

Considerations of Demography and Life Table Analysis for Conservation of *Acacia tortilis* in South Sinai

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Abstract: Populations of *Acacia tortilis* (Forssk.) Hayne subsp. *tortilis* were monitored in South Sinai, Egypt. Age determination was mainly based on canopy volume and stem circumference. Study sites were located in wadi systems in the upstream, midstream and downstream of the wadis. The upstream populations are represented in all size class distribution, while populations in the midstream and the downstream parts have one or more size classes missing due to the variation of water income and human impacts. Phenological monitoring showed that the appearance of new leaves started in December-January. Leaf shedding reaches its peak during November. *A. tortilis* has two flowering events. The first flowering event begins on old branches in March followed by peak fruiting in May. The second flowering event begins on the new branches in July followed by peak fruiting in September-October. Life table analysis and fecundity schedules showed that the flowers, seeds and seedlings are the shortest stages in the life span. The net reproductive rate was 0.281, the estimated intrinsic rate of increase reached -0.00337 per capita per year and the average generation time of the species attained about 380 years. Population demography, phenology and life table analyses draw the attention towards specific conservation considerations to manage the species population in the protected and nonprotected sites.

Key words: Age classes · phenology · population dynamics · Egypt

INTRODUCTION

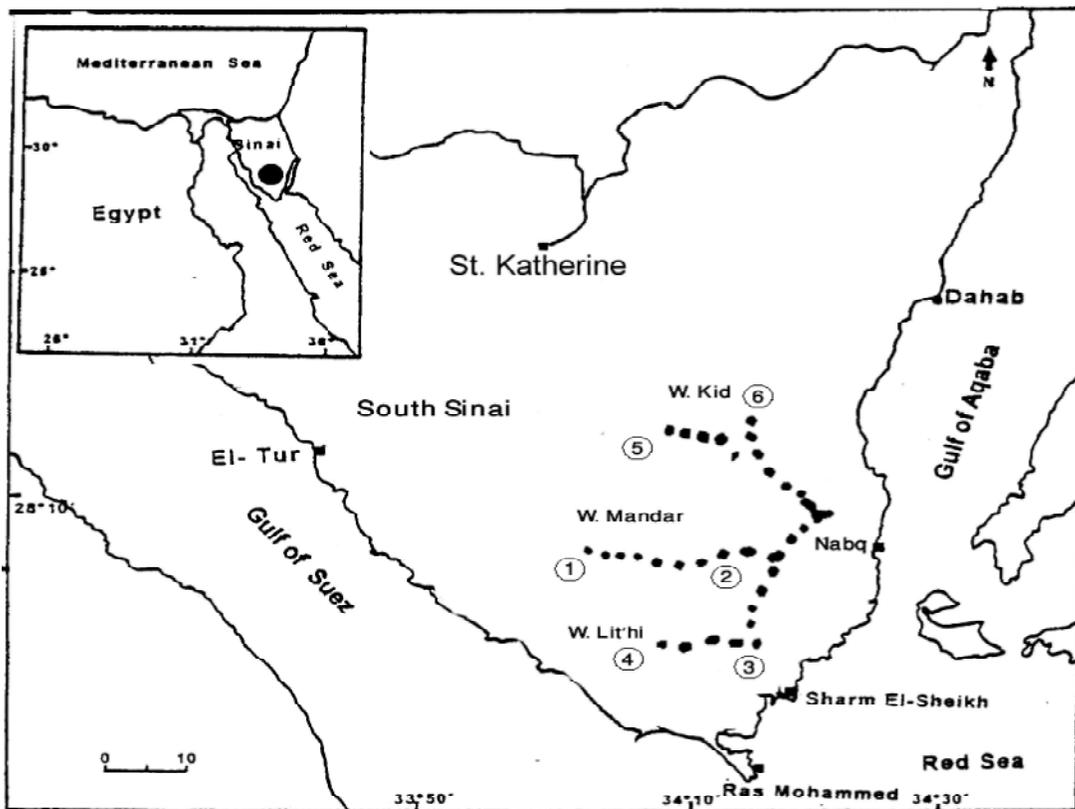
The dominant *Acacia* species in South Sinai, Egypt is *Acacia tortilis* (Forssk.) Hayne subsp. *tortilis*. The species provides food and shelter for many wild desert animals and is a major source of livestock feed and firewood for the native Bedouins [1]. High mortality and low recruitment of *Acacia* trees in arid lands was reported by Wiegand [2]. As a multipurpose species, it is subject of intensive human collection and use. In the Negev desert and Sinai Peninsula the mortality rates of *Acacia* trees vary with life stages and may reach 61% in the adult stage [3] as affected by insect seed attack, drought, high temperature and human impacts.

