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Age structure, regeneration-gap of *Ziziphus spina-christi* populations and implications for its conservation

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Abstract

The study was conducted to determine the age structure, regeneration status and possible factors for regeneration-gap of Ziziphus population of the southwestern valleys of Saudi Arabia. The population age structure was determined through stem disc ring analysis of fallen trees and girth value measurements of live trees. The average number of rings and annual ring width of trees were determined based on analysis of 95 sampled tree discs and the number of rings correlated with their circumference values. The girth values of 1662 individual live trees from 75 plots were measured and their age class frequencies were used to determine the age structure and regeneration status of the populations. Possible factors contributing to regeneration-gaps of the populations were assessed in relation to human interferences and trends of three decade climate data from the nearest metereolgical station. Of the total individual trees measured, only <0.96% were seedlings and 2.3% were saplings and the remaining 96.8% were adults. Based on age frequency distributions, only 0.42% were less than five years old and about 0.9% were between 5-10 years old, while 98.7% were between 10–400 years old indicating that the populations exhibited an even age conditions with serious regeneration gaps. Of the tatal adults about 12% of them were in a die-back condition. The few seedlings and saplings recorded in the study were observed to grow only in areas where associated with other thorny shrubs that might have protected them from animal grazing. The age structure distribution of the populations indicates that the regeneration gaps may have started many years back. The major contributing factors for the regeneration-gaps of the populations were associated with overgrazing, soil erosion and climate changes. It is concluded that if the trends continue in the same manner, the populations will disappear sooner or later. Intervention measures like area closure, planting of seedlings and restoring cultural practices with the full participation of communities would facilitate rehablitating and conserving the remaining relict forest patches and the very unstable population of *Ziziphus* species in particular.

Key words: Conservation, regeneration-gap, age structure, *Ziziphus spina-christi,* seedlings, populations, die-back, girth value, overgrazing and tree ring analysis.

Introduciton

Ziziphus spina-christi grows in a wide range of habitats from northwest Africa into the eastern Mediterranean, the Arabian peninsula and western and tropical Asia [33, 39], and naturally occurs in sixteen African [30] and thirteen Asian countries [39]. It is one of the most drought and heat tolerant plant species growing at altitudes from 0 to 2000 m.a.s.l. [33]. The tree is widely used to produce a range of products: food, fodder, fuel, drink, timber, medicine and as a shade tree and to protect against soil erosion [33]. *Ziziphus spina-christi* is an important source of choice grade and expensive honey particularly in the Middle East [41]. The species occurs widely in several southwestern valleys of Saudi Arabia where the fruit, leaves and even the bark of the tree are extensively eaten by livestock (goat, sheep and camel), which may negatively affect the regeneration of the species.

Several studies have documented the plant communities, vegetation types, species diversity, relative abundance and distribution in relation to different altitudinal gradients and other ecological factors for the south and southwestern regions of the country [2, 3, 7, 11, 18, 25]. However, very few studies have focused on assessing land degradation, deteroriation of forest lands and the declining of quality and quantity of forest trees [11, 24]. The studies reported the presence of extensive human activities (livestock grazing, fuel woodcutting, temporary arid land cultivation and road construction) that put great pressure on the vegetation of the region and led to the deterioration and continuous decline of many tree species and forest habitats of valley. Besides direct human interference, environmental factors like an increase in temperature, reduction in soil moisture, and flash floods contribute to the decline of valley forests in the region and as a threat for the persistence of endangered plant species [16, 23, 24].

The presence of die-back and poor regeneration of trees and a widespread decline of *Juniperus procera* woodlands were observed in the region [17]. Moreover, Hall *et al.* [24] reported the continuous decline of the remaining patches of relict forest habitats and some tree species like (*Mimusops laurifolia)* are endangered with only very few old adult trees with little or no regeneration. Because of long-term environmental factors and human interference, about 100 plant species have been listed as endangered or of vulnerable status in Saudi Arabia [5, 31].

