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Full Length Article

Existing Status of *Acacia* Woodlands in Central Saudi Arabia: A Case Study in Hawtat Bani Tamim and Al Duwadmi

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Abstract

Acacia woodlands are ecologically important and it is necessary to understand its structures and dynamics to develop sustainable conservation strategies. This study aimed to provide baseline information on the composition and growth of *Acacia* woodlands in the Hawtat Bani Tamim and Al Duwadmi regions of central Saudi Arabia. Height, diameter at breast height, crown diameter, seedling density, and soil seed bank content of *Acacia* tree species were characterized for 27 remote, circular, 0.1-ha plots in both study areas. At Hawtat Bani Tamim, *Acacia raddiana*, *A. tortilis*, and *A. ehrenbergiana* accounted for 45.53, 37.5 and 16.96% of all species present there. Most DBH were in the 6–10 cm class. *A. raddiana* was the main species in most diameter classes. Most trees were 4.1–5.0 m tall and *A. raddiana* predominated in this height class. *Acacia ehrenbergiana* had 92.63% damaged seeds. At Al Duwadmi, *A. raddiana* represented 78.99% of all Acacia trees there. *A. gerrardii* and *A. tortilis* accounted for 11.93 and 9.07% of the species there, respectively. Most of the DBH values were in the 6–10 cm and 11–15 cm classes, and *A. tortilis* and *A. raddiana* were abundant in both classes. Most trees were in the 4.1–5 m height class, which was dominated by *A. raddiana*. *A. ehrenbergiana* had 88.26% damaged seeds. In both areas, there was a gradual decline in the number of trees in DBH classes > 35 cm. The *Acacia* species in the two areas showed a fair regeneration status. There were more seedlings than saplings and fewer saplings than trees. This baseline study could contribute towards future sustainability planning initiatives after other assessment studies have been conducted to identify changes in the *Acacia* woodlands of this region.

Key words: Baseline; Crown diameter; DBH; Sapling; Seedling; Soil seed bank

Introduction

In Saudi Arabia, *Acacia* tree species are naturally distributed in small, low-density populations. Saudi Arabia is located in a desert belt region characterized by variable but very low amounts of rainfall and high temperatures. The Acacia woodlands in Saudi Arabia are undergoing intense grazing and logging for firewood and charcoal. *A. tortilis* is the preferred national fuelwood source. The level at which this species is being exploited far surpasses its ability to regenerate and meet the escalating demands of the local communities (Al-Abdulkader *et al*. 2004). Perturbations such as overgrazing and socioeconomic changes have caused severe rangeland and other forms of degradation in the interior of Saudi Arabia (Al-Rowaily *et al*. 2018). However, *Acacia* trees are palatable to herbivores and heavy browsing on them reduces their canopy cover and density (Noumi *et al*. 2010; Al-Rowaily *et al*. 2012).

Extreme environmental conditions such as drought impede plant growth and survival. Nevertheless, *Acacia* species can survive and even thrive under such conditions. In desert ecosystems, *Acacia* trees improve soil nutrient status (Munzbergova and Ward 2002) and soil moisture (Ross and Burt 2015). Despite hindrances such as drought and temperature, root nodule bacteria nonetheless associate with *Acacia* species in central Saudi Arabia (Alshaharani and Shetta 2015). This mutualism may enhance soil fertility in arid and semiarid habitats (Zahran 1999). De Boever (2015) reported that in Tunisia, a single *A. raddiana* tree improved soil water availability in the top 40 cm soil layer by ≤175% inside and outside the canopy.

A baseline or reference study evaluates degradation by comparison either with a previous state (FAO 2011) or with a contemporaneous reference condition (Thompson *et al*. 2013). In each case, the reference context must be derived from the same biome type in the same climate zone. The use of indicators such as shoot growth, soil seed banks, seedling abundance, or age structure of common woody plant species provides information regarding forest recovery in response to disturbances. Analyzing seedlings and young tree communities helps predict future forest dynamics (Ghazoul *et al*. 2015). A tree diameter class provides valuable forest-related information. A high frequency of individuals in the pole- and small-tree diameter classes (diameter at breast height (DBH) < 20 cm) indicates that forests are adversely affected by human perturbations (Nyland 2017). Puri *et al*. (2013) used baseline data to assess standing volume and periodic mean annual increment in four forests between 2005 and 2010. While the increment was excellent in two of the forests, the other two required regrowth.

The remarkable benefits of *Acacia* in fragile ecosystems such as deserts must be maintained by conserving trees. To develop sustainable *Acacia* forest conservation strategies, it is necessary to understand its population dynamics. As *Acacia* trees are ecologically important in their ecosystems, the aim of the current study was to explore the status of the *Acacia* woodlands in central Saudi Arabia. There were no prior baseline studies describing their structure, composition, or regeneration state. However, the current study was conducted to establish the current *Acacia* woodlands state. This information may help plan forest conservation and sustainability by monitoring changes in the *Acacia* woodlands using the findings of the current study as a frame of reference.

Materials and Methods

Study areas

The present study was conducted in 2013 at two heterogeneous areas (Table 1) spaced 350 km apart, namely Al Duwadmi (15 plots; sandy clay soil) and Hawtat Bani Tamim (12 plots; sandy loam soil). The two areas were open, unprotected public lands. They were selected according to their natural *Acacia* distributions and densities. The *Acacia* species in Saudi Arabia were described in details by Collenette (1999) and Chaudhary (1999).

Sampling of woody species

Woody species were sampled in circular plots (0.1 ha) with plastic ropes. There were three replicates per location. One end of the rope was fixed to a peg at the center of the plot while the other was connected to a freely moving peg used to draw circles 17.8 m in radius. The trees and seedlings within the circles were counted and measured as described below:

Measurement of tree characteristics: Tree diameter was measured with a tree caliper at 1.3 m above ground level. To determine total tree height, a telescoping measuring pole was pushed through the crown and the height was recorded when the pole reached the plane of the treetop. Smaller trees (< 1.30 m tall) were scored as seedlings. Trees whose height was > 1.3 m but < 2 m were rated saplings. Trees with multiple leaders forking above the DBH were considered to have single stems. Crown diameter was measured horizontally with a telescoping measuring pole in two fixed perpendicular directions. For groups of trees, crown diameters were measured for each individual tree.