Desert plants are adapted to the arid environment through various structural and functional characters to decrease water loss. Among the mechanisms diminishing water-loss is the reduction of the transpiring surface, where shedding of leaves and branches is a common behaviour [4-6]. In *A. tortilis*, the phenomenon of leaflet shedding was pointed out by Halevy and Orshan [7] and they related it to the intensification of drought during the dry rainless season.

A. tortilis is found in the Egyptian deserts and is entirely confined to arid and semi-arid habitats, where it occurs as small populations that are thinly scattered over an extensive range [1, 8]. At present the species is not endangered, but without immediate conservation measures, it is likely to move into the vulnerable category due to the continuous decline of its populations.

Most studies on survival and mortality were concerned with the early plant life stages, not only because these are generally the most critical stages in the plant's life span, but also because they are perhaps the only stages where manipulative experiments can easily be performed [9, 10]. For most plant populations with overlapping generations, the mortality, survival and reproduction tend to vary with age or size of the individual plants [10-17].

The present study covers the phenology, demography and dynamics of the plant populations in South Sinai, Egypt. Quantitative data on survival, mortality and reproductive ecology are analyzed as a base for provision of essential information for conservation considerations of the species.



Map 1: Study area and site location. The numbers indicate the localities of the six study populations of *A. tortilis*

MATERIALS AND METHODS

Study area and plant populations: Three main localities in South Sinai wadis, representing the natural variation of *Acacia* populations subjected to different physiographic, climatic and human impact conditions were selected for this study. The exact location and altitude of the study sites are shown in Table 1 and Map 1.

The populations of *A. tortilis* in South Sinai are usually grow as clumps or solitary scattered trees. The six study populations were generally divided into three main types according to the degree of isolation, water income and elevation: a) Populations in the upstream of the wadis (populations 1 and 2) that are subjected to the least human impacts and the lowest water run off, b) Populations in the midstream of the wadis (populations 3 and 4) which are subject to intensive grazing and browsing activities, moderate run off and moderate human activities and c) Populations in the downstream of the wadis (populations 5 and 6) which receives high amount of rainfall water run off and intensive human activities [18].

Table 1: Study site locations with Global Positioning System (GPS) readings in South Sinai, Egypt. U = upstream, M = midstream and D = downstream of the Wadis

Site No.	Location	GPS reading		Altitude (m) asl
		N	E	
1	W. Mander (U)	28.06444	34.15104	658
2	W. Mander (U)	28.15346	34.16239	664
3	W. Lit'hi (M)	28.15454	34.16014	470
4	W. Lit'hi (M)	28.06038	34.23754	438
5	W. Kid (D)	28.36249	34.20764	324
6	W. Kid (D)	28.04130	34.15070	338

South Sinai belongs to the Saharan-Mediterranean climatic region. Description of the study area, including climatic variation is given by Helmy *et al.* [18] and Moustafa and Klopatek [19]. Climatological conditions in the study area are those of mountain desert with scarce and sporadic rainfall. Some extra sporadic rain, up to 200-300 mm may occur in the highest mountain peaks due to orographic precipitation [20]. Over the past ten years a maximum mean monthly temperature of 42°C

was recorded in August, while a minimum mean monthly temperature of 7°C was recorded in February. Rain may generally occur between October and May where the average annual rainfall reaches 50 mm per year and is of torrential character. Flash floods are common and considered important disruptive ecological factor in the area, however, scarcity of water is the most limiting factor. Because of high evapotranspiration, water balance is negative; relative humidity of the air rarely surpasses 8% [1]. For detailed study of phenology and life table analysis one population was selected representing all size classes with moderate human impacts.

Population demography: Demographic survey of *Acacia tortilis* was performed in the six study sites in Saint Katherine Protected Area during the years 2002-2004. To determine the most suitable estimate of the tree age, the relationship between the tree age, stem circumference and canopy volume were studied. To estimate the canopy volume (V), the following equation [21] was applied: $V = 4/3 \pi ab^3$, where "a" is the average canopy radius and "b" represents the canopy height.

