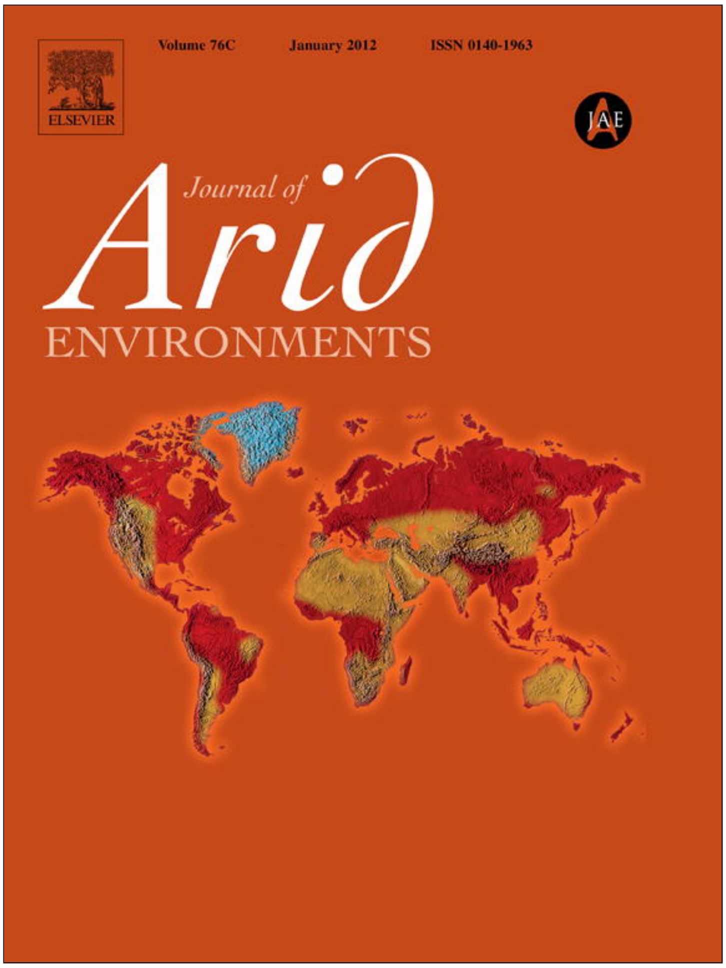
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Dorcas gazelle and livestock use of trees according to size in a hyper-arid landscape

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A B S T R A C T

We examined the relationship between Dorcas gazelle and livestock use of trees according to size. Our data suggest that Dorcas gazelle use of trees differs according to species and size. Larger *Acacia* trees are used for territorial purposes whereas smaller trees may be visited within the course of grazing. Our data show that tree size also determines potential food availability. On shorter trees, gazelles can graze on leafy vegetation at a range of heights between ground level until the top of the tree. In contrast, leafy vegetation on taller trees is available at heights that are often too high for gazelles to reach. However, larger trees provide another food source for gazelles not found on shorter trees such as seed pods, which were only found on larger *Acacia radiana* trees. There was no significant difference between the size of the other tree species that were used and not used by gazelles. Goats, camels, and donkeys were typically associated with only larger trees, regardless of species. Dorcas gazelle conservation will require maintaining viable *Acacia* populations that are characterized by recruitment and a variation of tree sizes and ages.

1. Introduction

The use of prominent landmarks by territorial species reduces costs associated with territoriality such as time and energy spent establishing and defending territories (LaManna and Eason, 2003). Many gazelle species use middens, sometimes referred to as latrines or dung piles, for activities related to territory maintenance, advertisement, and olfactory communication (Walther et al., 1983; Walther, 1984; Brashares and Arcese, 1999; Attum et al., 2006; Wronski and Plath, 2010). Given the investment involved in maintaining a midden, gazelles do not randomly place middens, but rather middens are likely to be placed near large landmark sized trees (Attum et al., 2006; Wronski and Plath, 2010), and concentrated along territorial boundaries (Walther et al., 1983) or within the core of an individual's homerange (Wronski and Plath, 2010).