Soil seed bank determination: Five soil samples were collected per plot to determine soil seed bank content. One sample was taken at the center of the plot while the other four were collected at random locations under the trees in the plot. A metal frame (0.5 m × 0.5 m) was placed under each sampled tree in the plot and a soil sample was collected at 5 cm depth and placed in a cloth bag. Soil samples were sieved through 3, 5 and 8 mm screens to remove stones, soil, and other debris. The seeds from each sample were counted and examined under a magnifying glass and categorized as intact or damaged.

Statistical analysis

As the two areas differed in topography and soil type, the data were analyzed separately for each of them. The sample sizes between areas were unequal. Thus, the MIXED procedure in SAS (v. 9.1; SAS Institute Inc., Cary, NC, USA) was used to conduct statistical analyses and estimate the variance. To identify differences between means, Duncan's new multiple range test was applied at $P < 0.05$.

Diameter distribution was plotted on a bar graph constructed using species frequency percentages (%; y-axis) categorized into eight diameter classes (x-axis): The DBH classes were 2–3 cm, 6–10 cm, 11–15 cm, 16–20 cm, 21–25 cm, 26–30 cm, 31–35 cm, and 36–40 cm. The frequency of each species in each diameter class was plotted on a bar graph constructed using the numbers of stems per species (y-axis) categorized in the eight aforementioned diameter classes (x-axis). The *Acacia* species height distributions were plotted on a bar graph constructed using the frequency percentage (%) of each species (y-axis) categorized in seven height classes (x-axis), namely, 2–3 m, 3.1–4 m, 4.1–5 m, 5.1–6 m, 6.1–7 m, 7.1–8 m, and 8.1–9 m. The frequency of each species in each height class was plotted on a bar graph constructed using the frequency percentage (%) of each species (y-axis) categorized in the aforementioned seven height classes (x-axis). The regeneration status of each *Acacia* species was determined based on the number of individuals at the seedling, sapling, and tree stages (Khumbongmayum *et al*. 2006).

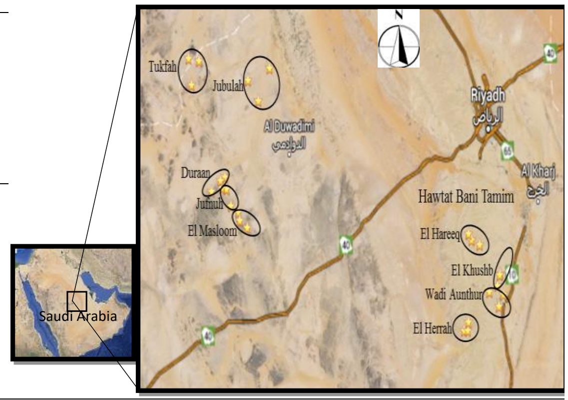
Results

Acacia growth in Hawtat Bani Tamim

The most common *Acacia* species in Hawtat Bani Tamim was *A. raddiana* (45.53%) followed by *A. tortilis* (37.50%) and *A. ehrenbergiana* (16.96%). Table 2 shows the growth parameters of the *Acacia* species in Hawtat Bani Tamim. Maximum height, DBH, and crown diameter of *A. raddiana* at Wadi Aunthur were 5.38 m, 10.22 cm, and 6.44 m, respectively. *A. raddiana* DBH was greatest at El Hareeq

Table 1: Coordinates of the two study areas in central Saudi Arabia

Area	Site	Elev. (m)	Coordinates (N-E)
Hawtat Bani Tamim	El Khushb	644	23.6786111°, 046.8358333°
	El Khushb	641	23.6102778°, 046.8072222°
	El Khushb	640	23.6855556°, 046.8422222°
	El Hareeq	761	23.9130556°, 046.5041667°
	El Hareeq	786	23.8822222°, 046.5997222°
	El Hareeq	782	23.9588889°, 046.4744444°
	El Herrah	640	23.3250000°, 046.4091667°
	El Herrah	658	23.3183333°, 046.4552778°
	El Herrah	660	23.3763889°, 046.4641667°
	Wadi Aunthur	624	23.5530556°, 046.8725000°
	Wadi Aunthur	649	23.5700000°, 046.7075000°
	Wadi Aunthur	665	23.4750000°, 046.8194444°
Al Duwadmi	El Masloom	973	24.1233333°, 043.7894444°
	El Masloom	987	24.0216667°, 043.8883333°
	El Masloom	1,010	24.0697222°, 043.8016667°
	Duraan	1,006	24.3286111°, 043.5830556°
	Duraan	1,008	24.3527778°, 043.6305556°
	Duraan	990	24.1611111°, 043.7013889°
	Jufnuh	1,019	24.2719444°, 043.6505556°
	Jufnuh	1,015	24.2852778°, 043.5977778°
	Jufnuh	1,026	24.2588889°, 043.4747222°
	Jubulah	857	24.9877778°, 043.9033333°
	Jubulah	868	24.8486111°, 044.0205556°
	Jubulah	849	25.0672222°, 044.1497222°
	Tukfah	970	24.9538889°, 043.2366667°
	Tukfah	973	25.1105556°, 043.3250000°
	Tukfah	957	25.1255556°, 043.2011111°



Enlarged map shows sites of sampled stands at Al Duwadmi and Hawtat Bani Tamim

Table 2: Means and standard deviation for *Acacia* species growth parameters in Hawtat Bani Tamim