To determine the approximate age of *Acacia* trees an average of 35 sections obtained from trunks of dead trees were used. Cross sections were then planed and in some cases sanded to produce a smooth surface. Tree growth rings were identified and counted by the denser and darker coloured latewood bands, assuming tree growth to be annual. Ring counts were made following Edwards [22] using magnifying lenses, along radii with the most distinct growth ring sequence free of knots, bark inclusions and rot. The growth rings were used for the

final age estimation through stem circumference (cm) at 50 cm above the soil surface. Intra-annual bands or 'false rings' were identifiable when they were abnormally narrow, faint or failed to be recognized around the entire circumference of the section. The canopy volume classes were categorized for the study populations as less than 1 m³ (A), 1-10 m³ (B), 10-50 m³ (C), 50-100 m³ (D), 100-200 m³ (E) and more than 200 m³ (F).

Phenology: The population was observed monthly from (January 2002 to January 2003). The plant individuals were monitored for vegetative growth, flowering, fruiting and senescence [17]. The phenophases were subjectively detected during the course of observations by following up marked single branches belong to canopy volume class "10-50 m³" as it was represented in all populations. To avoid the great variability in the phenology of different individual tree branches within the same site and even between branches of the same tree, the following measures were considered: (1) observations were made on fixed marked branch, (2) accurate diagrams of each branch were made throughout the observation period and (3) estimation of the quantity of foliage, inflorescence and fruits of the studied trees were made on one tree size class of the population.

Life table and fecundity schedule: Calculations of life table parameters (Table 2) followed those of Charlesworth [23], Pielou [24] and Hegazy [25]. Construction of the life table and fecundity schedule proceeded as follows: the first column sets out the various stages of the life cycle. The second and third columns list the estimated age in

Table 2: Life table and fecundity schedule calculated for *A. tortilis* from data on standing naturally growing population in wadi Manader

Stage or cohort	x(±SD)	N _x	L _x	d _x	q _x	Log ₁₀ N _x	K _x	e _x	b _x	L _x b _x	xl b _x	V _x
Flower bud	0.30±0.0576	13408750	1.00	1.9×10 ⁻¹	0.187	7.13	0.09	2.12	-	-	-	-
Flower	0.25±0.0595	10896200	0.81	5.3×10 ⁻¹	0.654	7.04	0.46	1.38	-	-	-	-
Seed rain	0.16±0.0238	3769000	0.28	2.5×10 ⁻¹	0.899	6.57	0.99	1.10	-	-	-	-
Intact seeds	0.58±0.0265	378905	0.03	2.7×10 ⁻²	0.970	5.58	1.52	1.03	-	-	-	-
Germinable seeds	1.3±0.3631	11367	8.50×10 ⁻⁴	8.4×10 ⁻⁴	0.999	4.05	3.75	1.00	-	-	-	-
Seedlings (A)	1.0±0.1693	2	1.50×10 ⁻⁷	-3.0×10 ⁻⁷	-2.000	0.30	-0.47	20.00	-	-	-	-
Juveniles (B)	9.0±2.1746	6	4.50×10 ⁻⁷	-2.9×10 ⁻⁷	-0.666	0.78	-0.22	6.33	295	0.000132	0.00118	628168
Adults (C)	35.0±3.2579	10	7.50×10 ⁻⁷	-2.2×10 ⁻⁷	-0.300	1.00	-0.11	3.20	6770	0.005048	0.17671	376724
(D)	154.00±15.8276	13	9.70×10 ⁻⁷	5.2×10 ⁻⁷	0.538	1.11	0.33	1.69	63645	0.061704	9.50254	284580
(E)	310.00±30.1484	6	4.50×10 ⁻⁷	2.2×10 ⁻⁷	0.500	0.78	0.30	1.50	260550	0.116588	36.14230	478692
(F)	614.00±91.7196	3	2.20×10 ⁻⁷	-	-	0.48	-	1.00	436285	0.097612	59.93377	436285
									Σ 0.281084	Σ 105.75650		

$R_0 = 0.281$, $T = 376.24$ and $r = -0.00337$

x = estimated age in year, N_x = number per stage, L_x = proportional of original cohort surviving to the start of each stage, d_x = proportional of original cohort dying during each stage, q_x = stage-specific mortality rate, k_x = killing power, e_x = expectation of future life, b_x = average number of seeds per individual, V_x = reproductive value, R₀ = net reproductive time, T = generation time and r = intrinsic rate of increase per capita

years (x) and the corresponding numbers per stage (n_x). The data have been standardized in the fourth column giving the proportion of the original stage surviving to the start of each stage (l_x). Accordingly, the proportion of original stage dying during each stage (d_x) and the stage-specific mortality rate (q_x) were calculated. The rate or intensity of mortality during different stages which reflects the killing power (k_x) was computed from the N_x values. The expectation of future life (e_x) in the age units was estimated by the summation of l_x for all ages successive to and including that of age x . The average number of seeds coming from two flowering events per individual per age class (b_x) is used in calculation of the reproductive rate ($l_x b_x$). From these values, the net reproductive rate (R_x) was calculated. The intrinsic rate of increase per capita per annum (r) was calculated as the natural logarithm of net reproductive rate divided by the generation time.