The presence of regeneration-gaps with few or no seedlings, saplings and young trees are becoming widespread threats at a global level for many tree species and plant communities which have been attributed to climate change [10]. When a plant community has an even-age population structure, a regeneration-gap can be severe. Indeed, the disappearance of *Acacia xanthophloea* woodland in Kenya as the result of the death of mature trees without prompt replacement with younger ones [44]; and, the prediction of the death of older Oak Savanna tree species in the USA with insufficient young trees to sustain the ecosystem have been reported [37]. Moreover, the absence of regeneration of species as result of human interference in eastern Himalayan forests [12] and poor natural regeneration of *Juniperus* woodland in the Arabian Peninsula [8, 21] have also been reported. The presence of regeneration-gaps as a result of overgrazing and excessive human utilization of *Boswellia papyrifera* populations in Sudan [1] and the long term decline and possible extinction of *Ziziphus celata* populations in Central Florida [19] have been also reported. These studies suggest that short and long term management goals are essential for the survival of endangered populations.

Regeneration conditions for a population of any species depend on adequate production and germination of seeds and the establishment of seedlings and saplings [36]. The growth stages: seedlings, saplings and young trees in plant communities are crucial for maintaining the population structure of any forest community [12]; the absence of any of these stages indicates a poor regeneration of tree species[38] and a general degradation of forest lands [17]. Assessing the age and size frequency distribution of a plant population indicates the demographic processes of plant populations and their regeneration status [26, 32]. Moreover, such studies are essential to understand the population dynamics, genetic diversity, population stability and also to understand the histrorical events as well as the future trajectory of a tree community [15].

Population structures and the regeneration status of different forest ecosystems and tree species have been studied [1, 9, 12, 14, 19, 37, 40] and have made recommendations to maintain forest communities and the conservation of vulnerable species in particular. However, factors contributing to regeneration-gaps and the disappearance of species could well vary in differing ecological contexts: climate changes (drought) [10], increased soil salinity [44], overgrazing and over exploitation by humans [1, 17, 37] and others.

Plants that grow under conditions of environmental stress like flooding or drought produce annual rings and phenological events like leaf flush or flowering may cause ring formation [15] both of which help in estimating the age of trees and the age structure of tree populations. To this end, stem disc analysis has been widely used to estimate the age of trees and to establish corrlations between the ages of trees and their diameters at breast height (DBH) and also to extrapolate the age and size relationship of populations [22]. Because they are easy, inexpensive and non-distructive measures, tree diameter and girth at breast height (GBH) classes have been widely used to assess population structure and regeneration in different forest communities [1, 12, 24, 27, 40].

Because of various environmental factors and human interference, several forest communities have been degraded and the natural regeneration of major tree species is believed to be threatened particularly in southwestern Saudi Arabia [17, 42]. However, concrete information on the extent and severity of forest degradation, population structure, age distribution and status of regenration gaps of different tree species are lacking, especially for *Ziziphus spina-christi,* populations. Such information is critical in understanding population dynamics and regeneration status which are necessary for appropriate interventions in conservation, rehabilitation and sustainable utilization of the species. In the present paper we report on the population structures and regeneration status of *Ziziphus spina-christi* in selected valleys based on stems disc analysis and tree girth (GBH) class frequencies. Moreover, an attempt was made to associate the major contributing factors for the regeneration-gaps of the species. Finally the consquences of regeneration-gaps of the species in the ecosystem and possible intervention measures are suggested.

