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# ASSESSMENT OF POPULATION STRUCTURE AND REGENERATION STATUS OF DIFFERENT COMMUNITIES OF *ACACIA TORTILIS* IN MAKKAH REGION, SAUDI ARABIA

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**Abstract**

Assessment of population structure provides necessary information about the status and disturbance of the forest key supporting indicator for forest management and conservation interventions. In this study, current *Acacia tortilis* community status in Makkah Region was assessed in term of population structure and regeneration pattern. To carry out vegetation survey we selected three main areas (Al-Qunfudah, Al-Leith and East Makkah) in Makkah Region. Further, within each area the data was collected from three different sites. Population structure was analyzed and classified according to tree height and crown area size class distribution. In order to determine the potential effects of other factors in the population we evaluated status of new regeneration, stand density, tree diameter, height, crown area, canopy cover percentage, associated trees and shrubs in addition to fluctuations in Emberger Aridity Index. The results of individual trees frequency distribution based on height size classes produced a bell-shaped curve in all the three populations with the highest density in 2-4 meters class. In regards to crown area the three populations revealed a reverse J-shaped pattern with most of the individuals falling in 0–20 $m^2$ class. In Al-Leith the combination of poor natural regeneration, low stand density, higher proportion of big trees and invading of exotic *Prosopis juliflora* indicating deterioration in this community. While in East Makkah the higher density of smaller trees and lowest canopy cover percentage may reflect the presence of selective cutting of big trees. Despite the good natural regeneration, nevertheless, the arid climate and very high year to year variation in dryness recorded as well as land use change may highlight the vulnerability of this species in Makkah region.

**Keywords:** Population structure, Regeneration, Stand density, Size-class distribution.

## Introduction

*Acacia tortilis* known as *Umbrella Thorn* (common name) and *Samur* (local name) is arid leguminous phreatophyte tree (Anon., 2009). It has many uses and values (Jamal *et al.*, 2013). It represents one of the most important components of vegetation communities in the South-Western Saudi Arabia. However, recently many deteriorating biotic and abiotic factors threatening the tree in its natural range. For instance, browsing affected population structure of the species (Noumi *et al.*, 2010), whereas heavy grazing (Hosny *et al.*, 2018) or bruchid infestation (Elfeel & Abohassan, 2016) influencing natural regeneration in the field.

*A. tortilis* is native to arid and semi-arid areas of Tropical Africa, North Africa, and the Middle East (Arabian Peninsula and Palestine) (Heuze & Tran, 2015). It is found between 15 and 30°N and between high 0-1000 m altitude above sea level (Orwa *et al.*, 2009). In Saudi Arabia it is found in the western slopes between 50 and 1000 meters above sea level. However, now days in these slopes it is restricted in form of batches because of repeated cutting for firewood and wood for the manufacture of traditional agricultural tools (Anon., 2007). The tree naturally distributed from Al Madinah to Al Baha and Aseer regions (Al-Mefarrej, 2012). It represents one of the most important components of the vegetation in the area of Tihama, where it is occurs in the forms of pure or mixed stands forests. In these areas it is more common in gravel sites extending from west coast to the east coast excluding deep sands areas and high mountains (Anon., 2007). It grows well in semi-flat lands and inland hills, particularly in places where soil is moved with torrents on the hills and sloppy sites (Abo-Hassan *et al.*, 2005).

Population structure provides necessary information about the disturbance of species and the impact of biotic and abiotic factors. This kind of information is crucial for any future rehabilitation and conservation interventions (Ma *et al.*, 2019) or management plans (Su *et al*., 2021). Recently, species composition, structure and dynamics are becoming an important tool to describe the level of adaptation to the environment and providing beneficial information of high ecological significance (Borogayary *et al.*, 2018). Therefore, assessment of population structure is useful and functional in forest management practices (Sahu *et al.*, 2012). Ecologists and environmentalists widely investigated population structure to assess the effects of environmental degradation on regeneration status, samplings survival and population trend (Ma *et al.*, 2019). Also, size and age difference of the species can provide important information on their regeneration capabilities (Shi *et al*., 2018).

This study aimed to assess the status of *Acacia tortilis* populations in Makkah region in term of regeneration pattern, population trend and associated trees and shrubs.

## Materials and Methods

**Description of the study area:** Makkah Region is located in Hejaz area and lying in the Western part of Saudi Arabia extending up to the eastern coastline of the red sea. It represents the meeting point of Tihama with the Sarawat Mountains (Fig. 1). Most of the land of Makkah Region is fragile system composed of wadis between the mountainous (Abdel-Khalik *et al.*, 2013). The maximum average temperature in the Makkah region around 35.9°C in July, while the minimum value of monthly average temperature about 23.9°C in January (Abdou, 2014). The rate of rainfall ranges between 50-80 mm / year (Ashrae, 2005).