RESULTS

Population demography: The canopy volume and the stem circumference are tested as predictors for the age of *A. tortilis* trees (Fig. 1). Strong correlation coefficients are obtained $r^2=0.98$ and 0.87 for the canopy volume class and stem circumference, respectively.

The age of *A. tortilis* trees is more explained by the canopy volume giving almost a linear relationship. No remarkable differences were observed between stem circumferences and canopy volume in most age classes. The estimated average age of the oldest individuals in the population reached 614 ± 91.7 years old. About 50% of the trees have an age range from 5 to 50 years, while only 12.5% of the trees are of age less than 5 years.

The canopy volume class distribution of the six study populations are shown in Fig. 2. All volume classes are represented in the first two populations occurring in the upstream of the wadis. The volume class distribution in the first population (wadi Manader) demonstrates that classes A and F are equally represented by 12.5% of the total population, while classes B, D and E are represented in total by 17.5%. The volume class C is represent by 22.5% of the total population. Alternatively, the volume class distribution in the second population (wadi Manader) shows more variation among classes than in the first population. The maximum contribution was for volume class C which is represented by 35.7%, while the lowest contribution is for classes A and E as both represented by total of 3.5% (Fig. 2).

The rest of the populations lack at least one or more volume class stages. Midstream population no. 3 lacks the two volume classes A and E. The volume class C shows the highest contribution (33.3%), while both classes B and F are represented by 10%. Population no. 4 lacks only the volume class A. The classes C and E are represented by 30%, while the lowest contribution was for class B which is only represented by 5%. The two populations no. 5 and 6 (downstream populations) are presented by volume classes A, B and C. The volume class B in population no. 5 has the highest contribution (65.8%) as compared to the other five populations (Fig. 2).

Phenology: The observations on vegetative growth of *A. tortilis* trees as represented by the development of new leaves or replacing either the shedded or senescing leaves over the year are shown in Fig. 3.

During January the leaves cover about 44% of the tree branches while the rest of the branch was naked (Figs. 3 and 4). The maximum leaf cover occurred in February (56%) where there was no additional phenological activity except lateral branch growth which continued till June where the apical part of the main branch gradually dies back and the new branches flourish (Fig. 3). The leaf senescence on the main branch increased till June reaching 64%. The minimum leaf cover takes place in November (8%) where the branches seem to be naked due to leaf senescence and shedding (Figs. 3 and 4). During December, the leaf cover reached about 38%.

A. tortilis flowered twice in the year. The first flowering event begins on old branches in March followed by peak fruiting in May. The second flowering event begins on the new braches in July followed by peak fruiting in September-October. The second flowering event is more pronounced and results in higher amounts of fruit production as compared to the first flowering event (Fig. 3).

Life table and fecundity schedule: The survivorship curve (L_x) as illustrated in Fig. 5 demonstrates sharp decline in survivorship values from flower bud to juvenile life stage, where L_x value reached 4.5×10^{-7} (Table 2). This is followed by gradual and slight increase in the L_x values towards the adult stage E before it ends at stage F with L_x value of 2.2×10^{-7} .

The mean expectation of future life (e_x) for the different cohorts surviving to successive years is shown