Materials and Methods

The study area: The study areas were located in the Al-baha Region in southwestern Saudi Arabia (Fig. 1) in two locations: the first at about 40 km northeast of Baljurashi town (in the Majma, Berha and Wable valleys), (19°58ʺ52'-20°06ʺ41' N and 41°43ʺ52'-41°45ʺ18' E) and over an altitude range of 1200-1700 masl. The second site was to the southwest of Baljurashi town in the Alkhatani and Neera valleys (19°43ʺ18'-19°46ʺ21' N and 41°38ʺ52-41°40ʺ04' E) over an altitude range of 500 -1000 m.a.s.l. The total land area of the study sites was about 40 km². The nature of the vegetation in both locations are old forest with little diversity. The dominant plant communities in the Mejma, Berha and Wable valleys are: *Ziziphus spina-christi, Acacia etbiaca,* while in the Alkahatani and Neera valleys the dominant plant communities are: *Ziziphus spina-christi*, *Ziziphus spina-christi-Acacia johnwoodii*, *Acacia ehrenbergiana-Acacia tortilis-Anisotes trisulucus* and others. *Ziziphus spina-christi* was mostly observed growing in the valley bottoms and the dominant soil in most sites is alluvial which is deposited by floods from the hillsides. The climatic conditions of the area are generally dry and hot with a range in temperatures of 20-40°C and relative humidity of 16-50%. The mean annual rainfall is about 133.9 mm.

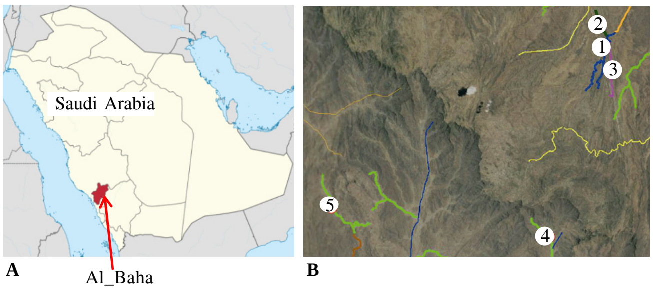

Figure 1. Map of the studied areas: A= Saudi Arabia, (Al-Baha region); B = specific studied valleys (1 = Majma, 2 = Berha, 3 = Wable, 4 = Alkhatani, 5 = Neera).

Methodology: The regeneration status of the *Ziziphus* tree populations was studied in the five valleys (wadis) namely: Majma, Wable, Berha, Alkahatani and Neera between 2012 -2013. Seventy-five stands of 1000 m² each were sampled. In each plot the presence of any new and old stump remnants (cut by humans) that might have interfered with the age distribution study of the populations were recorded. The study was based on girth value measurements and stem disc ring width analysis. The girths at breast height (1.37 m) of all individual *Ziziphus* trees (*N* = 1662) in the plots were measured and circumferences were assigned to different age categories: seedlings (composed of the individuals with >30 cm height but <10 cm girth); saplings (>10 cm to <30 cm girth at breast height) and adult trees (≥30 cm girth at breast height) [12, 27, 40]. The adult trees were further categorized into 12 classes based on their girth values. The frequencies and percentages of each category were calculated from the total population measured. Likewise, the conditions of each tree were recorded as: living (healthy), die-back (starting to dry from the tips and branches) and dead (standing, fallen and completely dry).

The ages of the trees in the population were estimated based on the analysis of the average annual ring widths. To minimize the effects of site variations, equal proportions of tree disc samples were taken from different sites and slopes. A total of 95 tree discs of different girth values at breast height ranging from 45-180 cm were taken from recently fallen trees using a chain saw. The discs were sanded with progressively finer sandpaper using a motorized grinder and their annual rings were determined following the methods of Garrison *et al.* [22]. The tree rings were counted by three individuals with the help of a hand lens and average ring counts were taken. The mean annual ring widths of the sampled trees were obtained by dividing the tree radius (inside the bark) by the total number of the annual rings. Because tree age is positively correlated with tree diameter or circumference [15], the average annual ring width (mean annual increment) at breast height (1.37 m) data was used to estimate the age of the rest of trees in the population based on their circumference values.

The presence of strong significant correlations between number of rings and girth values were checked. Then the ages of the live trees were calculated from the circumference/radius of the trees at GBH divided by the average annual ring width of the sampled trees in the area. During calculating the radius of the trees, the average bark thickness was excluded so that:

$$\text{Age of a tree} = \frac{\text{Circumference}/2^{\pi}}{\text{Average annual ring width}} \qquad (1)$$

To evaluate possible factors contributing to the regenerations-gaps of the populations, conditions such as soil erosion and livestock grazing intensity were assessed. In addition the presence of disease symptoms, parasites and insect infestations were noted. Moreover, the general trends of climate (temperature, rainfall and humidity) of the area were examined by taking 28 years available climate data from the nearest meteorological station. Finally, to analyze the data, simple descriptive analyses and correlation were employed using SPSS version 16 software.

