.4	292.9 ± 124.6	60.2 ± 73.9	0.98 ± 0.30	
2,000–2,100	< 100	85.7 ± 22.6	65.7 ± 18.4	75.7 ± 15.9	0.6 ± 0.4	1.40 ± 0.57	
	100–200	150.5 ± 43.0	148.6 ± 37.1	149.5 ± 31.6	5.7 ± 3.5	1.05 ± 0.36	
	200–300	237.5 ± 49.2	274.7 ± 42.6	256.1 ± 28.9	28.4 ± 9.2	0.89 ± 0.24	
	300–400	334.6 ± 54.4	362.2 ± 58.5	348.4 ± 30.2	69.1 ± 20.1	0.96 ± 0.27	
	400–500	418.6 ± 59.6	437.7 ± 55.5	428.1 ± 24.7	125.2 ± 25.4	0.98 ± 0.26	
	Total	276.2 ± 113.7	298.2 ± 121.4	287.2 ± 110.0	54.0 ± 53.9	0.98 ± 0.32	
2,100–2,200	100–200	147.2 ± 28.0	124.4 ± 30.8	135.8 ± 26.8	3.9 ± 2.6	1.21 ± 0.23	
	200–300	241.4 ± 44.0	285.6 ± 41.0	263.5 ± 27.6	31.3 ± 9.1	0.87 ± 0.22	
	300–400	322.9 ± 41.7	381.3 ± 47.3	352.1 ± 27.1	74.2 ± 17.9	0.86 ± 0.17	
	400–500	392.6 ± 46.9	497.6 ± 65.6	445.1 ± 26.4	152.6 ± 34.7	0.81 ± 0.23	
	Total	303.9 ± 78.5	362.7 ± 104.5	333.3 ± 83.7	73.3 ± 47.3	0.88 ± 0.23	
> 2,200	100–200	163.4 ± 27.4	116.6 ± 45.1	140.0 ± 32.8	4.2 ± 3.7	1.53 ± 0.44	
	200–300	271.7 ± 41.2	251.7 ± 27.9	261.7 ± 15.9	26.8 ± 4.8	1.10 ± 0.27	
	300–400	336.9 ± 46.6	351.2 ± 54.1	344.1 ± 19.6	64.9 ± 15.3	1.00 ± 0.30	
	Total	266.8 ± 92.9	271.1 ± 137.2	269.0 ± 107.7	46.0 ± 49.5	1.13 ± 0.43	
Total	< 100	78.1 ± 23.8	67.7 ± 25.2	72.9 ± 21.0	0.7 ± 0.5	1.26 ± 0.46	
	100–200	156.4 ± 34.3	142.5 ± 42.2	149.5 ± 31.1	5.6 ± 3.7	1.18 ± 0.38	
	200–300	238.7 ± 46.6	274.8 ± 44.0	256.7 ± 27.9	28.5 ± 9.1	0.90 ± 0.25	
	300–400	325.9 ± 50.0	368.4 ± 51.8	347.2 ± 28.0	69.7 ± 18.3	0.91 ± 0.24	
	400–500	410.8 ± 57.9	467.2 ± 62.3	439.0 ± 27.4	140.3 ± 31.5	0.91 ± 0.24	
	500–600	546.0 ± 110.8	532.7 ± 112.2	539.4 ± 28.9	237.5 ± 67.6	1.09 ± 0.42	
	> 600	805.0 ± 147.5	548.5 ± 77.3	676.8 ± 77.7	384.3 ± 132.0	1.50 ± 0.37	
	Total	283.7 ± 118.6	312.0 ± 123.1	297.9 ± 112.2	59.9 ± 61.2	0.97 ± 0.31	
F-value	F _{alt}	10.74***	47.64***	72.25***	21.80***	6.24***	
	F _{cla}	397.29***	427.25***	1152.68***	594.44***	16.71***	
	F _{alt x cla}	2.44***	2.66***	1.44	3.29***	3.31***	

H: height; D: diameter.
****p* ≤ 0.001.

1,900–2,000 m a.s.l. with a maximum mean of 1.33.