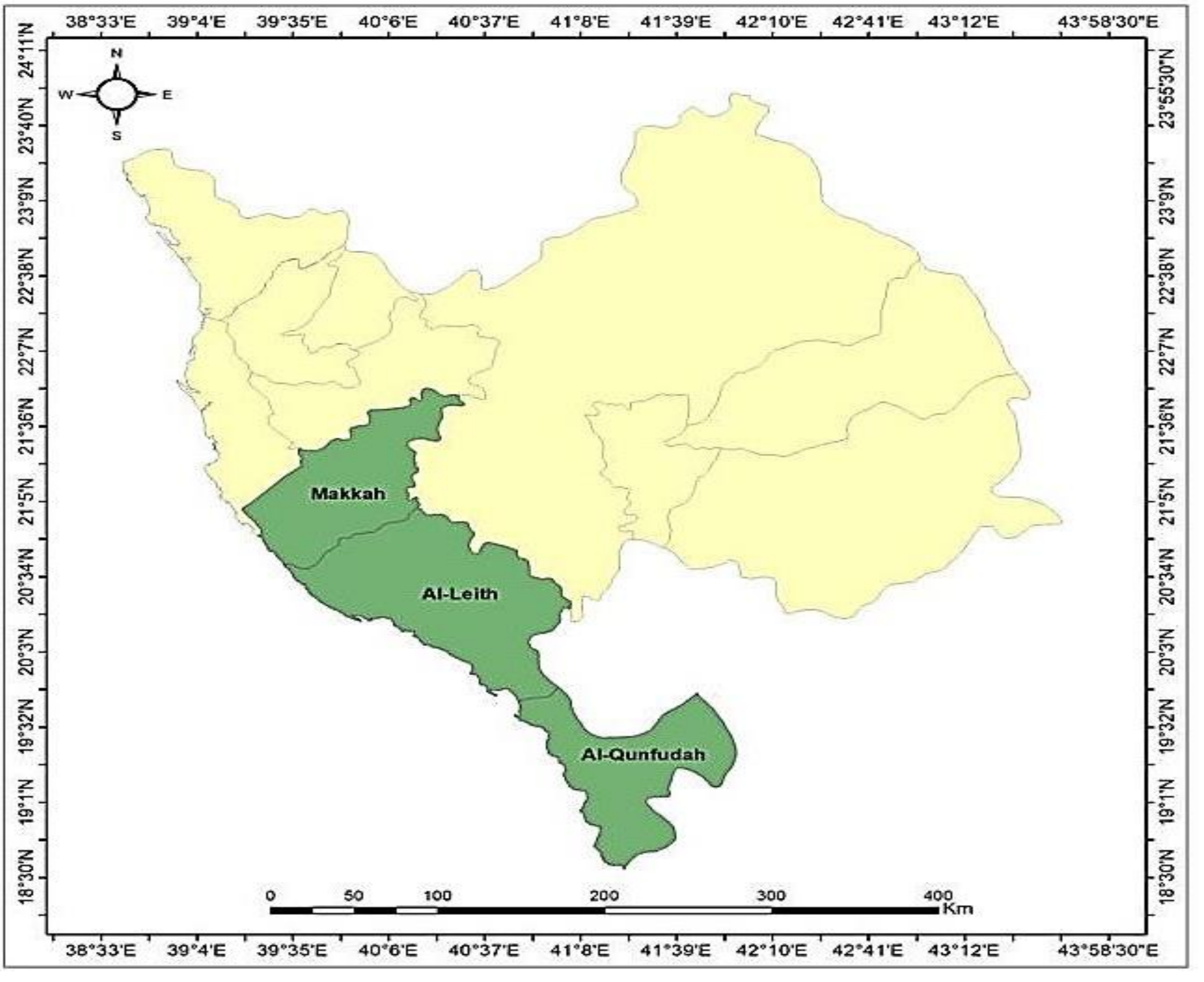


Fig. 1. Map of Saudi Arabia with Makkah Region (green color). Source: (Saudi Geological Survey).