Acacia trees are keystone species of arid ecosystems whose shade provides higher soil water content and lower soil temperatures beneath the tree canopy. As a result, the underneath of *Acacia* canopies often contains high concentrations of annual plants (Dean et al., 1999; Munzbergova and Ward, 2002), which are vital to herbivorous mammals. Animals that visit *Acacias* will contribute to the high soil nutrient content underneath *Acacia* canopies through defecation and urination that further improve soil quality (Dean et al., 1999). In addition, *Acacia* trees are recognized as keystone species due to their use as a refuge for many wildlife and nesting habitat by numerous bird species (Dean et al., 1999; Hollamby et al., 2006). *Acacia* trees are also highly valued by pastoralists as the trees are relatively drought resistant, used for firewood, charcoal production, and fodder for livestock, and the tree gum is used for medicinal purposes (Krzywinski and Pierce, 2001; Mahmoud, 2010).

Livestock and feral wildlife populations often have negative consequences on native wildlife. For example, feral animals compete with native ungulates (Madhusudan, 2004), modify habitat through grazing (Zalba and Cozzani, 2004), act as a vector for disease transmission (Morgan et al., 2006), or prey on native wildlife (Fordham et al., 2006). In arid systems, livestock and feral animals may compete with native ungulates for limiting resources such as vegetation and access to waterholes (Attum, 2007; Attum et al., 2009). Gazelle populations worldwide are experiencing population declines as a result of overhunting, habitat destruction,

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and habitat degradation (Ryder, 1987; Newby, 1990). Dorcas gazelles, *Gazella dorcas,* have experienced population declines in Egypt due to the above-described reasons (Saleh, 1987). Egypt's largest Dorcas gazelle populations occur in the southern Eastern desert (El Alqamy and Baha El Din, 2006).

In this study, we examined the relationship between Dorcas gazelle and midden presence in relation to tree size and species. We hypothesized that if middens are used for territorial or communication purposes, then they would tend to be placed at the largest trees in the immediate area, as such trees would be more conspicuous to conspecifics than smaller trees. We also examined the relationship between feral donkey and livestock presence with tree size and species. We predicted that livestock and feral donkey presence would be associated with larger trees due to larger trees providing more shade and food.

2. Methods

2.1. Study area

This study occurred in Egypt's Eastern Desert, Red Sea mountains located within Wadi El Gemal National Park (N 24° 27′, E 34° 56′; 7000 km^2), Egypt. The study site is characterized by a hyper-arid climate, with hot, rainless summers and mild winters. Precipitation is not an annual event and is characterized by high temporal and spatial variation. Rainfall is often localized in the form of short, heavy rains that may result in flash flooding. The monthly mean temperature varies between 24 and 38 °C during the summer and 12–26 °C during the winter (Baha El Din, pers. comm.). Camels are owned by the local community residing in the park, but range freely unattended during the day to graze and often return to their owners at night. There are feral donkey populations within the park as a result of the local community releasing unneeded donkeys in the past. Goats/sheep are owned by the local people residing with the park and are usually accompanied by herders while grazing.

2.2. Methodology

We sampled four valleys (wadi), Wadi Eraiar, Wadi Ramareem, Wadi El Gemal, and Wadi Um El Abas, between 3/16–3/28, 2009. The surveys begin from the mouth of the valley and end when the valleys become too narrow to be suitable gazelle habitat (Attum, 2007). The valleys where characterized by sandy or silty beds and contain the densest vegetation in the national park. These four valleys were chosen because they are known to contain the largest gazelle population in Wadi El Gemal National Park.

We used ArcMap 9.0 to map every wadi into polygon units. A polygon unit was delineated by drawing a two kilometer long, line through the center of the wadi. Then the area of wadi floor for each polygon unit was drawn along the border of the valley walls surrounding the two kilometer line. We used Hawth's Analysis Tools to randomly select three sampling points within each polygon (Beyer, 2004). A total of 47 polygons were delineated and 141 points sampled.

We used a 4-wheel-drive vehicle and a hand-held GPS unit to navigate to our random point. For every point surveyed, the following data were collected: date, time of visitation, tree/shrub species, maximum height measured through the use of a clinometer, and the maximum canopy diameter for every tree/shrub within a 100 m radius from the sampling point. Gazelle, feral donkey, camel, and goat/sheep were considered present if tracks or black/dark brown fecal pellets were found within a 10 m radius from the base of the tree. We defined a midden as an accumulation of feces with a minimum diameter of 25 cm.

We examined *Acacia tortilis radiana* potential availability as a food item during the dry season. These surveys occurred between May 1and May 6, 2010 in Wadi Gemal. We sampled 28 *Acacia tortilis radiana* and recorded tree height, number of fallen seed pods on the ground, and the height of the lowest green leaf.