Density

The total mean density of the *J. phoenicea* population decreased with the increase of altitude. Inversely, the density of *J. procera* population increased with the increase of altitude (Fig. 5). The maximum means density of the *J. phoenicea* populations was 202.9 ind. ha⁻¹ at 1,900–2,000 m a.s.l. and the minimum was 18.8 ind. ha⁻¹ at < 1,900 m a.s.l. On the other hand, the maximum density of *J. procera* was 151.8 ind. ha⁻¹ at > 2,200 m a.s.l., while there is no growth at < 1,900 m a.s.l. The density of *J. phoenicea* differed significantly along the location, altitude gradients and interactions between them (*F* = 11.78, *p* < 0.001; *F* = 3.57, *p* < 0.01; *F* = 3.67, *p* < 0.01, respectively), while that of *J. procera* differed significantly only along the location (*F* = 4.84, *p* < 0.01) (Table 1).

Population size structure

The size index frequency distributions of *J. phoenicea* population approximated the positive skewed shape towards the relative preponderance of small individuals (Fig. 6). On average, the first three size index-classes contributed 46.9% of the total individuals comparing with 13.0% of the last three classes, while the moderate individuals (middle class) contribute 40.2%. At elevations of < 1,900, 2,000–2,100, and > 2,200 and bell shaped at 1,900–2,000 and 2,100–2,200 m a.s.l. the frequency distribution of *J. phoenicea* population approximated the positive skewed shape towards the relative preponderance of the small individuals.

On the other hand, the size index-class frequency distributions of *J. procera* population approximated the bell shape (Fig. 7). On average, the first three size index-classes contributed 26.8% of the total individuals comparing with 39.0% of the last three classes, while the moderate individ-

Table 3 Altitude vs. size class variations in the mean±standard deviation of *Juniperus procera* dimensions in Sarawat Mountains