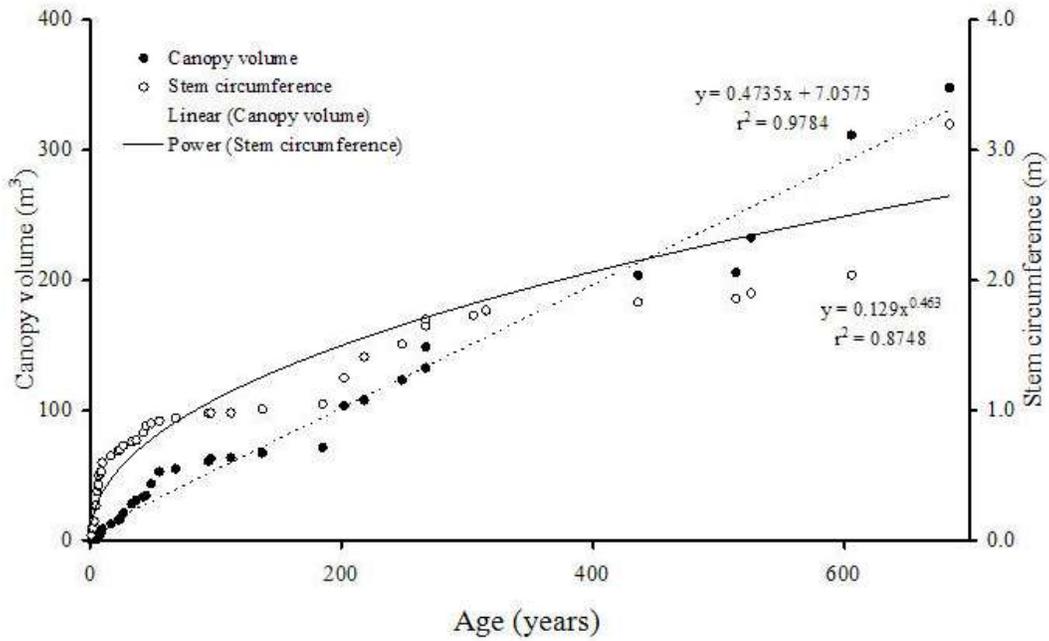


Fig. 1: Age, canopy volume classes and stem circumference relationships in the study population of *A. tortilis*

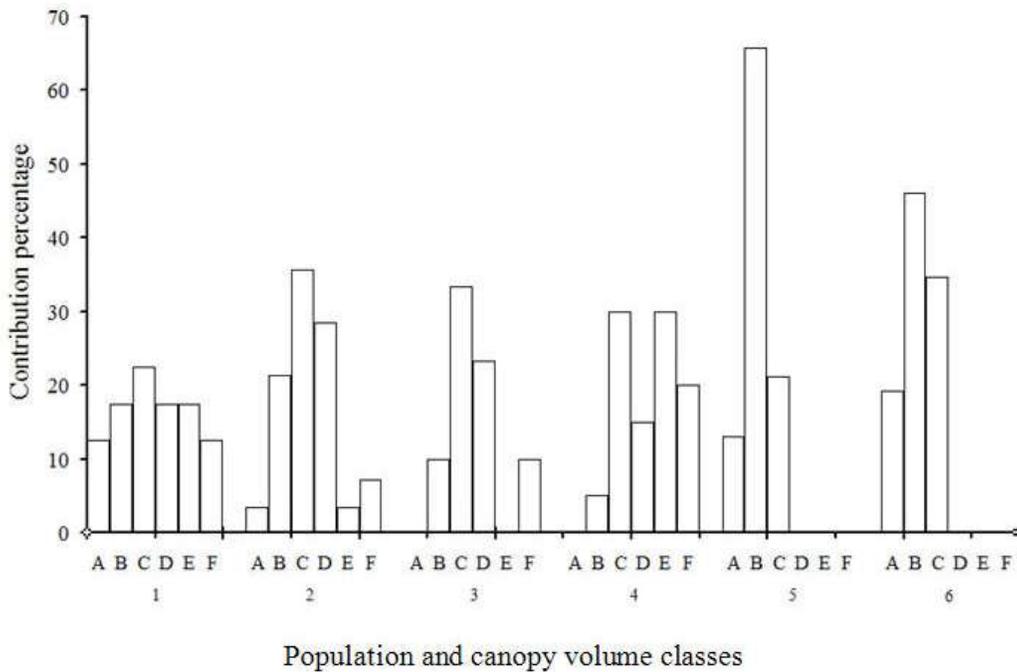


Fig. 2: Canopy volume class distribution in the six study populations. Volume classes are: A $\leq 1\text{ m}^3$, B=1-10 m^3 , C=10-50 m^3 , D=50-100 m^3 , E=100-200 m^3 and F $\geq 200\text{ m}^3$