Site	Species	Height (m)	DBH (cm)	Crown diameter (m)	Seedlings (0.1 ha)	Saplings (0.1 ha)	Trees (0.1 ha)	Intact seeds (%)	Damaged seeds (%)	Coexisting species
El Khushb	*A. raddiana*	4.80±0.88	10.41±2.72	5.42±1.67	36.0±8.41	3.0±0.52	7.0±1.62	77.22	22.78	*Lycium shawii*
	A. ehrenbergiana	4.65±0.96	4.32±2.49	5.35±2.12	22.0±7.06	0	3.0±0.76	7.69	92.30	*Rhayza stricta*
El Hareeq	*A. raddiana*	4.98±2.70	14.96 ±6.62	5.26± 2.30	2.0±0.93	2.0±0.50	3.0±0.98	40.90	59.09	*Cassia italica*
	A. ehrenbergiana	4.12±0.41	4.00±1.32	2.84± 0.70	3.0±1.01	0	2.0±0.35	6.06	93.94	*Leptadenia*
	A. tortilis	3.01±0.97	7.67±2.05	4.35± 2.13	9.0±2.54	3.0±0.60	2.0±0.56	39.60	60.40	*pyrotechnica*
El Herrah	*A. raddiana*	4.62±1.04	10.00±3.0	5.00±1.46	2.0±0.82	3.0±0.57	4.0±1.63	44.57	55.43	*Rhanterium*
	A. tortilis	4.20±1.01	9.29±2.41	5.53±1.67	7.0±2.01	4.0±0.86	6.0±1.98	*	*	*epapposum*
										Lycium shawii
Wadi	*A. raddiana*	5.38±0.88	10.22±3.07	6.44±2.03	25.0±5.65	2.0±0.67	3.0±1.20	45.00	55.00	*Lycium shawii*
Aunthur	*A. ehrenbergiana*	4.93±2.00	9.01±3.03	4.94±1.98	7.0±2.59	0	3.0±1.08	8.33	91.66	*Cassia italica*
	A. tortilis	5.22±1.45	10.21±2.37	6.38±1.85	11.0±3.95	3.0±0.86	6.0±2.01	12.50	87.50	*Citrullus colocynthis*

*Indicates absence of intact or damaged seeds; DBH. Diameter at breast height

Table 3: Comparison of *Acacia* growth parameters and seedling density among sites in Hawtat Bani Tamim

Site	Height (m)	DBH (cm)	Crown diameter (m)	Seedlings (0.1 ha)	Nearby human community
El Khushb	$4.74{\pm}0.92^{ba}$	$8.34{\pm}2.6^{b}$	$5.44{\pm}188^{a}$	$29.55{\pm}7.35^{a}$	Yes
El Hareeq	$4.63{\pm}1.40^{\mathbf{ba}}$	$12.67{\pm}3.30^{a}$	$5.07{\pm}1.77^{a}$	$4.06{\pm}1.49^{c}$	No
El Herrah	$4.37{\pm}1.02^{b}$	$9.58{\pm}2.7^{b}$	$5.32{\pm}1.63^{a}$	$4.90{\pm}1.41^{c}$	No
Wadi Aunthur	$5.20{\pm}1.44^{a}$	$9.98{\pm}2.8^{b}$	$6.12{\pm}1.90^{a}$	$13.71{\pm}4.06^{b}$	No
$P < 0.05$	0.0272	0.0333	0.3243	0.0011	

Values represent means ± standard deviations
Different letters (a, b, c) in the same column indicate significant differences among sites for each variable (P < 0.05);
DBH: Diameter at breast height

(14.96 cm). El Khushb had the highest *A. raddiana* seedling density (36 per 0.1 ha). The lowest *A. raddiana* seedling densities per 0.1 ha were found at El Hareeq (2) and El Herrah (2). At El Herrah, *A. tortilis* tree, sapling, and seedling densities were 6, 4, and 7 per 0.1 ha, respectively. The proportions of damaged seeds were >55% at all sites except El Khushb (22.78%).

Table 3 compares *Acacia* growth parameters and seedling densities among the sites in Hawtat Bani Tamim. There were significant differences in height (P = 0.0272), DBH (P = 0.0333), and seedlings/0.1 ha (P = 0.0011) among Hawtat Bani Tamim sites. Maximum tree height was measured at Wadi Aunther (5.20 m) but did not significantly differ from those evaluated at El khushb and El Hareeq. Moreover, the maximum tree heights at the latter two sites did not significantly differ from that found at El Herrah. The maximum mean DBH (12.67 cm) was located at El Hareeq and it significantly differed from those measured at the other sites. Seedling density differed significantly among sites. The highest seedling density per 0.1 ha was recorded at El Khushb (29.55) followed by Wadi Aunthur (13.71).

Table 4 compares the tree growth parameters among *Acacia* species in Hawtat Bani Tamim. Significant differences in DBH (P = 0.0041) and the number of seedlings/0.1 ha (P = 0.0055) were observed among *Acacia* species. *A. raddiana* had the highest DBH (11.56 cm) followed by *A. tortilis* (9.64 cm). They did not significantly differ from each other but did significantly differ from *A. ehrenbergiana*. *A. raddiana* had the highest average seedling density per 0.1 ha (19.17) followed by *A. ehrenbergiana* (14.90). Both differed significantlly from *A. tortilis*. *A. raddiana*, *A. ehrenbergiana*, and *A. tortilis* accounted for 68.25, 19.05 and 12.70% of all seedlings, respectively.