**Table 1. The coordinates of the different areas and site within areas selected in Makkah Region, Kingdom of Saudi Arabia for this study.**

| Area | Stratum | Altitude (m) | Latitude (N) | Longitude (E) |
|---|---|---|---|---|
| Al-Qunfudah | A | 15 | 18$^{o}$ 53.876' | 041$^{o}$ 16.095' |
| | B | 68 | 19$^{o}$ 14.271' | 041$^{o}$ 17.453' |
| | C | 90 | 19$^{o}$ 14.798' | 041$^{o}$ 19.636' |
| Al-Leith | A | 63 | 20$^{o}$ 15.943' | 040$^{o}$ 25.019' |
| | B | 104 | 20$^{o}$ 20.384' | 040$^{o}$ 26.818' |
| | C | 200 | 20$^{o}$ 19.411' | 040$^{o}$ 33.290' |
| East Makkah | A | 480 | 21$^{o}$ 30.717' | 040$^{o}$ 04.068' |
| | B | 562 | 21$^{o}$ 30.069' | 040$^{o}$ 07.852' |
| | C | 585 | 21$^{o}$ 30.826' | 040$^{o}$ 07.922' |

In Makkah *A. tortilis* tree is spreading in the Tihama sector and reaching up to high altitudinal areas of East Makkah. This tree grow in different locations, where it can be found between 15-90 meters above sea level in Al-Qunfudah to 480 - 585 meters above sea level in East Makkah area (Table 1).

**Vegetation survey:** In order to determine the areas of the natural distribution of *A. tortilis* in Makkah region and the locations of the different populations a reconnaissance survey was conducted in September, 2018. The information obtained from this survey was used for the selection of three areas representing the natural distribution of the species in the region: these are East Makkah (northern part of the region), Al-Leith (central part) and Al-Qunfudah (southern part) (Table 1). Within each area, three sites differing in topography were selected for data collection. Then to measure the population status and regeneration patterns a vegetation survey was carried out during the period 2018/2019. In this survey within each site among area a set of random square sample plots (50 X 50 meters) were delineated and their co-ordinates were recorded

(Altitude, latitude and longitude) using Garmin GPSMAP 62s. During the survey, the total numbers of *Samur* trees encountered in each sample plot were counted and their respective height, diameter and crown diameter were measured. Crown diameter was estimated by measuring diameter across the widest length of the canopy (crown length CL), then turning $90^o$ and measuring diameter perpendicular to CL (crown width CW). Average crown diameter was calculated as ((CL+CW)/2) (Chatting *et al.*, 2020). In addition, in each sample plot total number of other associated trees and shrubs were recorded. For the assessment of natural regeneration smaller sample plots (10 X 10 m) within each of the big samples plots were laid and the number of the new regeneration were counted.

**Data analysis:** For the assessment of the population structure for the different areas, tree height and crown area data were arranged into size classes. Then a size class distribution frequency curves were constructed (Gadow *et al*., 2011). While stand density was estimated as number of trees per hectare. To determine the regeneration status of these populations regeneration abundance (number per hectare) were calculated (Nautiyal *et al*., 2015. Also, the association of other tree and shrubs with *tortilis* was analyzed. In addition to that, average tree height, diameter and crown area, plus canopy cover percent. Canopy over (percent of canopy cover over land area) was calculated as sum of the crown areas of all *Samur* trees encountered in the sample plot divided by the area of the sample plot and then converted into hectare.

**Climate analysis:** The climatic data of the study area covering a period from 1998 to 2018 was obtained from the Meteorological Station in Makkah Region. These data were used to calculate Emberger Aridity Index (IE), for the different years to determine the degree of dryness of the climate and year to year variation in this dryness. This was done to explain their potential effects on population status and structure. IE was calculated by the following formula; IE = (100*P/M2 – m2 (Attorre *et al.*, 2007). Where P is the annual average rainfall (mm), M is the average temperature of the hottest month (°C) and m is the average temperature of the coldest month (°C).

The value of aridity index was used for the classification of the climate in the study area according to the following scale: IE > 90 Humid; IE 50 – 90 Subhumid; IE 30–50 Semiarid; IE<30 Arid (Emberger, 1932).

## Results

**General:** The results of the field survey showed that *A. tortilis* trees in Makkah Region grow and spread in low altitudinal areas in Tihama sector and extending up to relatively higher areas in East Makkah (Table 1). Moreover, within these areas it grows in different locations with different topography. The altitude ranges between 15-90 meters above sea level in Al-Qunfudah area to elevation of 63-200 meters above sea level in Al-Leith area (both are located in the Tihama sector). While in East Makkah it is spread between 480 - 585 meters above sea level.