To examine if Dorcas gazelle and livestock presence around trees is dependent upon size (height and canopy diameter), we compared the size of the tree in which the animal was found to those trees without any signs of the respective animal presence. We compared the sizes of the trees with middens to those trees without middens, to assess whether gazelles used midden sites based on tree size. We also compared the size of trees used as midden sites to trees used by gazelles but not for midden purposes. We analyzed each comparison separately through the use of a MANOVA. If the MANOVA was significant, we then examined which tree size characteristic, height and canopy diameter, was significantly different between treatments through the use of ANOVA. We analyzed the relationship between *Acacia tortilis radiana* tree height with the number of fallen seed pods and the lowest green leaf height through the use of separate linear regressions.

3. Results

The plant species recorded in our study include 58 *Acacia tortilis raddiana*, 18 *Acacia tortilis tortilis*, 131 *Balanites aegyptiaca*, 1 *Calotropis procera*, 6 *Salvadora persica*, 29 *Tamarix aphylla*, and 30 *Tamarix nilotica*. Gazelle signs ($n = 61$) were present at 69% ($n = 40$) of *A. t. raddiana*, 50% ($n = 9$) of *A. t. tortilis*, 10% ($n = 3$) of *T. nilotica*, and 6.9% ($n = 9$) of *B. aegyptiaca*. A total of 25 middens were found

Table 1
The relationship between tree size and animal presence. Present = If one of the following signs: tracks, fecal pellets, or middens were found within the vicinity of the tree. GNM = gazelle signs, tracks or fecal pellets were present but no midden was found. Midden = gazelle midden present within vicinity of the tree. All measurements reported as meters.

Species	Signs	*Acacia*			*Balanites aegyptiaca*			*Tamarix*		
		N	Height	Canopy	N	Height	Canopy	N	Height	Canopy
Dorcas gazelle	None	27	5.1 ± 0.6	38.3 ± 9.0	122	5.5 ± 0.4	51.8 ± 5.4	56	3.4 + 0.2	100.6 ± 19.0
	Present	49	6.0 ± 0.4	53.1 ± 6.3	9	7.7 ± 0.4	64.3 ± 8.9	3	3.2 + 1.0	110.7 ± 66.6
	No midden	54	5.1 ± 0.4	42.3 ± 6.5	122	5.6 ± 0.3	52.6 ± 5.2	59	3.4 + 0.2	101.1 ± 18.2
	GNM	27	5.0 ± 0.6	46.3 ± 9.6	6	7.3 ± 0.4	68.9 ± 13.2	0		
	Midden	22	7.1 ± 0.4	61.4 ± 7.6	3	8.4 ± 0.8	55.1 ± 2.9	0		
Camel	None	19	4.2 ± 0.8	24.8 ± 8.7	31	1.5 ± 0.3	4.5 ± 1.9	37	3.0 + 0.2	61.3 ± 14.8
	Present	57	6.2 ± 0.4	55.5 ± 6.0	100	6.9 ± 0.3	67.6 ± 5.8	22	4.1 + 0.3	168.1 ± 38.7
Goat	None	66	5.4 ± 0.4	42.6 ± 5.1	84	4.05 ± 0.4	27.6 ± 4.6	59	3.4 + 0.2	101.1 ± 18.2
	Present	10	7.6 ± 1.0	82.5 ± 18.0	47	8.5 ± 0.4	97.4 ± 8.0	0		
Donkey	None	53	4.9 ± 0.4	43.5 ± 6.5	130	5.6 ± 0.3	53.0 ± 5.1	59	3.4 + 0.2	101.1 ± 18.2
	Present	23	7.4 ± 0.5	57.9 ± 8.4	1	5.5	3.9	0		

within the vicinity of vegetation, with 20 near *A.t. raddiana*, 2 near *A. t. tortilis*, and 3 near *B. aegyptiaca* (Table 1). Camel dung was the most common livestock dung found ($n = 187$), followed by goats ($n = 61$), and feral donkey dung was the least common ($n = 24$).