Altitude (m)	Size class (cm)	Height (cm)	Diameter (cm)	Size index (cm)	Volume (m ³)	H:D
1,900–2,000	< 100	80.0 ± 31.6	67.1 ± 15.1	73.6 ± 19.4	0.6 ± 0.4	1.21 ± 0.42
	100–200	137.4 ± 23.8	143.7 ± 62.0	140.6 ± 38.8	5.4 ± 8.0	1.08 ± 0.41
	200–300	242.3 ± 33.6	268.1 ± 55.0	255.2 ± 26.2	27.9 ± 10.5	0.95 ± 0.29
	300–400	332.4 ± 61.9	351.2 ± 80.1	341.8 ± 29.9	64.2 ± 22.7	1.03 ± 0.43
	400–500	455.0 ± 102.6	431.1 ± 79.3	443.1 ± 22.1	127.8 ± 24.9	1.14 ± 0.50
	500–600	651.3 ± 144.7	477.7 ± 128.5	564.5 ± 23.9	225.8 ± 74.3	1.60 ± 1.00
	> 600	718.3 ± 116.0	543.5 ± 124.5	630.9 ± 43.3	334.3 ± 123.2	1.44 ± 0.68
	Total	398.3 ± 198.0	363.0 ± 143.0	380.7 ± 147.2	109.1 ± 102.6	1.17 ± 0.61
2,000–2,100	< 100	67.0 ± 52.3	38.0 ± 30.4	52.5 ± 41.4	0.3 ± 0.4	1.78 ± 0.05
	100–200	136.0 ± 36.6	132.1 ± 45.5	134.0 ± 29.4	4.1 ± 3.1	1.18 ± 0.65
	200–300	225.0 ± 57.2	272.9 ± 67.6	248.9 ± 32.6	26.5 ± 12.1	0.90 ± 0.43
	300–400	343.0 ± 44.6	340.9 ± 50.0	341.9 ± 25.3	62.9 ± 16.6	1.04 ± 0.24
	400–500	450.8 ± 78.6	452.5 ± 69.6	451.7 ± 26.8	143.0 ± 30.8	1.04 ± 0.37
	500–600	547.5 ± 76.1	524.6 ± 62.4	536.1 ± 30.5	235.3 ± 47.0	1.07 ± 0.25
	> 600	693.3 ± 11.5	612.1 ± 128.2	652.7 ± 66.4	420.5 ± 184.1	1.16 ± 0.22
	Total	356.7 ± 149.9	355.8 ± 140.3	356.3 ± 135.8	98.5 ± 98.8	1.06 ± 0.37
2,100–2,200	< 100	71.4 ± 14.5	73.8 ± 36.2	72.6 ± 20.5	0.7 ± 0.7	1.28 ± 0.92
	100–200	157.6 ± 32.1	160.4 ± 30.3	159.0 ± 26.6	6.8 ± 3.0	1.00 ± 0.19
	200–300	252.6 ± 64.3	240.8 ± 58.2	246.7 ± 33.3	23.2 ± 10.1	1.14 ± 0.49
	300–400	311.4 ± 60.0	396.0 ± 65.9	353.7 ± 30.1	76.3 ± 21.8	0.83 ± 0.30
	400–500	393.0 ± 71.0	488.3 ± 72.2	440.7 ± 29.3	145.4 ± 33.7	0.84 ± 0.28
	500–600	457.5 ± 45.7	578.3 ± 31.6	517.9 ± 12.6	239.1 ± 14.0	0.80 ± 0.12
	> 600	310.0 ± 111.1	372.5 ± 148.8	341.3 ± 117.7	88.9 ± 74.2	0.92 ± 0.38
> 2,200	< 100	77.5 ± 10.6	80.5 ± 25.5	79.0 ± 18.0	0.9 ± 0.6	0.99 ± 0.18
	100–200	155.0 ± 49.5	145.8 ± 20.2	150.4 ± 34.8	5.4 ± 3.1	1.05 ± 0.19
	200–300	270.0 ± 42.4	305.5 ± 7.8	287.8 ± 17.3	39.4 ± 4.2	0.89 ± 0.16
	300–400	333.6 ± 35.3	380.9 ± 44.8	357.3 ± 19.2	76.0 ± 14.3	0.89 ± 0.18
	Total	281.9 ± 101.8	317.2 ± 122.8	299.6 ± 108.7	58.8 ± 37.3	0.92 ± 0.17
Total	< 100	74.3 ± 24.1	67.3 ± 28.6	70.8 ± 21.8	0.7 ± 0.5	1.29 ± 0.62
	100–200	147.2 ± 33.3	147.7 ± 41.3	147.5 ± 30.6	5.6 ± 3.4	1.07 ± 0.41
	200–300	244.3 ± 53.5	258.9 ± 59.3	251.6 ± 30.9	26.0 ± 10.8	1.02 ± 0.42
	300–400	328.0 ± 55.4	367.2 ± 67.9	347.6 ± 28.2	69.3 ± 20.8	0.95 ± 0.33
	400–500	420.8 ± 84.8	466.6 ± 75.8	443.7 ± 27.1	140.7 ± 31.5	0.96 ± 0.38
	500–600	593.9 ± 136.8	505.5 ± 107.9	549.7 ± 30.2	230.4 ± 60.7	1.33 ± 0.83
	> 600	695.0 ± 99.5	585.5 ± 130.2	640.2 ± 46.6	377.2 ± 140.1	1.29 ± 0.57
	Total	346.4 ± 155.2	362.3 ± 143.5	354.3 ± 132.3	95.6 ± 89.1	1.03 ± 0.46
F-value	F _{alt}	35.09***	3.62*	56.94**	12.89***	6.80***
	F _{cla}	195.30***	169.00***	1047.92***	281.40***	3.48**
	F _{alt x cla}	2.44**	1.49	1.63	1.72*	1.61

H: height; D: diameter.
* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

uals (middle class) contribute 34.3%. Generally, this species cannot grow at altitude under 1,900 m a.s.l. The size index-class frequency distributions approximated the negative skewed shape towards the relative preponderance of the large individuals at elevations of 1,900–2,000, 2,000–2,100, and 2,100–2,200 m a.s.l. while the bell shape at > 2,200 m.

Discussion

The present study indicated that *J. phoenicea* and *J. procera* only grow at altitude above 1,900 m a.s.l. This may be due to effects of animal browsing, human interference,

poor seed-setting, changes in land use patterns and prevalence of unfavorable climatic conditions (Negash 2002). Since the fecundity and survival of plants is often much more closely related to size than to age, some authors (e.g., Kirkpatrick 1984) have argued that it is better to classify the plant life history by size rather than age. Size differences in plant populations may be caused directly or through differences in growth rates due to age difference, genetic variation, heterogeneity of resources, herbivory, and competition (Harper 1977; Weiner 1985). In the study area, *J. phoenicea* showed three different size structures (positive, negative and bell shapes) reflecting the differences in the nature of the bedrock and the water availability, the populations of both species at locations with less altitudes (Hada