Results

The study revealed that the *Zizphus* populations of the study areas were at an even age state and dominated by adult trees. Based on girth measurement values, only 16 or about <0.96% were seedlings and 2.3% were saplings and the remaining were adult trees (Fig. 2).

When we further classified the adult trees into different girth categories (Fig. 3), starting from the 121-150 girth value category to recent seedlings, the age distribution trend shows that the frequency of trees with smaller girth values (relatively young trees) was gradually declining compared to trees with high girth values (older trees) in each consecutive category. This may indicate that the occurrence of regeneration-gaps began well in the past. On other hand, for the girth values above the 151 classes (Fig. 3), the trend was the reverse and the proportion of trees with high girth values were relativelly fewer than those with low girth values for consecutive categories so that in past the proportion of young trees was greater than that of older trees.

According to the ring disc analysis, the caculated average width of the annual rings was 1.9 mm and the correlation between the number of annual rings and girth values was highly significant ($N=95$, $r = 0.920$, $F_{1,93}$, $P = 0.001$, Fig. 4). However, for many years the annual rainfall was less than 100 mm and in some years as little as 18.4 mm/annum and in these drought conditions the trees might

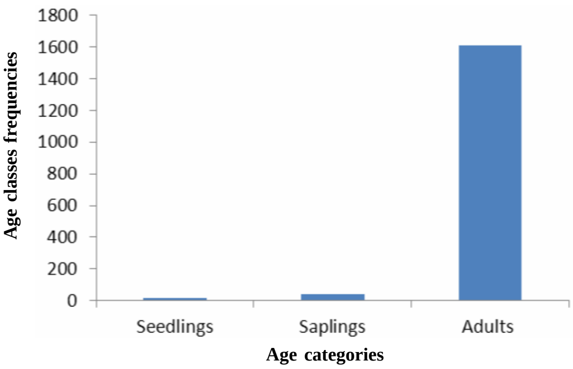

Figure 2. Age distribution of sampled trees.

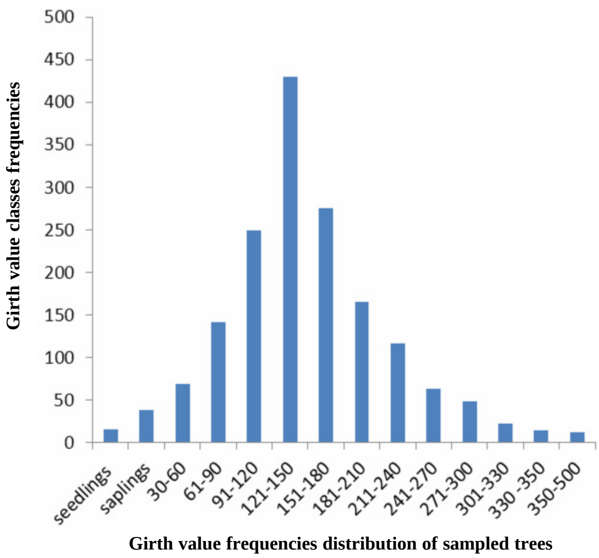

Figure 3. Girth value frequencies distribution of sampled trees.

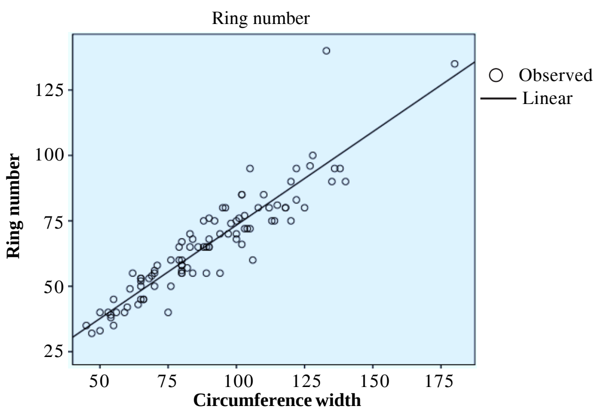

Figure 4. Correlation between tree ring numbers and circumference values.

not have attained significant vegetative growth and annul rings every year. So in this study the estimated ages of the trees could be less than the actual ages of the trees. Applying our estimation methodology for the annual ring width value to age values, the ages of individuals in the population varied from three to more than 400 years.