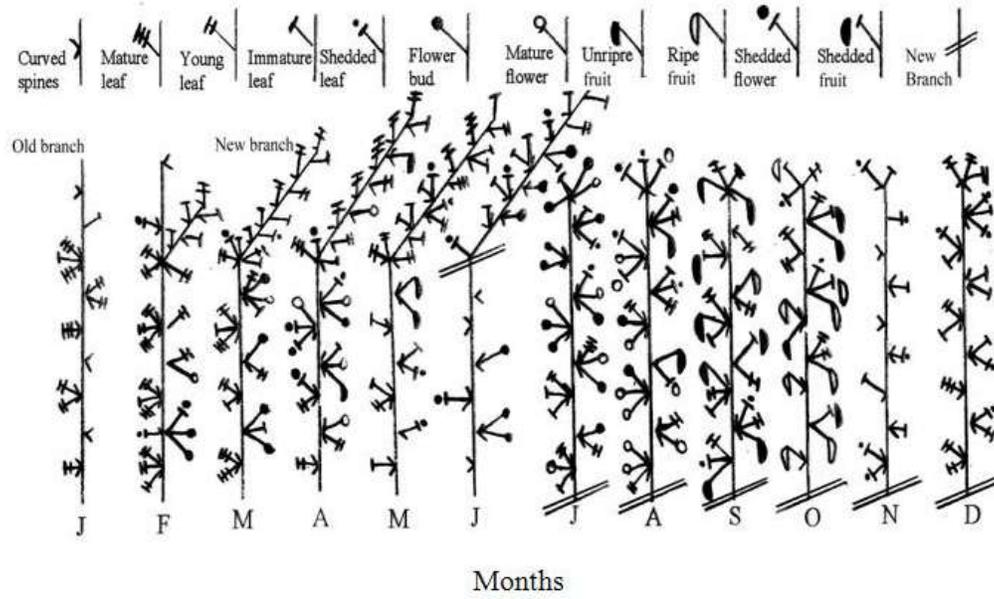


Fig. 3: Phenological monitoring of *A. tortilis* growing branches observed during one year of growth

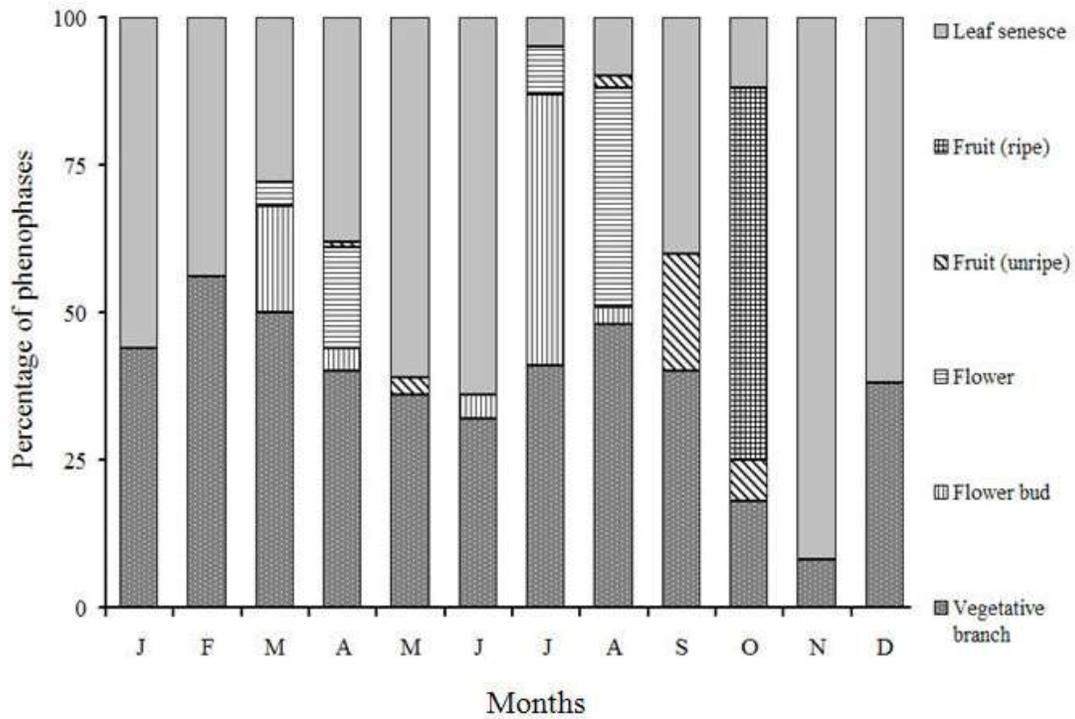


Fig. 4: Percentage of phenophases of *A. tortilis* population during one year of growth