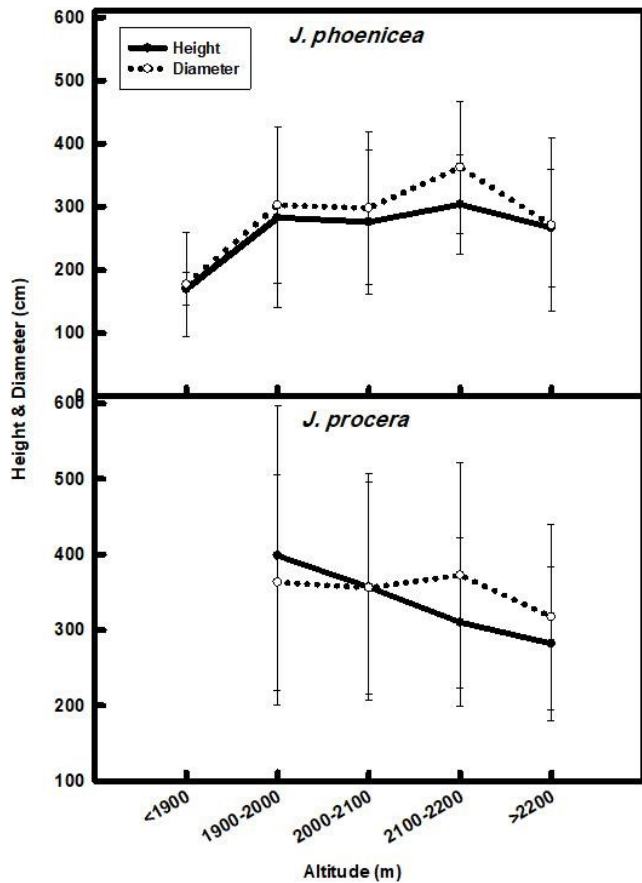


Fig. 4 Variations in the mean and standard deviation (vertical bars) of height and crown diameter (cm) of *Juniperus* spp. (*J. phoenicea* and *J. procera*) along different altitudes in Sarrawat Mountains at Taif.

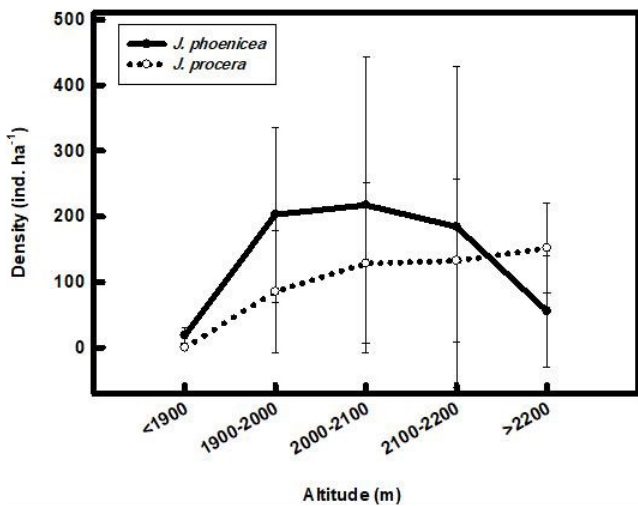


Fig. 5 Mean and standard deviation (vertical bars) in the individual density (ind. ha⁻¹) of *Juniperus* spp. (*J. phoenicea* and *J. procera*) along Sarrawat Mountains at Taif.

Mountain) had a comparable proportion of young and mature individuals, which may indicate that recruitment is frequent due to the low altitude than locations with high altitudes (Shafa Mountain).