From the total 1662 measured trees only 0.42% were less than five years old and about 0.9% of them were between 5-10 years old, while 98.7% of the individuals in the measured population were between 10-400 years old, indicating the presence of a serious regeneration gap in the populations.

Considering frequency distributions of the age categories of trees (Fig. 5) from the 111-130 years age category to the present, the frequencies of younger trees (seedlings categories) were grauadlly declining in the past to the present for every consecutive category indicating the occurrence of regeneration-gaps for many years in the past. On other hand, for the age categories (111-130 years) onward (Fig. 5), the frequency of younger trees was greater than older ones for every consecutive category which indicates normal trends of regeneration.

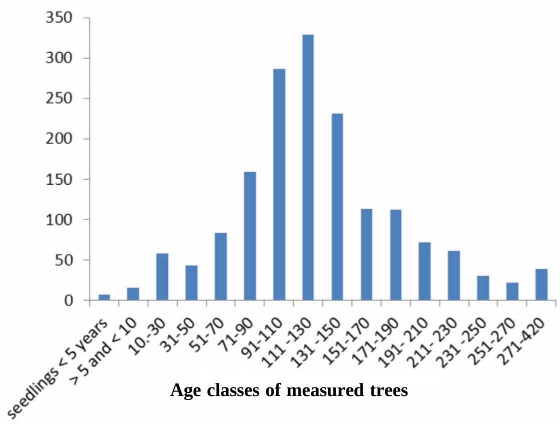

Figure 5. Age categories frequencies of measured trees.

Surprisingly, of the total 54 seedlings and saplings recorded in this study, 47 (87%) of them were found only in one very limited area (less than 0.5 km^2) at Alkahatanin valley growing in association with thorny shrubs (*Acacia ehrenbergiana* and *Acacia tortilis).* The current study revealed that not only were the adult trees dominant, but a significant porportion (12%) of the measured adult trees were either in a state of die-back in which the branches were totally or partially dried or were dead (fallen or stand) (Fig. 6).

Many adult trees were infested with either parasitic plants (*Phargmanthera austroarabica*) or climbers (*Cocculus pendulus*) in several valleys. Although *Cocculus pendulus* grows independently, they use the trees as supports and then their branches spread completely over the entire host plant preventing it access to sunlight for photosyntesis. Eventually such trees die as result of strangling by the climber species (Fig. 7). The parasitic *Cocculus pendulus* affects *Ziziphus* tree by absorbing material from the phloem of the host.

In many valleys of the southwest regions soil erosion was observed as one of the greatest threats to the species. In most cases the top soil was washed away leaving only rocks and at some sites so that about 50-100 cm top soil was removed by flood runoff (Fig. 8). In severe cases it was observed that the floods

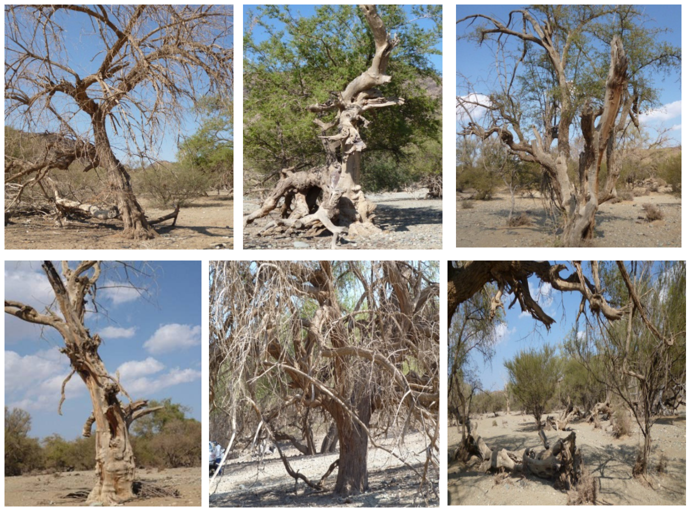

Figure 6. Die-back conditions of the *Ziziphus* trees in populations.