Table 4: Comparison of growth parameters among Acacia species in Hawtat Bani Tamim

Species	Height (m)	DBH (cm)	Crown diameter (m)	Seedlings (0.1 ha)	Frequency (%)	Percentage (%) of individuals in various stage			
						Seedlings	Saplings	Trees	Regeneration status
A. raddiana	4.95^a	11.56^a	5.84^a	19.17^a	45.53	62.77	3.65	33.57	Fair
A. ehrenbergiana	4.65^a	5.61^b	4.87^a	14.9^a	16.96	45.71	0	54.29	Fair
A. tortilis	4.56^a	9.64^a	5.60^a	9.12^b	37.50	36.36	9.09	54.55	Fair
$P < 0.05$	0.3314	**0.0041**	0.2477	**0.0055**					

Different letters (a, b, c) in the same column indicate significant differences among species for each variable ($P < 0.05$)
DBH: diameter at breast height

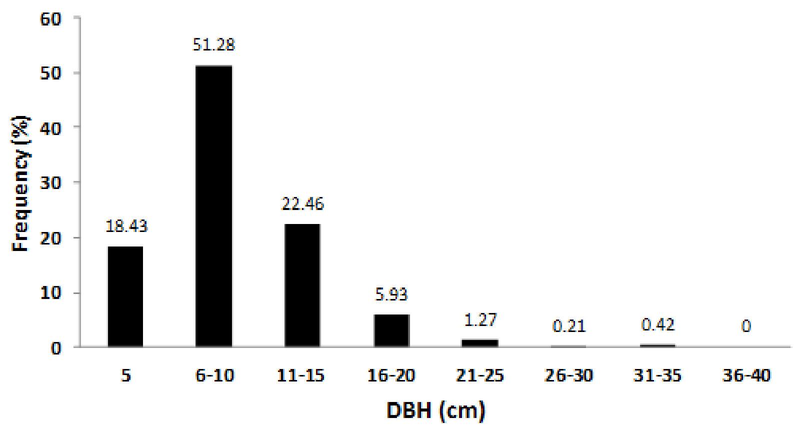


Fig. 1: *Acacia* species DBH (diameter at breast height) frequency distribution at Hawtat Bani Tamim

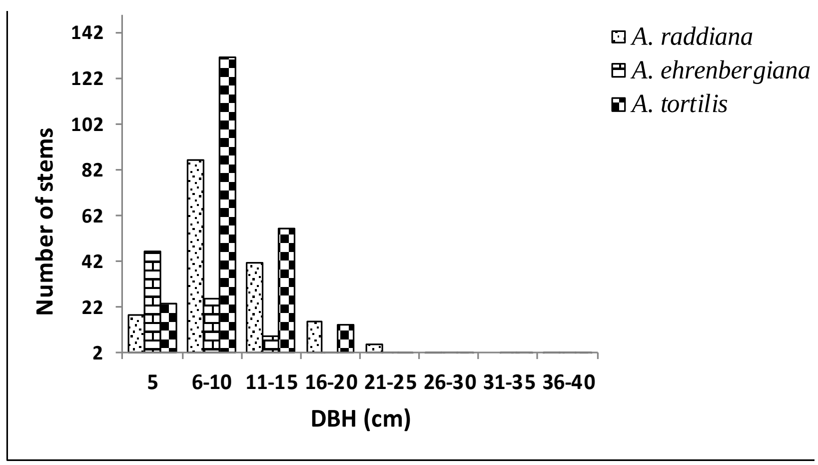


Fig. 2: *Acacia* species DBH (diameter at breast height) frequency distribution at Hawtat Bani Tamim

The proportions of *Acacia* seedlings, saplings, and trees varied with species in Hawtat Bani Tamim (Table 4). *A. raddiana* accounted for 62.77% of all seedlings but only 3.65% of all saplings. *A. tortilis* comprised 9.09% of all saplings. There were no *A. ehrenbrigiana* saplings. *A. tortilis* and *A. ehrenbergiana* comprised 54.55% and 54.29% of all trees, respectively, whereas 33.57%. of the trees were *A. raddiana.* All species regenerated when the percentages of seedlings were higher than those of the saplings and when the proportions of saplings were lower than those of the trees.

Fig. 1 depicts tree diameter frequency distribution in Hawtat Bani Tamim. Most DBH were in the 6–10 cm class. About 51.28% of the total tree diameter frequency was in this class. In contrast, only ~0.42% of the total tree diameter frequency was in the 31–35 cm class. *A. ehrenbergiana* significantly contributed to the 5 cm diameter class whereas *A. tortilis* and *A. raddiana* figured prominently in the 6–10 cm and 11–15 cm diameter classes (Fig. 2). No trees with DBH > 36 cm were observed. The largest DBH categories, namely, 21–25 cm, 26–30 cm and 31–35 cm, included only *A. raddiana*.

Fig. 3 shows the tree height frequency distributions. The 4.1–5 m tree height class accounted for 39.29% of the

Table 5: Means and standard deviation for growth parameters of *Acacia* species in Al Duwadmi

Site	Species	Height (m)	DBH (cm)	Crown diameter (m)	Seedlings (0.1 ha)	Saplings (0.1 ha)	Trees (0.1 ha)	Intact seeds (%)	Damaged seeds (%)	Coexisting species
El Masloom	*A. gerrardii*	4.55±2.39	13.80±7.94	4.77±3.63	5.50±2.82	2.0±0.46	3.0±2.00	6.66	93.33	*Lycium shawii*
	A. raddiana	3.83±0.55	10.76±3.15	3.02±0.61	11.0±8.08	2.0±0.94	2.0±0.76	19.44	80.55	*Ochradenus baccatus*
	A. tortilis	3.85±2.33	6.83±3.05	3.12±1.19	3.0±1.15	1.0±0.61	3.0±1.40	12.50	87.50	
Duraan	*A. raddiana*	5.55±1.33	17.90±6.17	4.9±1.79	21.0±3.93	3.0±1.52	8.0±0.93	14.42	85.57	*Lycium shawii ; Ziziphus spina christi*
Jufnuh	*A. raddiana*	4.58±1.26	11.60±5.04	4.61±2.01	20.0±4.21	3.0±1.14	9.0±1.30	11.19	88.80	*Lycium shawii; Zilla spinosa*
Tukfah	*A. raddiana*	5.23±1.82	18.27±8.89	5.68±2.86	7.15±3.66	2.0±1.24	5.0±1.02	5.47	94.52	*Lycium shawii*
	A. raddiana	4.98±1.95	12.66±5.30	5.11±1.60	5.42±2.63	3.0±0.84	7.0±0.95	8.11	91.88	*Lycium shawii*
Jubulah	*A. gerrardii*	5.76±1.61	20.57±4.92	6.55±0.50	3.33±0.81	2.0±0.81	2.0±057	16.90	83.09	