There was no significant difference in size between trees used by gazelles and those not used by gazelles (MANOVA: *Acacia*: $F_{2, 73} = 0.96$, $p = 0.39$; *B. aegyptiaca*: $F_{2, 128} = 2.25$, $p = 0.113$; *Tamarix*: $F_{2, 56} = 0.07$, $p = 0.93$; Table 1). However, *Acacia* trees with middens were significantly larger than *Acacia* trees without middens (MANOVA: $F_{2, 73} = 3.88$, $p = 0.025$) and trees without middens but used by gazelles (MANOVA: $F_{2, 46} = 7.21$, $p = 0.031$). *Acacia* trees with middens were significantly taller than *Acacia* trees without middens (ANOVA: $F_{1, 74} = 7.76$, $p = 0.007$) and trees without middens but used by gazelles (ANOVA: $F_{1, 47} = 3.74$, $p = 0.010$). There was no significant difference between canopy diameter of *Acacia* trees with middens and *Acacia* trees without middens (ANOVA: $F_{1, 74} = 2.84$, $p = 0.096$) and *Acacia* trees without middens but used by gazelles (ANOVA: $F_{1, 47} = 1.42$, $p = 0.24$).

There was a significant linear relationship between *Acacia* tree height and the lowest green leaf height ($F_{1, 26}$, $F = 6.73$, $p = 0.015$). As tree height increased, the lowest green leaf height increased from the ground ($B = 0.12$_SE 0.05, $t = 2.59$, $p = 0.015$; Fig. 1). There was no significant linear relationship between tree height and the number of *Acacia* seed pods on the ground ($F_{1, 26}$, $F = 1.41$, $p = 0.25$). However, no seed pods were found beneath *Acacia* trees with a height less than 3.8 m (Fig. 1).

There was no significant size difference between *B. aegyptiaca* trees with middens and *B. aegyptiaca* without middens (MANOVA: $F_{2, 128} = 2.37$, $p = 0.097$) or trees that did not have middens but used by gazelles (MANOVA: $F_{2, 6} = 1.35$, $p = 0.33$). No middens were found within the vicinity of *Tamarix* shrubs (Table 1).

All livestock species visited trees that were significantly larger than trees not visited by livestock (Table 1). Camels were found at trees that were significantly larger (MANOVA: *Acacia*: $F_{2, 73} = 4.05$, $p = 0.022$; *B. aegyptiaca*: $F_{2, 128} = 37.95$, $p < 0.0001$; *Tamarix*: $F_{2, 56} = 8.14$, $p = 0.001$), being both taller (ANOVA: *Acacia*: $F_{1, 74} = 6.69$, $p = 0.012$; *B. aegyptiaca*: $F_{1, 129} = 75.63$, $p < 0.0001$; *Tamarix*: $F_{1, 57} = 9.13$, $p = 0.004$) and having more cover (ANOVA: *Acacia*: $F_{1, 74} = 7.04$, $p = 0.010$; *B. aegyptiaca*: $F_{1, 129} = 35.79$, $p < 0.0001$; *Tamarix*: $F_{1, 57} = 9.14$, $p = 0.004$) than trees not used by camels. Goats were found at trees that were significantly larger (MANOVA: *Acacia*: $F_{2, 40} = 5.63$, $p = 0.007$; *B. aegyptiaca*: $F_{2, 128} = 36.56$, $p < 0.0001$), being significantly taller (ANOVA: *Acacia*: $F_{1, 41} = 10.77$, $p = 0.002$; *B. aegyptiaca*: $F_{1, 129} = 61.00$, $p < 0.0001$) and having more cover (ANOVA: *Acacia*: $F_{1, 41} = 0.19$, $p = 0.067$; *B. aegyptiaca*: $F_{1, 129} = 65.90$, $p < 0.0001$) than trees not used by goats. No goat signs were found within the vicinity of *Tamarix* shrubs. Donkeys were found at *Acacia* trees that were significantly larger (MANOVA: $F_{2, 73} = 8.22$, $p = 0.001$), being significantly taller (ANOVA: $F_{1, 74} = 13.28$, $p < 0.0001$) but not having significantly more cover (ANOVA: $F_{1, 74} = 1.65$, $p = 0.20$) than *Acacia* trees not used by donkeys. Donkeys were only found within the vicinity of one *B. aegyptiaca* and no signs were found within the vicinity of *Tamarix* shrubs.