Figure 7. Ziziphus trees strangled to die by climber (*Cocculus pendulus).*

uprooted all the trees in the valley.

Large herds of sheep, goats and camels were observed grazing freely in the study areas. Because the rainfall is very low and of short duration, the growth of annual grasses and herbs is very limited. As a result, the herds are dependent on the foliage, pods, fruits and seeds of perrenial trees and shrubs. The herds were observed to consume all plant material: seeds, seedlings and even the bark of live trees and shrubs (Fig. 9).

Discussion

In this study since 98.7% of the *Ziziphus* trees sampled were in the adult stage so that the populations suffered serious regeneration-gaps. In a normal population, good regeneration requires that: seedlings>saplings>adults; fair regeneration if the seedlings>or≥saplings≥adults; while poor regeneration occurs if the species survives only in the sapling stage, and there are no seedlings [12, 40]. If a species is present only in the adult form it is considered as not regenerating [27] which agrees with the current study results. Moreover, as shown in the age structure distribution of the tree populations (Fig. 5) for the past 130 years, there were fewer younger trees than older ones. This probably indicates that the problem of regeneration gaps in the populations might have begun many years back (assuming that cutting of trees by humans

Figure 8. The effect of erosion and floods on ziziphus and other tree species.

Figure 9. Over grazing and its effect.

was either absent or reduced). Besides, the populations reported here, in many valleys of south-west Saudi Arabia, particularly in the Albaha and Asir regions, it is very rare to observe naturally growing young *Ziziphus* trees. The general occurence of forest degradation and natural poor regeneration of trees have been previously noted [17]. Most of the adult trees were not only very old, but also a significant proportion of them were in die-back state which indicates serious degradation and very poor regenration conditions for the populations in the area.

Factors contributing to regeneration-gaps of *Ziziphus* populations could be attributed to many interelated factors including both human interference and enviromental stresses. Human interference consists of uncontroled and unbalanced overgrazing by goats, sheep and, camels which is very intense. Most of the sheep and goat herds were kept and managed by semi-commericial owners and were above the carrying capacity and available forage in the area. *Ziziphus* has the potential to produce enormous amounts of viable seeds (pers. obs.) and after rain showers many seedlings with 2-4 leaves were common around adult trees but not a single seedling escaped animal grazing. The severity of overgrazing has gone to the extent of consuming the actual bark of adult *Ziziphus* trees (Fig. 9) which eventually kills the trees. From this assessment it would be possible to generalize that overgrazing could be one of the major contributing factors for the regeneration gap of the species. A total absence of regeneration of *Acacia* species as result of severe overgrazing has also been reported for the region [17].

For many years in the past, rainfall was relatively low and has actually been declining in the area [6]. In some years the drought was serious enough to limit the growth of annual herbs and grasses that serve as source of animal forage which has led animals to depend on trees and perrenial shrubs (foliage, seeds and seedlings) as sources of forage and this indirectly put pressures on tree and shrubs. Heavy grazing/browsing by camels/goats has been identified as a major factor for the rapid loss of biodiversity in general and floral diversity in particular [42].

Only a very few young *Ziziphus* trees were observed in the area where they grow in association with the thorny shrubs (*Acacia ehernbergian* and *Acacia tortilis*). The shrubs might have protected the *Ziziphus* seedlings until they became wel-established and attained heights sufficient to escape from grazing and browzing animals. The positive association and co-existence of different species may give a good clue that approaches to rehablitation should focus on establishing mixed forests with reasonable species diversity. In restoring programs of degraded ecosystems, the importance of focusing on diverse species has been reported [28, 35].