On the other hand, the populations at locations with

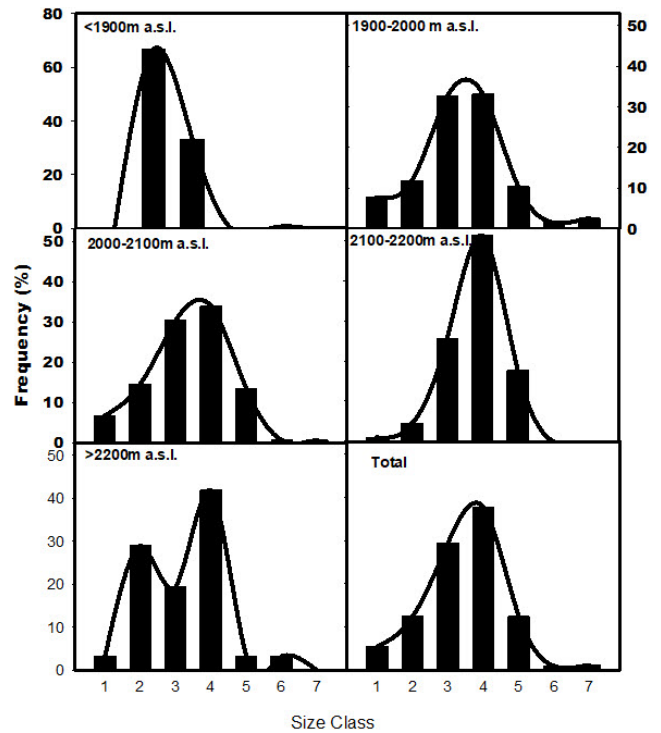


Fig. 6 Size index-class frequency of *Juniperus phoenicea* population along different altitudes in Sarrawat Mountains at Taif. The different size index class as follows: 1. < 100, 2. 100–200, 3. 200–300, 4. 300–400, 5. 400–500, 6. 500–600, and 7. > 600 cm.

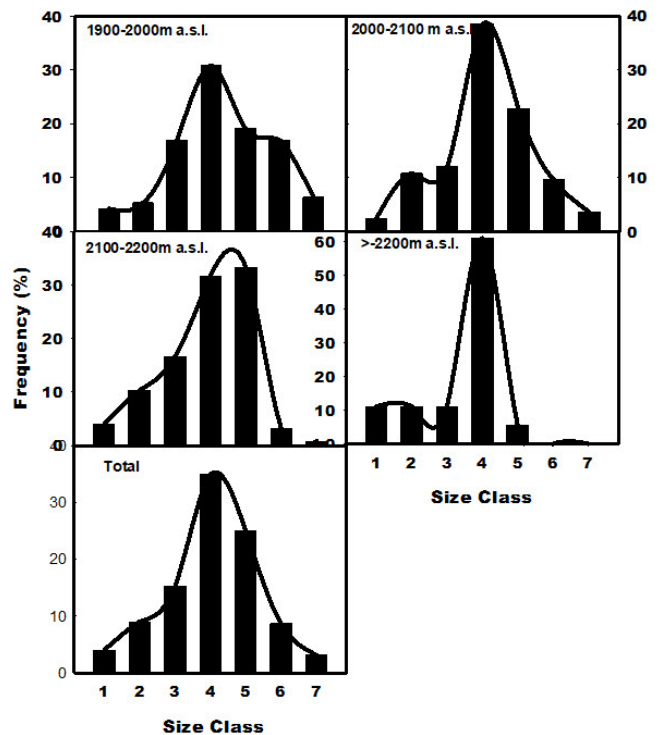


Fig. 7 Size index-class frequency of *Juniperus procera* population along different altitudes in Sarrawat Mountains at Taif. The different size index class as follows: 1. < 100, 2. 100–200, 3. 200–300, 4. 300–400, 5. 400–500, 6. 500–600, and 7. > 600 cm.

high altitudes were dominated by mature and senescent individuals, thus indicating a recruitment limitation of individuals. The poor conditions for the trees can be related to

the dominance of fissured hard rocks that limit the water availability (Danin 1978). Thus, fluctuation of annual rainfall with several consecutive dry years in these habitats may cause the death of trees and prevent the regeneration. Since the local rainfall over the anticlines is almost uniform, the spatial distribution of plant species and communities appear to be more affected by topography and rock type that control the moisture available for plant growth (Abd El-Wahab et al. 2008; Danin 1999).

Bare ground microsites have become rare due to a combination of some ecological factors such as soil erosion and the abandonment of traditional management practices such as grazing and mowing (Burton 1993). It is also well documented that under unfavorable conditions female plants may decrease reproductive efforts resulting in less number of viable seed sets (Block and Treter 2001). So far, few studies have quantified demographic changes in juniper populations (Clifton et al. 1997; Rosen 1995). No study has yet evaluated the dynamics of juniper populations in Sarrawat area, and there is a lack of primary information concerning age of plants, extent of regeneration, grazing pressure, and management practices. The present study was performed to investigate size structure present in these areas of the common Juniper population in Sarrawat Mountains, this information, reflecting the dynamics of the population, enables us to reconstruct regeneration dynamics in the past and there by predict the future status of juniper forest.