DBH: diameter at breast height

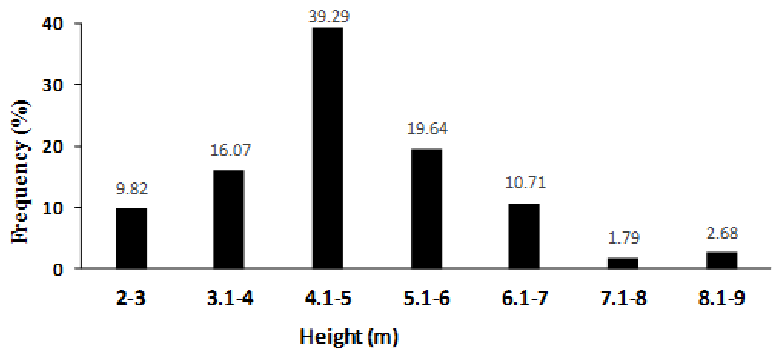


Fig. 3: *Acacia* species height frequency distribution at Hawtat Bani Tamim

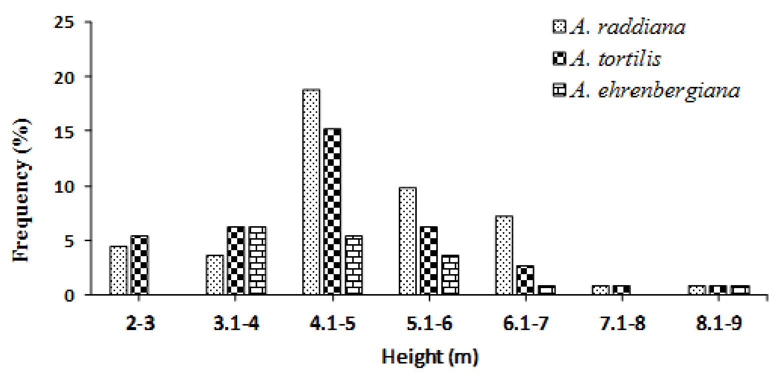


Fig. 4: *Acacia* species height frequency distribution at Hawtat Bani Tamim

total tree height frequency while the 7.1–8 m tree class accounted for only 1.79%. All species were represented in the 4.1–5 m tree height class but it was nonetheless dominated by *A. raddiana* (Fig. 4). There was no *A. ehrenbergiana* in the 2–3 m or 7.1–8 m tree height classes.

Acacia growth in Al Duwadmi

The most commonly occurring *Acacia* species at Al Duwadmi was *A. raddiana* (78.99%) followed by *A. gerrardii* (11.93%) and *A. tortilis* (9.07%). Table 5 lists the growth parameters for the *Acacia* species at Al Duwadmi. At El Masloom, the *Acacia* species were *A. gerrardii*, *A. raddiana*, and *A. tortilis*. *A. gerrardii* was the dominant species there. At Jubulah, *A. gerrardii* and *A. raddiana* occurred in mixed stands. In Duraan, Jufnuh, and Tukfah, there were mainly pure *A. raddiana* stands. At Jubulah, the maximum height, DBH, and crown diameter for *A. gerrardii* were 5.76 m, 20.57 cm, and 6.55 m, respectively. The highest seedling density was 21 for *A. raddiana* at Duraan whereas the lowest seedling and sapling density/0.1 ha were 3 and 1, respectively, for *A. tortilis* at El Masloom. There were ≤3 saplings/0.1 ha for all species except A. *tortilis* (1 sapling/0.1 ha). The highest tree density was 9 for *A. raddiana*. The proportion of damaged seeds at Al Duwadmi was > 80% for all *Acacia* species (Table 5).

Table 6 compares the tree growth parameters among sites at Al Duwadmi. Significant differences in height (P = 0.0344), DBH (P = 0.0002), crown diameter (P = 0.0117), and seedling density (P = 0.0001) were detected among all Al Duwadmi sites. Duraan had the tallest trees (5.55 m) but their heights did not significantly differ from those of the

Table 6: Comparison of *Acacia* growth parameters among sites in Al Duwadmi

Site	Height (m)	DBH (cm)	Crown diameter (m)	Seedlings (per 0.1 ha)	Nearby human community
El Masloom	4.14 ± 1.75^{b}	10.14 ± 5.55^{c}	3.93 ± 1.81^{b}	4.72 ± 2.35^{c}	No
Duraan	5.55 ± 1.33^{a}	17.90 ± 6.17^{a}	4.90 ± 1.75^{ab}	21.90 ± 3.75^{a}	No
Jufnuh	4.59 ± 1.26^{ba}	11.60 ± 5.04^{bc}	4.61 ± 2.41^{ba}	20.00 ± 4.19^{a}	Yes
Tukfah	5.23 ± 1.82^{ab}	18.27 ± 8.89^{a}	5.68 ± 2.93^{a}	7.15 ± 3.58^{b}	Yes
Jubulah	5.15 ± 1.78^{ba}	14.44 ± 5.11^{ba}	5.67 ± 1.66^{a}	4.96 ± 1.72^{c}	Yes
$P < 0.05$	0.0344	0.0002	0.0117	0.0001	

Values represent means ± standard deviations
Different letters (a, b, c) in the same column indicate significant differences among sites for each variable ($P < 0.05$); DBH: diameter at breast height

Table 7: Comparison of growth parameters, seedling density, and population structure among *Acacia* species in Al Duwadmi