Because most populations of *Ziziphus* are found at the bottom of the valleys which are surrounded by bare rock mountains, hills and escarpments, the valleys are very vulnerable to precipitation runoff that can easily wash away seeds and seedlings. In addition to washing away seeds and seedlings, floods and soil erosion are important contributing factors for the deaths of adult trees by exposing their roots and even uprooting them. This has been more aggravated by the increasing trend of abandoning of terraces and farm lands in the region which is associated with the discovery of oil in the country that has widened opportunities for livelihood options more lucrative than farming. The abandoned agricultural terraces led to gradual damage and destruction by runoff, which in turn has resulted in serous soil erosion and forest degradation [34] particularly at lower basins of the valleys.

Moreover, in many parts of the valleys, the top soils have been depleted by erosion leaving bed and gravel rocks and the loss of soil components such as organic matter, profile depth and moisture holding capacity, all of which probably contributed to the absence of regeneration of the *Ziziphus* population. However in some valley bottoms, even if the soil layer is deep enough to support the growth of seedlings and they receive precipitation runoff from numerous flood courses, but no seedlings were observed. This could well indicate that the major factors for regeneraton gaps in the *Ziziphus* populatons could be due to overgrazing.

Other possible contributing factors for the regeneration-gaps could be climate change such as increasing temperatures, declining annual rainfall and relative humidity. Similarly, a decreasing trend of precipitation by 47.8 mm and an increase in mean ambient air temperature by 0.60°C per decade were reported for Saudi Arabia [6]. These changes might have contributed to declining soil moisture, soil organic matter and rising temperatures, and an increase in aridity of the area which undoubtedly directly and indirectly contributed to regeneration-gaps of the *Ziziphus* population.

In the past, the forests were protected by the local communities through tradition and customs called *Al Hema*, a system whereby every tribe or a clan or family used to have its own forest and no one was allowed to enter it without permission. However, in more recent times, an open grazing system was established and this has led to the lack of ownership and subsequent degradation of the natural forests. Moreover, in the past, farmers in the area had good agroforestry practices that assisted the regeneration of trees. Adult trees were pruned and the branches used as fences around the trees thereby protecting the young *Ziziphus* seedlings against grazing damage (Mr. Abdla, personal communication). The change in cultural agroforestry practices and abandoning of farmlands and terraces for better opportunities has greatly impacted the degradation of *Ziziphus* populations and contributed to regeneration-gaps. Changes in agricultural practices have been extensively reported to lead to the degradation of natural vegetation and the depletion of biodiversity which affects ecosystems in general [4, 17, 29, 43]. Plant parasites also contribute to the death of many adult trees and suppresses the establishment of seedlings around adult trees this is in accordance which agrees with findings of El-Juhany [17], who reported that plant parasites are an imporant contributing factor to forest degradation.

Conclusions

It has been demonstrated in this study that *Ziziphus* populations in the areas studied are experiencing serious regeneration-gaps for a number of interelated factors. If this trend continues, existing adult trees will die out without sufficient young trees having been established to succeed them. Because the *Ziziphus* tree populations are very important in soil and water conservation, agroforestry, animal forage and honey production, the disappearance of the populations will lead to both environmental and economic crises in the region. For the sustainable use of the trees, it is imperative that suitable management practices be implemented to restore normal population structure. Rehabilitation of the populations can be attained through area closure and, restricting human and animal interference in the degraded areas thereby increasing the chances for the seedlings to naturally establish and replace the aged trees. Moreover, raising and planting seedlings in degraded areas has to be implemented. Traditional practices like pruning and leaving the pruned branches around the adult trees to protect the young seedlings and eradicating parasitic climbers will also contribute to the rehabilitation of the population.

The integration of beekeeping with conservation and rehabilitation of natural resources would be an important incentive to mobilize communities to participate in rehabilitation programs for both economic and environmental reasons. Further research on assessing the possibility and potential of natural regeneration of the population, through area closure or planting of seedlings in degraded places, will be important to fully understand the natural regeneration of the populations and factors contributing for regeneration-gaps.

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