**Population structure:** The results for population structure based on height and crown area size class distribution were represented in Figs. (2 and 3, respectively). The frequency distribution of the individuals based on tree height size classes yielded more or less normal distribution pattern giving a bell-shaped curve in all the three areas (Al-Qunfudah, Al-Leith and East Makkah). Most of the individuals in the populations of the three areas were categorized within 2-4m height class accounting near to 68% of the individuals in Al-Qunfudah and more than 50% in East Makkah and less than 50% in Al-Leith. However, in Al-Leith there were some trees found in 6–8m height size class (more than 15% of the individuals) and in East Makkah populations, some individual trees were represented in 0–2 meter class (more than 20% of the individuals) (Fig. 2a, b and c). In regard to crown area size classes distribution all the three areas showed a reverse J-shaped curves. The highest density was recorded in 0–20 $m^2$ class and decreased with increasing crown area (Fig. 3a, b and c) accounting close to 50% of the individuals in Al-Qunfudah and Al-Leith and about 70% in East Makkah. This was resulted in sharply right skewed distribution curves in East Makkah populations, reflecting higher density of smaller individuals. While in relation to stand density the highest density was recorded in East Makkah, followed by Al-Qunfudah and the lowest was in Al-Leith (Fig. 4). In regards to the difference between the sites (populations) among the area the highest stand density in both Al-Qunfudah and Al-Leith was obtained in site “C”, where in East Makkah the highest density was found in site “B” (this site have an overall highest density of about 77 trees/ha) (Fig. 4).

**Regeneration status:** For the new natural regeneration, generally, Al-Leith populations obtained a lowest number of new regeneration/ha, while Al-Qunfudah and East Makkah obtained close results. The highest number of regenerated seedlings was recorded in site “B” in Al-Qunfudah (1211 seedling/ha), followed by site “B” in East Makkah (1180 seedlings/ha). While the lowest regeneration density was recorded in site “B” in Al-Leith with only 257 new regenerations per ha (Fig. 5).

***A. tortilis* growth characteristics**: Statistical analysis results indicated that there was significant differences in all tree growth characteristics between different areas (Table 2). The highest mean height, diameter and crown area of *A. tortilis* trees were recorded in Al-Leith area, accounting for 11.64 cm, 4.77 m and 28.81 m² respectively (Table 2). Whereas the lowest mean height, diameter and crown area of trees recorded in East Makkah area, ranging from around 7.43 cm, 3.22 m and 18.14 m² respectively.

The results also, revealed significant differences between the sites within each of the areas studied. In all the three areas the growth characteristics (height, diameter and crown area) were higher in Site “A”, where the values were lower in site “C” (Table 2). It is clear from the results of this study that the highest canopy cover percent which is equal to 11.99% was recorded in Al-Qunfudah area whereas the lowest was obtained in East Makkah area (about 10.08%) (Table 2).

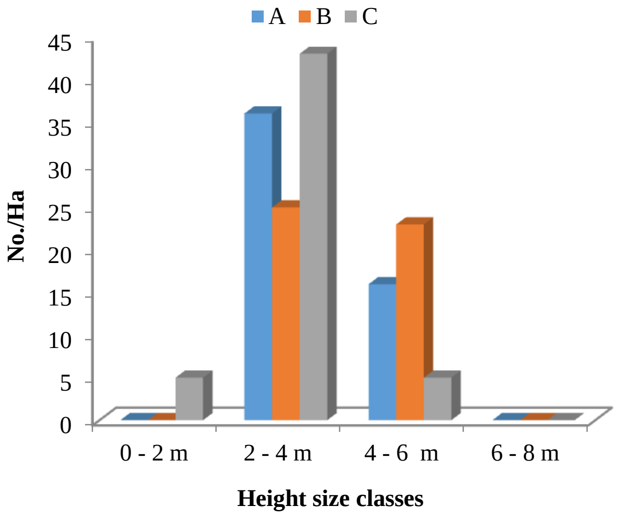


Fig. 2a. Frequency distribution of *Acacia tortilis* individuals in Al-Qunfudah populations according to height size classes.

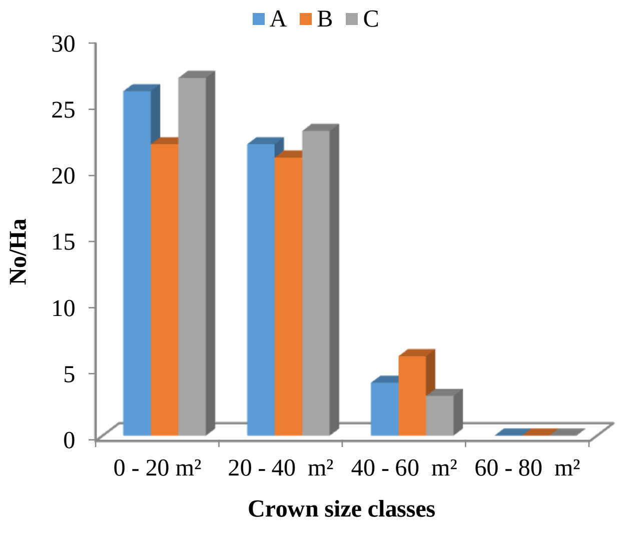


Fig. 3a. Frequency distribution of *Acacia tortilis* individuals in Al-Qundufudah populations according to crown area size classes.