Positively skewed size distributions towards the small (i.e., young) individuals of *J. phoenicea* at elevations of < 1,900, 2,000–2,100, and > 2,200 in the study area mean that this may represent rapidly growing populations with relatively high reproductive capacity, since in most stable populations one would expect an excess of juvenile over mature individuals (Crisp and Lange 1976; Goldberg and Turner 1986; Shaltout and Ayyad 1988). Moreover, these species were recorded as palatable to the livestock in the study area. The cumulative effect of grazing is evidenced by signs such as pale unnatural color of herbage, reduced height of growth and reduced volume and biomass of individual plant and plant life per unit area. Furthermore, Gray (1975) reported that the positively skewed distribution is indicative of a self-perpetuating species, with markedly more frequency of the smaller (younger) size classes. Similar conclusion was made by Shaltout and Ayyad (1988).

Negative skewed shape of *J. procera* at elevations of 1,900–2,000, 2,000–2,100, and 2,100–2,200 m a.s.l. in the study area towards the relative preponderance of large individuals may be due to several external factors responsible for mortality of saplings. Consequently, recruitment rate was found smaller than a typical secure population (Al-Sodany et al. 2019; Price 1997; Shahi et al. 2007). Similar patterns of mortality caused by low recruitment have been shown in south Spain (Garcia et al. 1999), England (Clifton

et al. 1997; Ward 1981), and Belgium (Verheyen et al. 2005). On the other hand, overgrazing, overcutting, changes in land use strategies, drought, habitat quality (e.g., eutrophication and drought) have been claimed to be responsible for high seedling death. In addition, the bell-shaped size distribution of these species at 2,000–2,100 m above the sea level indicated comparable representation of the juvenile and mature individuals. If current situation continues, a reduction in population size of these species is expected in the future. Similar results were reported by Shaltout and Mady (1993) in their study on the size distribution of *Lycium shawii* in Central Saudi Arabia.

Few studies have been published addressing the population processes of semi-desert trees and shrubs. Thus, information is lacking on the life-history stages that mostly affect their population dynamics and regeneration processes. Demographic studies carried out with *Prosopis glandulosa* and some species of the genus *Acacia* indicate that the demographic processes that contribute mostly to population dynamics are stasis and growth (Golubov et al. 1999; Midgley and Bond 2001). The knowledge of the most vulnerable life cycle stages and of the numerical variation that occurs within populations of keystone species (Fagg and Stewart 1994) may be an important element to consider in the design of management plans for semi-arid ecosystems and for the development of conservation strategies aimed to protect these species and hence whole semi-arid communities.

The results of the present study showed a demographic study for the two common trees in Sarrawat Mountains distributed in a semi-desert region in Saudi Arabia which is well known for its high biological diversity. This allowed to evaluate the potential ability of these populations to withstand the increasing habitat degradation levels apparent in the area. For some years, the Juniper trees in the study area show obvious signs of degradation and until now several individuals died completely. Also, *J. procera* is included on the IUCN red list of threatened species. This may be due to many reasons such as: delaying of rain, excessive water due to flooding after rain, pollution by human impact and firing of main trunk of Juniper trees, constructing new roads at Hada and Shafa Mountains, and building of new summer resorts (Fig. 8). Like the study of Warrag et al. (2019), in this study, the west-facing *J. procera* had low impact from dieback and had greener vegetation Normalized Difference Vegetation Index classes than the east-facing slopes. The west-facing slopes receive higher rainfall than the south-western monsoons precipitation patterns in Alsouda region (Vincent 2008), and consequently higher soil moisture content than the east-facing slopes. Further studies on the effects of different climate conditions on growth performance and other physiological and biochemical aspects are encouraged. Such studies will help in understanding the favorable growth conditions of