Species	Height (m)	DBH (cm)	Crown diameter (m)	Seedlings (0.1 ha)	Frequency (%)	Percentage (%) of individuals in various stage			
						Seedlings	Saplings	Trees	Regeneration status
A. gerrardii	5.07 ± 2.0^{a}	16.70 ± 6.4^{a}	5.56 ± 2.06^{a}	4.57 ± 2.66^{b}	11.93	45.45	13.64	40.91	Fair
A. raddiana	5.01 ± 1.38^{a}	14.53 ± 5.71^{a}	5.54 ± 177^{a}	14.70 ± 4.50^{a}	78.99	63.36	3.88	32.76	Fair
A. tortilis	3.95 ± 2.18^{a}	7.34 ± 2.41^{b}	4.92 ± 1.82^{a}	3.37 ± 1.33^{b}	9.07	75.00	11.40	13.60	Fair
$P < 0.05$	0.3263	0.0042	0.3919	0.0098					

Values represent means ± standard deviations
Different letters (a, b, c) in the same column indicate significant differences among species for each variable ($P < 0.05$); DBH: diameter at breast height

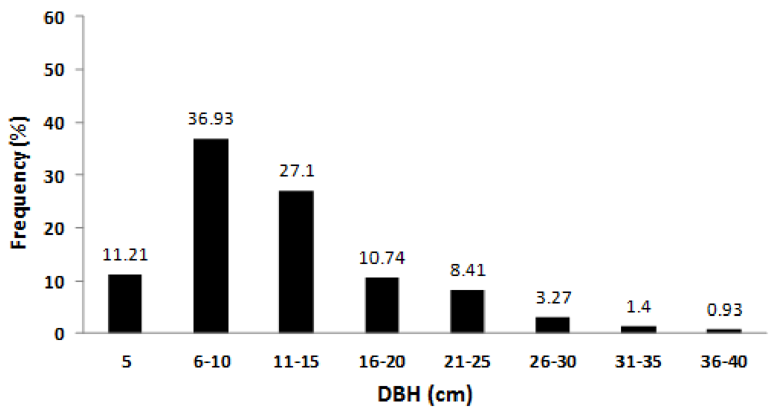


Fig. 5: *Acacia* species DBH (diameter at breast height) frequency distribution at Al Duwadmi

other sites except for El Masloom (4.14 m). The trees at Tukfah had the highest DBH (18.27 cm) but this value did not significantly differ from those at Duraan or Jubulah. The crown diameter was greatest at Tukfah (5.68 m) but did not significantly differ from those at Jubulah or Duraan. Duraan and Jufnuh had 21.90 and 20.0 seedlings per 0.1 ha, respectively.

Table 7 compares the tree growth parameters among *Acacia* species in Al Duwadmi. Significant differences in DBH ($P = 0.0042$) were observed among *Acacia* species. *A. gerrardii* had the highest DBH (16.70 cm) but this value did not significantly differ from that for *A. raddiana*. Moreover, the DBH for these two species significantly differed from that of *A. tortilis* (7.34 cm). Significant differences ($P = 0.0098$) in seedling density were observed among *Acacia* species. *A. raddiana* had the highest average seedling density per 0.1 ha (14.7). *A. raddiana*, *A. tortilis* and *A. gerrardii* seedlings accounted for 77.36, 17.36, and 5.28 of all *Acacia* seedlings, respectively. The proportions of seedlings were 75, 63.36 and 45.45 for *A. tortilis*, *A. raddiana*, and *A. gerrardii*, respectively. Saplings accounted for 3.88% of *A. raddiana*, 11.40% of *A. tortilis*, and 13.64% of *A. gerrardii*. Trees accounted for 40.91, 32.76, and 13.6% of *A. gerrardii*, *A. raddiana*, and *A. tortilis*, respectively. The regeneration status for *Acacia* species was fair. The proportion of seedlings was greater than that of the saplings and the percentage of saplings was lower than that of the trees.

Fig. 5 illustrates a tree diameter frequency distribution for *Acacia* species. Most of the DBH were in the 6–10 cm and 11–15 cm classes. Together, these classes accounted for ~36.93% and ~27.1% of the total DBH frequency, respectively. Only 0.93% of the DBH were in the 36–40 cm class. *A. tortilis* and *A. raddiana* were abundant in the 6–10 cm and 11–15 cm classes (Fig. 6). Only *A. raddiana* was in the largest DBH categories including the 26–30 cm and 31–35 cm classes. *A. gerrardii* was abundant in the 6–10 cm diameter class. The 36–40 cm DBH category included only a few *A. gerrardii* and *A. raddiana* individuals (Fig. 6). Fig. 7 shows the tree height frequency distributions. The highest

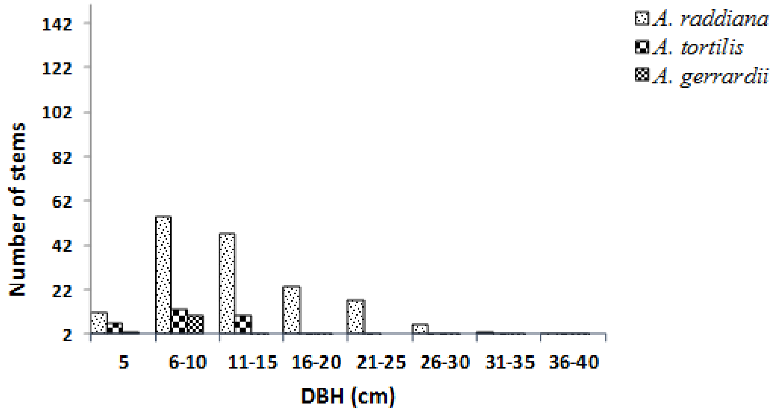


Fig. 6: *Acacia* species DBH (diameter at breast height) frequency distribution at Al Duwadmi