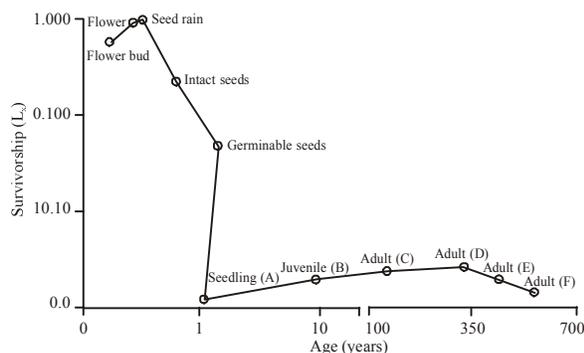


Fig. 5: Survivorship curve (log scale) of *A. tortilis* population

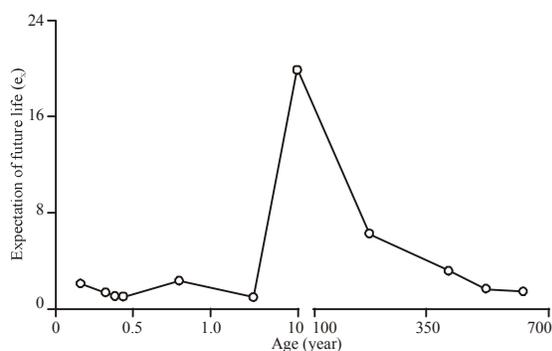


Fig. 6: Expectation of future life (e_x) of *A. tortilis* population

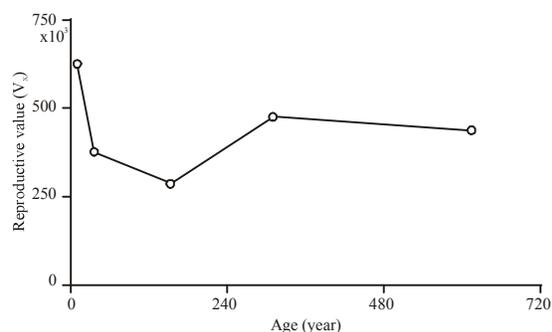


Fig. 7: Age specific reproductive value (V_x) of *A. tortilis* population

in Fig. 6. The e_x values showed no observed variation from flower bud to juvenile stage, where the later stage is followed by sharp increase with maximum value of expectation of future life (19.86) at age 9 years. The curve shows steady decrease in all adult stages till age 614 year (Fig. 6).

The fecundity schedule (Table 2) as based on seed output from the two fruiting events shows the contribution made by the fraction of the population in different adult cohorts. The reproductive value V_x demonstrates that the seed production is not evenly distributed over the different adult cohorts (Fig. 7) where the largest value occurred in the population cohort of age around 10 years, then decreased towards the age of 150 years. The reproductive value for individuals around age 300 years old reached 478692, compared to value of 436285 for individual of age around 600 years.

DISCUSSION

Population demography: Usually Acacias in South Sinai are very inconspicuous and their relative abundance varies with site variation. In dry years or during long-lasting dry periods, populations experience high mortality and low recruitment [2, 3, 18, 26, 27].

Tree age and canopy volume are more correlated to each other than tree age and stem circumference ($r^2 = 0.98$ and 0.87 , respectively). For trees less than 200 years old, the stem circumference and canopy volume are contrasting. This agrees with the findings of van Rooyen *et al.* [28] and Alcorn *et al.* [29] for trees along the Nossob River bed in Kalahari Gemsbok National Park. This may be interpreted as oldest trees have reasonably well developed root system, which allow them to survive through the drought periods [21, 30]. In agreement with Guerrant [31], the death rate significantly declined as the age increased. Significant difference was found between the two canopy volume classes A ($<1 \text{ m}^3$) and B ($1-10 \text{ m}^3$). This may be interpreted as a function of the tree size [32-34]. This difference was reduced with age increase till 50 years old trees which appeared healthier, greener and have a dense canopy than any other canopy volume class. The remaining age classes, older than 200 years did not show significant difference in tree canopy volume. Similar findings were reported by Steenkamp [32], Barnes [33] and Wiegand [35].

The disappearance of large volume classes is probably the result of the intense human impact together with other factors such as drought. As the degree of isolation of *A. tortilis* population decreased, the populations are subjected to greater impact due to the high grazing rate, mainly by camels [1, 36].

Phenology: The phenological spectrum reflects the annual cycle of growth and flowering of *Acacia* with the climatic

conditions and change of water supply during the year. The field observations demonstrates the occurrence of partial defoliation during the hot and dry summer may be considered as an adaptation to the climatic conditions dominating in South Sinai desert. The flush of new leaves seems to be favoured by high temperatures and high humidity [36]. The first rain may occur around November where leaf shedding reaches its maximum. It was observed that even in trees with partial leaf shedding, most of mature fruits occurred on the naked branches. This observation indicted that perhaps the leaf growth do not affect flowering, but it may inhibit fruit development on the same branch.