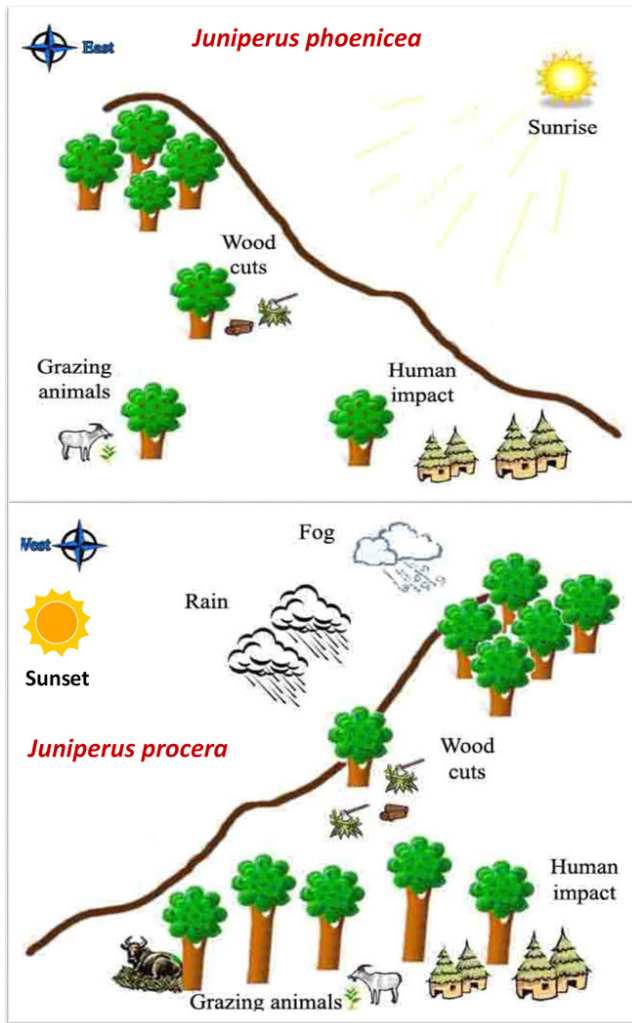


Fig. 8 Pressures and environmental conditions affecting *Juniperus* spp. (*J. phoenicea* and *J. procera*) in the study area.

these species for regeneration and to preserve soils with less plant cover in semi-arid and arid conditions, where the plant is subjected to deterioration by several means such as harsh growing conditions and grazing.

According to the demographic characteristics obtained in this study, it appears that the juniper populations in the research area are sustained by long lifespans and good seed characteristics, which act as a partial counterbalance to losses caused by unfavorable environmental conditions and postpone the potential extinction process (Shahi et al. 2007). Due of the current climate's unfavorable regression period and ongoing drought, these inertias would keep populations stable. However, the trend towards global warming could alter the situation by intensifying the drought, which would then have an impact on survivorship and recruitment rates (Menendez et al. 2006). Consequently, it is advised to conduct more thorough demographic research and monitoring population changes are recommended.

Ministry of Agriculture is responsible for the administrative management of all the forests in the Saudi Arabia,

including the juniper woodlands. Meanwhile, the NCWCD, is required to establish a comprehensive and practical management plan for juniper woodlands from the viewpoint of its position to conserve the juniper woodlands as natural woodlands with high biodiversity. The goal of the management plan is the effective conservation of the whole of juniper woodlands in the Sarawat Mountains. However, juniper woodlands have been familiar to human life in this country for a long time. It is not realistic to prohibit the residents from entering or using the juniper woodlands. Therefore, the only possible approach under this situation is a form of coexistence between human life and the juniper woodlands. To achieve coexistence between the two, the goals of the plan need to be established in accordance with the respective natural and social aspects. In the plan, the juniper woodlands were divided into various zones and the conservation approach to be taken for each type is clarified. This plan will not be difficult to implement since it was developed in consideration with the current natural and social conditions of the juniper woodlands. Since the conservation of the juniper woodlands is a critical issue for the Saudi Arabia, specific action plan and timetable for the conservation of the juniper ecosystem are expected to be developed in the area, and to be implemented as soon as possible by the stakeholders of the Kingdom. The present study suggests applying this plan in Hada and Shafa area for *J. phoenicea* and *J. procera* because the two species present together in this area all over the world.

Conclusions

According to the current study, neither species grows above 1,700 meters above sea level; instead, they are low-lying species. The two *Juniperus* species—*J. phoenicea* and *J. procera*—are related to each other in the study area.

Everywhere in the region. The findings were debated and contrasted with those of other relevant research. So that, the present study suggests applying the plan of conservation of juniper woodland ecosystem.

Abbreviations

IUCN: International Union for Conservation of Nature

NCWCD: National Commission for Wildlife Conservation and Development

ANOVA-3: Three-way analysis of variance

H:D ratio: Height to diameter ratio

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Authors' contributions

YMAS and HMAJ analyzed and interpreted data regarding transplant experiment. YMAS and SKS performed statistical analysis and was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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