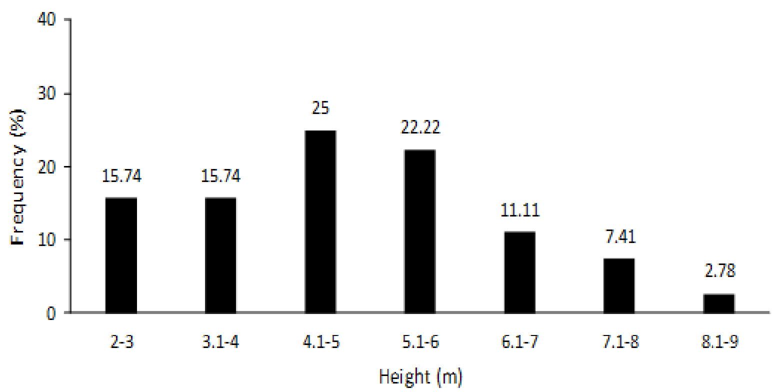


Fig. 7: *Acacia* species height frequency distribution at Al Duwadmi

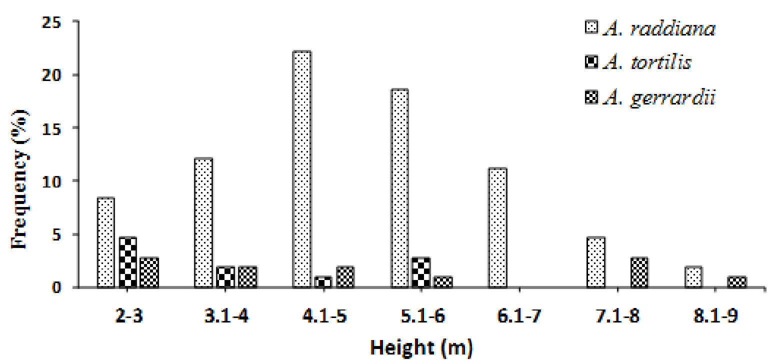


Fig. 8: *Acacia* species height frequency distribution at Al Duwadmi

tree height frequencies were 25 and 22.22% in the 4.1–5 m and 5.1–6 m classes, respectively. The lowest tree height frequency was only 2.78% in the 8.1–9 m class (Fig. 7). *A. raddiana* dominated all height classes (Fig. 8). There were no *A. tortilis* trees in the 6.1–7 m, 7.1–8 m, or 8.1–9 m height classes and no *A. gerrardii* trees in the 6.1–7 m height class.

Discussion

In this study, there were comparatively few large-diameter (>35 cm) *Acacia* trees. The abundance of trees with small DBH and the gradual decreases in height and DBH for the higher classes indicate that mature large-diameter trees had already been cut down. Wickens *et al.* (1995) reported that *A. raddiana* in Tunisia reached a diameter of 40 cm in 125 y and 90 cm in 250–300 y. The slow growth of the genus *Acacia* is an adaptation to its native arid environments (Elfadl 2013). For this reason, *Acacia* woodlands must be conserved. The frequencies of trees with DBH > 25 cm were only 0.5% in Hawtat Bani Tamim and 3.27% in Al Duwadmi. Atsbha *et al.* (2019) explained the low frequency

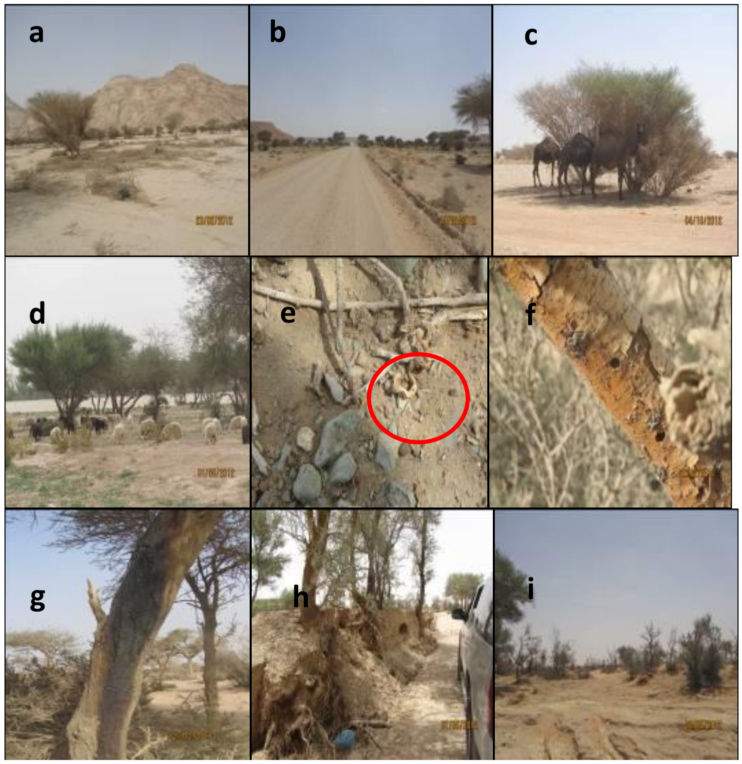


Fig. 9: Photographs showing hazards to *Acacia* species in central Saudi Arabia; (a) cutting, (b) road building, (c and d) grazing by camels and sheep, (e) seed predation, (f) insects, (g) diseases, (h) soil erosion, and (i) drought

(2.58%) of large-diameter (> 25.1 cm) trees in Ethiopia by illegal local cutting for construction materials and fuelwood. Several factors such as human activities, insects, disease, seed predation, grazing, and drought may have impeded *Acacia* growth and regeneration (Fig. 9).