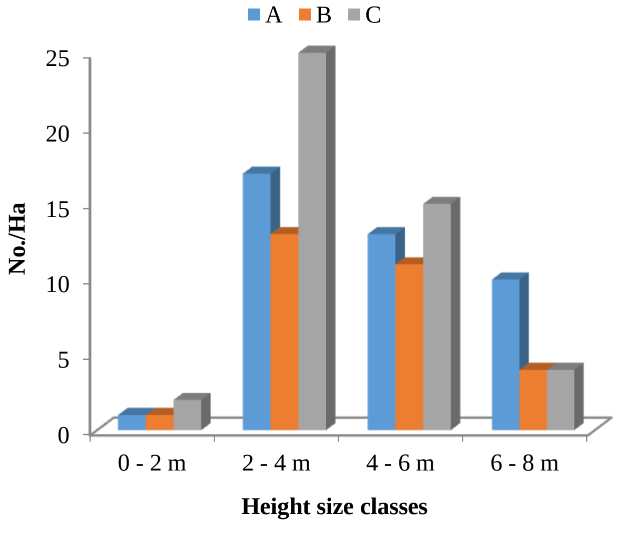


Fig 2b. Frequency distribution of *Acacia tortilis* individuals in Al-Leith populations according to height size classes.

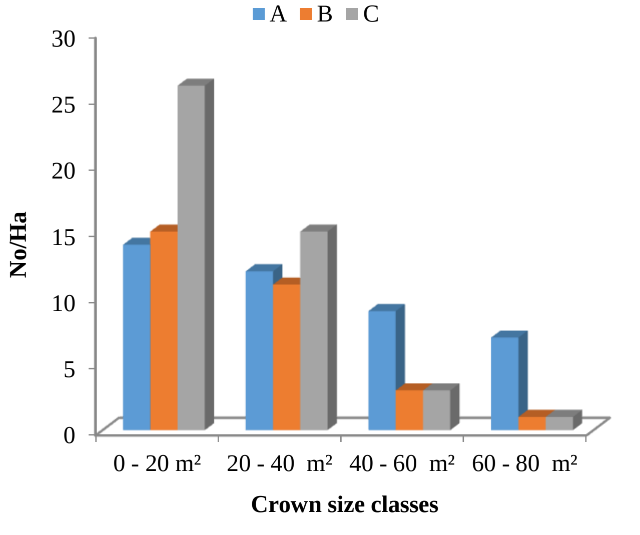


Fig. 3b. Frequency distribution of *Acacia tortilis* individuals in Al-Leith populations according to crown area size classes.

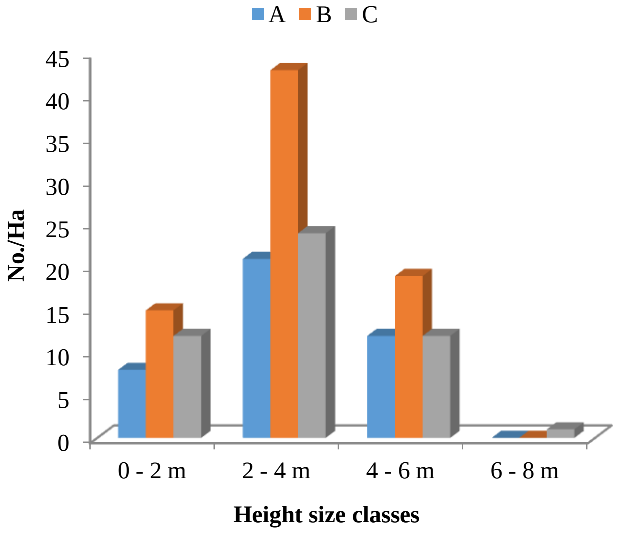


Fig. 2c. Frequency distribution of *Acacia tortilis* individuals in East Makkah populations according to height size classes.

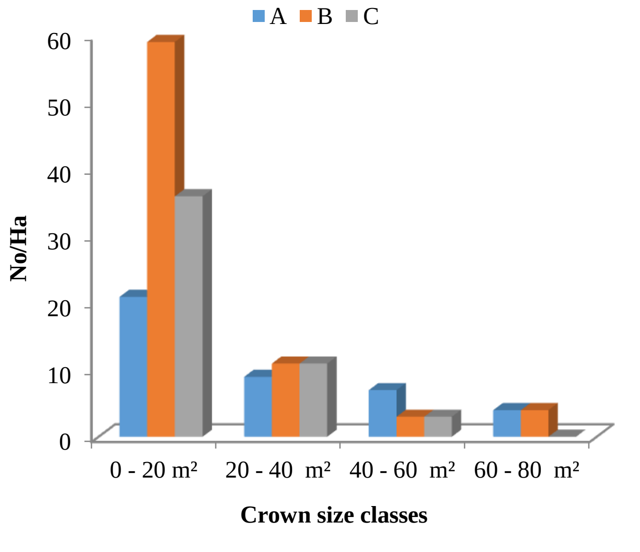


Fig. 3c. Frequency distribution of *Acacia tortilis* individuals in East Makkah populations according to crown area size classes.