A complete leaf shedding in summer is not common [37, 38]. In some years, summer leaf shedding may occur even in wet habitats. This leaf senesce may be partially attributed to the high temperatures within the canopy of the trees than in the surrounding air [39].

The identity of the phenological behaviour is manifested by the flowering period [36]. The phenological cycle of *Acacia* is the result of endogenous rhythm which is a relict of its original phenology that is well adapted to its original habitat in Africa [40]. Slight modifications may develop in response to the ample water supply in winter and early summer. This is demonstrated by the decreased amounts of leaf shedding during the summer dry season in South Sinai, in the same time where tree crown never show complete leaf shedding around the year. This behaviour disqualifies the use of the term "evergreen" for *A. tortilis* and suggested the term "raingreen".

From the reproductive ecology point of view, another aspect of the phenological cycle is the importance of the existence of two flowering-fruited seasons during spring and summer. These two flowering-fruited events can be explained by presence of more than one overlapped green branch growths of *A. tortilis* on the same individual tree [41].

Life table and fecundity schedule: The life table and fecundity schedule, as summarized in the age-specific survivorship curve, reflects high mortality of flowers, seeds and seedling as it represent the most sensitive life stages in *A. tortilis* life span. This is followed by low mortality of juveniles and adults which are considered the strongest life stages. The average mortality rate per year (q_x) and killing power (K_x) increased towards the seedling stage and then fell towards the juvenile stage. This shows that early reproductive stages from the flower bud to seedling

are at greater risk than the juvenile and adult individuals. According to Hegazy [16, 25] and Harper and White [42], this survival pattern means that selective forces in the habitat are acting on the weakest stages of the life cycle.

The combination of the expectation of future life (e_x), reproductive value (V_x) of old individuals and their intrinsic rate of increase (r) per year indicates that the major contribution to the population was made by the early adult stage (10-50 years). The reason for the higher expectation of life of *A. tortilis* in this age range was not easy to elucidate, but it may relate to the low mortality rate (q_x) and killing power (K_x).

The net reproductive rate (R_0) of the whole population describes its recruitment potential. A value of 0.281 indicates low increase in seed production. This shows the endangered situation of the population for maintaining its persistence over the long-term. This is confirmed by the negative intrinsic rate of increase (-0.00337 per capita per year). An interesting aspect of reproductive value (V_x) is that, although the population maintained relatively high values, it exhibits low intrinsic rate of increase. This indicates that high fecundity of adult individuals may not ensure maintenance of the population [17].

In conclusion, the demographic study reflects that *Acacia tortilis* populations are threatened unless conserved. Production of huge amounts of seeds may not ensure its successful regeneration. The seedling stage is extremely endangered due to low recruitment, long drought periods for successive years and human impacts. Life table and fecundity schedule analysis demonstrated that early reproductive stages from flower bud to the seedling stage have low expectation of future life and this should be taken into consideration for management of the species.

Conservation considerations: The findings of this study helps to put forward a management plan to conserve and to sustainably use the *Acacia* trees as based on demography, life table and fecundity schedule data analysis.

The survivorship curve of *Acacia* suggests that seed and seedling stages have the highest mortality risks in *A. tortilis*. The populations are in a declining state and their survival cannot be ensured without species conservation measures. The low intrinsic rate of increase may be due to the establishment of reproductively mature individuals from seeds was a lengthy and hazardous

process. Meanwhile, long-lived adult individuals are insufficient in number; therefore, conservation should be directed to protect the adult reproductive plants (age range from 10 to 50 years) which represent over 50% of the adult population. These age cohorts' provide a substantial contribution to future generations and are considered a resourceful genetic material for the population as long as they are able to produce viable seeds. In regions where conservation efforts were curtailed by severe lack of money or dearth of information about individual species, such as in South Sinai, demographic studies on survival, mortality and reproduction were the logical cost-effective studies to be undertaken [17, 25, 43], where thorough understanding of population dynamics and biology are critical for sound conservation plans [44, 45].

Some specific actions are required to conserve the species: a) Regular assessment of population dynamics through monitoring of demography, phenology and life table analysis of plant populations; b) Prevention of fruit and seed collection and protection of plant seedlings around the mother trees; c) Nursing the seedlings and juvenile plants for use in restoration of degraded populations or afforestation of appropriate habitats; and d) Regulation of local human activities, e.g. grazing, wood collection and ecotourism.

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