In Saudi Arabia, high local demands for fuelwood have hindered vegetation cover by woody species such as *A. tortilis* which has high thermal value (20.45 MJ kg^{-1}) (Nasser and Aref 2014). This *Acacia* species is preferable fuelwood for that nation (Al-Abdulkader *et al.* 2004). The frequent harvest of *A. tortilis* for fuelwood explains the low numbers of stems with diameters < 15 cm and the lack of diameter classes > 15 cm at Al Duwadmi. The lack of coppice regeneration was evident in the two areas surveyed. Despite the important of coppicing as a management practice, it is not applied in all *Acacia* woodlands. Coppice management is very efficient because it promotes regeneration and shortens regrowth time (Spinelli *et al*. 2017). In *Acacia* woodlands, single-stem species such as *A. gerrardii* and *A. raddiana* or those with multiple stems such as *A. tortilis* and *A. ehrenberigiana* are cut 5–10 cm above ground. The ability of cut trees to sprout new branches depends on biotic and abiotic factors such as cutting height and stem size (Khan and Tripathi 1986; Tiwari and Das 2010), stump diameter (Shackleton 2001), and soil moisture (Ferm and Kauppi 1990; Liu and Dickmann 1996). Mayo *et al*. (2016) demonstrated that resprouting is both water- and nutrient-limited in cut trees and resource addition does not replenish stem carbon storage. Soil with high moisture content increases sprouting vigor and the transfer and supply of phytohormones such as auxins, cytokinins, and gibberellins (Ferm and Kauppi 1990). However, these responses are absent in soils with very low moisture (Liu and Dickmann 1996).

The soil seed bank comprises the viable seeds in the soil (Baker 1989). However, the high seedling density at El Khushb reflected the high percentage of intact seeds (>77%). Natural regeneration of vegetation at disturbed sites depends on soil seed bank recruitment. Nevertheless, recruitment may be limited when insufficient seeds are available. In the two areas studied here, the soil was subjected to frequent vehicle passage and that may lead to damage seeds and the new seedlings. Off-road vehicle driving in the Saudi Arabia rangelands contributed to soil compaction and the soil bulk density was 38% higher under the motor vehicle tracks than that of undisturbed soils (Assaeed *et al*. 2018). Compacted soil exposes seeds to predators, inhibits seed germination, and impedes seedling growth (Kozlowski 1999). Stelli (2012) stated that the seed bank density of certain *Acacia* species significantly increased with decreasing soil compaction.

Seeds are the primary source of *Acacia* regeneration. In Saudi Arabia, mature *Acacia* pods are scarcely available as camels consume the unripe green seedpods and/or the seeds themselves. There are ~848,000 camels in Saudi Arabia (Abdallah and Faye 2012). Camels may be endozoochorous dispersal agents in *Acacia* woodlands but at the same time camels are large herbivores that consume unsplit *Acacia* pods that retain moisture and nutrients. After successful establishment, however, the seedlings are more palatable to camels than the mature plants. The high percentage of infested seeds observed in the present study was consistent with the findings of Ward *et al*. (2010). They reported that 97% of all *A. raddiana* and *A. tortilis* seeds sampled were infested with bruchid beetles (*Bruchidius*). Variations among species in terms of percentage of infected seeds may reflect their relative ability to produce defensive compounds. *Acacia* seeds accumulate non-protein amino acids as secondary metabolites (Evans *et al.* 1993) that could deter predation and may even be toxic to insects (Romeo 1998). Endosperm weight may influence insect predator seed selection (Alshahrani 2018).

Protection of *Acacia* woodlands is the most effective way to restore vegetative cover. Traoré *et al*. (2008) observed good *Acacia* regeneration in Burkina Faso in protected areas of livestock grazing and poor regeneration in areas with high human impact. Ten-year protection of some *Acacia* trees by restricted planting in Abéché, Chad improved total land cover and enhanced tree height and density (Malagnoux *et al*. 2007).

The sparsity of *Acacia* saplings in the study areas reflects the shortage of seedlings in transition to the sapling stage caused by drought and/or grazing. In Saudi Arabia, the average annual rainfall is 114 mm (DeNicola *et al*. 2015) and minimizing the risk of severe drought may have a positive impact on seedling growth and tree reproduction where water harvesting can sustain seedling, sapling, and tree growth. The high seedling density observed at El Khushb in Hawtat Bani Tamim (29 seedlings per 0.1 ha) was attributed to unplanned water harvesting in small, random bunds near a human community. In the Thal Desert of Pakistan, using a sloping catchment technique enhanced water supply and increased the maximum average height of *A. tortilis* to 155 cm within 1.5 y (Sheikh *et al*. 1984). Saoub *et al*. (2011) found that implementing water harvesting and protecting plants from grazing for 3–4 y increased plant biomass and the number of species in the Badia of Jordan. To overcome water problems in Saudi Arabia, treated wastewater can be used to irrigate seedlings in nurseries and plantations. Wastewater improves essential nutrient availability in the deficient soils of arid regions (Tabari and Salehi 2009).

Conclusion

Acacia species in two study areas of central Saudi Arabia comprised *A. raddiana, A. tortilis, A. ehrenbergiana* and *A. gerrardii. A. raddiana* was the dominant species at all sites in both areas. The gradual decline in the number of trees in the high-DBH categories may be due to selective removal of the wider trees. The regeneration status for the *Acacia* species in both areas was fair. There were more seedlings than saplings and fewer saplings than trees. These data may serve as a baseline for future comparison studies to monitor local and regional changes in *Acacia* species. Thrust may be to design sustainable silvicultural systems for *Acacia* woodlands. Local communities should be designated to monitor and maintain the regeneration, growth, and protection of *Acacia* woodlands. To promote stress resilient woodlands, it is necessary to protect existing trees, apply coppicing, use water-harvesting techniques, and plant nursery-grown seedlings inoculated with root microbial strains.

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Author Contributions

The author collected and analyzed the data and wrote the paper.

Conflict of Interest

The author declares no conflict of interest of any sort.

Data Availability

The data relevant to the paper are available with the author and will be available on reasonable request.

Ethics Approval

Not applicable

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