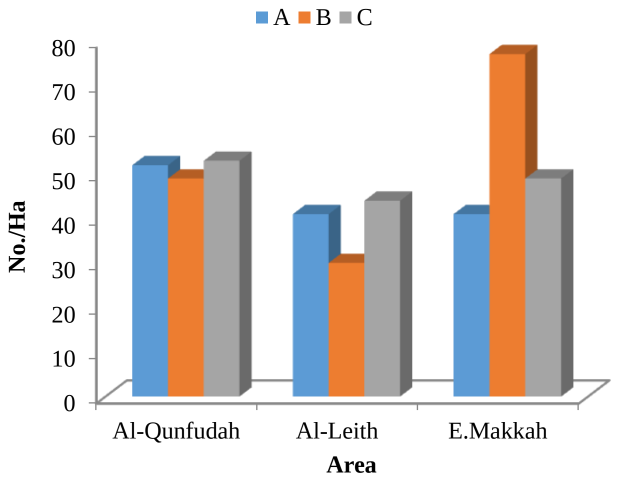


Fig. 4. Stand density (number of trees per hectare) of *Acacia tortilis* in different areas and sites (populations) within areas in Makkah Region.

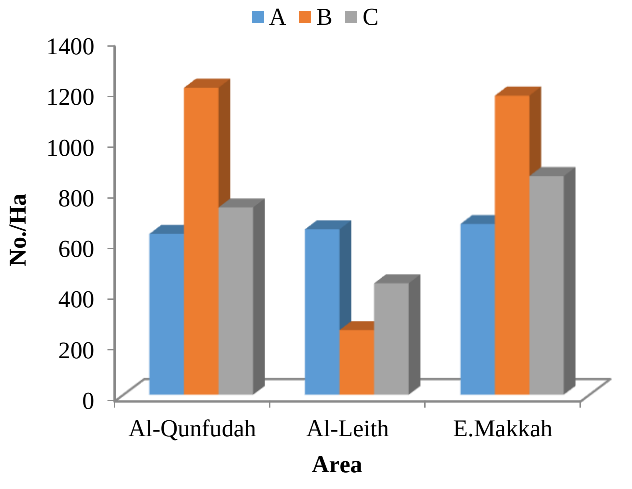


Fig. 5. Regeneration abundance (number of new regenerations/ hectare) in different areas and sites of *Acacia tortilis* in Makkah Region.

**Table 2. Mean diameter, height, crown area and canopy cover (%) for *A. tortilis* trees in different areas and sites within area in Makkah Region, Saudi Arabia.**

| Area | Sites | Diameter (cm) | Height (m) | Crown area ($m^3$) | Canopy cover % |
|---|---|---|---|---|---|
| Al-Qunfudah | A | 12.18 [a] | 3.97 [a] | 30.82[a] | 14 |
| | B | 11.56 [a] | 3.60 [b] | 20.00 [b] | 10.4 |
| | C | 8.269 [b] | 3.042 [c] | 20.20 [b] | 10.8 |
| | **Area mean** | **10.61** | **3.52** | **23.46** | **11.99** |
| Al-Leith | A | 13.156 [a] | 6.172 [a] | 44.55 [a] | 18.4 |
| | B | 13.153 [a] | 4.512 [b] | 22.804 [b] | 6.7 |
| | C | 9.273 [b] | 3.66 [c] | 18.351 [c] | 8.3 |
| | **Area mean** | **11.64** | **4.77** | **28.81** | **11.14** |
| East Makkah | A | 8.794[a] | 3.32[a] | 25.86 [a] | 10.7 |
| | B | 7.029 [b] | 3.283[a] | 16.128 [b] | 12.3 |
| | C | 6.917 [b] | 3.127[a] | 14.763 [b] | 7.3 |
| | **Area mean** | **7.43** | **3.22** | **18.14** | **10.08** |

* = Means followed by different letters are significantly different according Duncan's Multiple Range Test at $p \leq 0.05$

**Associated trees and shrubs:** The results of the association analysis showed that *Acacia ehrenbergiana* was associated with *A. tortilis* in all the areas, with the highest joint occurrence percentage of 88.9% which was recorded in East Makkah. In another hand *Salvadora persica* was associated with *Samur* only in Al-Qunfudah area, while *Prosopis juliflora* was only found in Al-Leith and *Rhazya stricta* was associated with *Samur* in East Makkah (Table 3).

**Climate analysis:** The results obtained by the analysis of Emberger Aridity Index (IE) classified Makkah region as dry land area, as it recorded less than 30 in all years (Fig. 6). Moreover, the results obtained showed year to year variation based on their IE values. Year 1990 was recorded as drier year with IE of 2.4, followed by years 2004 and 2014 with IE of 4.2 and 5.6, respectively. While year 1992 was less dry year with 29.4 IE value, followed by year 1996 (28.9 IE) and 2016 (26.0 IE).

**Table 3. Association of other trees and shrubs with *Acacia tortilis* in the study area (calculated as percent of plots with joint occurrence of other species with *Samur* out of total sample plots surveyed).**

| Association | Species | Percentage of plots with joint occurrence |
|---|---|---|
| Al-Qunfudah | *Acacia ehrenbergiana* | 44.4 |
| | *Salvadora persica* | 22.2 |
| Al-Leith | *Acacia ehrenbergiana* | 44.4 |
| | *Prosopis juliflora* | 66.7 |
| East Makkah | *Acacia ehrenbergiana* | 88.9 |
| | *Rhazya stricta* | 33.3 |

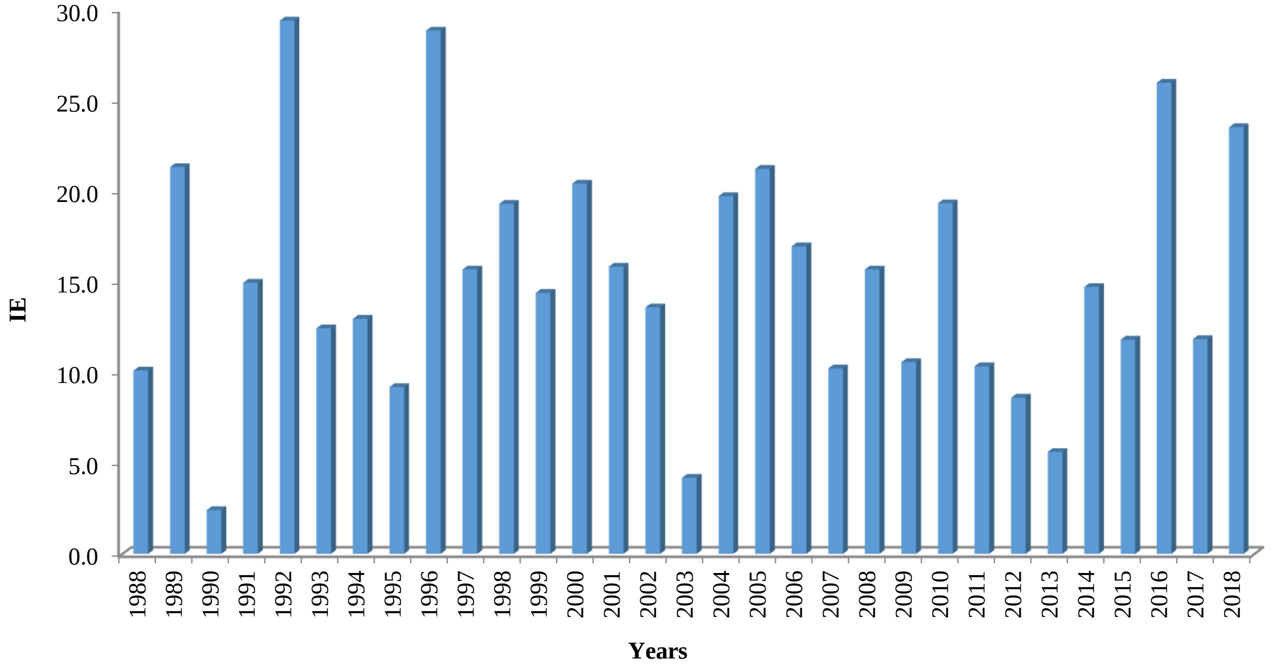


Fig. 6. Fluctuations in Emberger Aridity Index (IE) values for 31 years (period from 1988 to 2018) in Makkah Region. IE range from as low as 2.4 to as high as 29.0.

## Discussion

In general, the highest stand density, which was recorded in East Makkah and Al-Qunfudah indicating that these areas are in better condition compared to Al-Leith. This was not only because of higher value of stand density, but also abundant new natural regeneration which was reported in these two areas. While the forest stands in Al-Leith composed mainly of big trees with higher diameter, height and crown area associated with poor natural regeneration and low proportion of smaller trees, indicating poor regeneration pattern (Li *et al*., 2020). Whereas, the higher proportion of smaller trees recorded in East Makkah with the highest stand density, but the lowest canopy cover percentage means that most of the trees are of small sizes, that may reflect presence of selective cutting of big trees. This is further supported by our personnel communications with the people in charge of forest in Makkah who reported that there is very extensive cutting of *Samur* trees in these areas for firewood production. However, in the three areas the combined effects of hyper arid climate and the very high year-to-year fluctuations of Emberger Aridity Index (IE) recorded in this study as well as the recent change in land use system, land tenure and human activities (Anon., 2017) clearly suggests that all these communities are under threat.

In regards to population size class distribution our results revealed that size class distribution based on height was resulted in a normal distribution pattern with slight irregularities led to the production of a bell-shaped curve in all the three areas. The highest density of the individuals reported in all areas encountered in 2-4 meter class indicating that this class represents the average height of the trees in this region. In another hand the distribution of individual trees based on crown area yielded a reverse J-shaped distribution, this indicates higher proportion of smaller trees in the population. Higher proportion of smaller normally suggests an evolving and stable population in forest ecosystem (Byakagaba *et al.*, 2011; Sahu *et al.*, 2012). However, our explanation to the higher proportion of smaller trees, especially in East Makkah may be attributed to the presence of some human disturbance activities such as cutting of big trees for firewood. Our field observation and witness of the field authorities supported this. This is similar to Luoga *et al*., (2004) who reported that disturbances caused by human activities has an influence on tree density leading to the change in size-class distributions.

Concerning the variation in stand density between sites, the highest density that was recorded in site “C” in Al-Qunfudah and Al-Leith may be attributed to the fact that in these two areas the site “C” is relatively far away from human interruption compared to site “A” and “B” which are near the settlements and Jeddah-Jazan high way. While site “B” in East Makkah represent the mid altitude site in this area. So the variation in stand density between sites revealed in this study can be related to human activities impacts among the different sites such as grazing and cutting of wood for fuel, in addition to environmental change as environmental factors affects stand density of trees (Liu *et al.*, 2019).

Statistical analysis results indicated that there were significant differences in this species growth characteristics including height, diameter and crown area between the different areas and sites. The variability in tree size between areas and sites within areas may be attributed to the differences in topography rainfall and temperature. Khumbongmayum *et al*., (2006) indicated that micro-environmental factors has an impact on different growth stages of trees in the population. Variation in *A. tortilis* in relation to environmental condition was also recorded across the red sea area of Sudan and Egypt (Abd-El-Rahman & Krzywinski, 2008). In average the tree height in Makkah region ranged between 3–4 meters. This is less than recorded values elsewhere (Anon., 2009; Orwa *et al.*, 2009). This difference may be due to the drought and dryness of this region.

This study revealed an association of exotic invasive *Prosopis juliflora* with *Tortilis* in Al-Leith area in more than 2/3 of the area surveyed. Many experiences around the World showed that this invasive *Prosopis* tree has high ability of colonizing the lands, which indicates that *A. tortilis* threatened by deterioration in this area. While in East Makkah there is association of *Rhaza stricta* shrub with *tortilis*. It is well known that this species is considered as invasive species which has high allelopathic inhibitory effects on germination and early growth of other species (Alqarawi *et al.*, 2018). This recorded spread of *Rhaza* species n East Makkah may lead to potential effects in the future regeneration and seedlings development of *Samur*.

The results obtained by the analysis of Emberger aridity index (IE) classified Makkah region as dry land area, because across all the years the produced IE value was less than 30. Gunawat *et al.*, (2016) specify that an Emberger aridity index (IE) of less than 30, the area will be classified as dry land. This was agreed with Khan & Alghafari (2017), who classified Makkah region as arid region. Whereas, the year-to-year variation in IE values observed indicates fluctuations in dryness. This fluctuation in dryness will affect the vegetation communities in the area. It was recorded by many authors that the change in climatic conditions will lead to changes in vegetation status (Theurillat & Guisan, 2001). This will be increased by the impact of the local people who regularly cut the trees for fuel wood or other purposes (Anon., 2007).

## Conclusion

The results of the population structure of *A. tortilis* communities obtained in this region revealed area-to-area and sites among areas variations in tree status. El-Leith seems to be the most affected by disturbance and impact of invasive *Prosopis* species accompanied by poor natural regeneration. In turn East Makkah subjected to continuous removal of big trees and spread of allelopathic *Rhaza stricta* plant which may raise an early warning of vulnerability of this area. All these factors were further aggravated by the dryness of this region and year-to-year variation in dryness recorded by the analysis of Emberger Aridity Index. Thus, the impacts of these disturbance and fluctuation in climate may call for immediate intervention such as in situ protection and rehabilitation of degraded sites. This intervention must be based on proper seed source that match planting sites and better seedlings development techniques for arid lands.

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