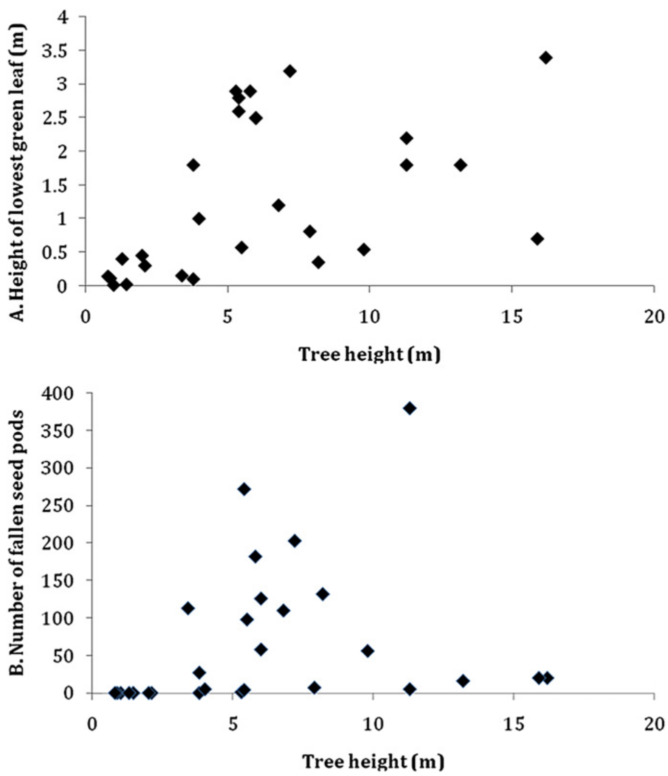

Fig. 1. The relationship between tree height (m) and the height of the lowest green leaf and the number of fallen seed pods.

4. Discussion

Our data suggest that Dorcas gazelle use of trees differs according to species and size. Dorcas gazelles visited numerous tree species, but more often visited *Acacia* trees despite *B. aegyptiaca* being the most common tree. Larger *Acacia* trees are used for territorial purposes whereas smaller trees may be visited within the course of grazing. Dorcas gazelles, just like other gazelle species, placed middens within the vicinity of larger *Acacia* trees which make better advertisement sites due to the conspicuousness of the larger trees (Attum et al., 2006; Wronski and Plath, 2010). In addition, larger trees provide more shade and cover from predators than smaller trees and are therefore more likely to be visited or noticed by conspecifics.

Ungulates will often utilize a limiting resource, regardless of quantity, in a resource poor environment (Attum et al., 2009). Dorcas gazelles opportunistically utilize any tree regardless of size, which is not surprising, given the rarity of vegetation during the dry season. On shorter trees, gazelles can graze on leafy vegetation at a range of heights between close to ground level until the top of the tree. In contrast, leafy vegetation on taller trees is available at heights that may be too high for gazelles to reach. However, larger trees provide another food source for gazelles not found on shorter trees such as seed pods, which were only found on *A. t. radiana* trees with an approximate height of four meters or more (Fig. 1).

The low use *B. aegyptiaca* trees was surprising because this species was the most common at our study site and gazelles are known to feed on *B. aegyptiaca* (Grettenberger and Newby, 1986; Grettenberger, 1987; Hall, 1992). We do not have any logical explanation as to why Dorcas gazelles used *B. aegyptiaca* trees less than *Acacia* trees. Gazelles used *Tamarix* trees the least, which is not surprising given that *Tamarix* are believed to be the poorest forage of the three species (El-Beheiry and El-Kady, 1998; El Seed et al., 2002; Araya et al., 2003). Although *T. aphylla* and *T. nilotica* are considered trees, in the Wadi Gemal National Park both species have a shrub-like morphology, and are therefore less likely to be used as territorial landmarks.

Dorcas gazelles have the potential to experience exploitive and interference competition from livestock. Livestock and feral animals are more water dependent than gazelles and must drink regularly (Attum, 2007; Attum et al., 2009). Livestock are therefore more likely to retreat to the shade of larger trees to avoid the high daytime temperatures and aid in water conservation. Humans also assist livestock in providing a form of interference competition because gazelles may avoid large trees visited by livestock and pastoralists, due to gazelles viewing humans as predators (Grettenberger, 1987). Gazelles maintain middens at larger trees, but may visit smaller *Acacia* trees in order to avoid livestock or feral donkeys and feed on leafy vegetation. Although there is the potential for competition between livestock and Dorcas gazelles over large trees, livestock consumption of seed pods may actually increase *Acacia* recruitment by reducing seed mortality by burchid beetles and promoting germination through enhancing the scarification of the hard seed coat during digestion (Rohner and Ward, 1999; Goheen et al., 2004). In addition, some studies have shown that moderate grazing by livestock does not negatively impact and in some cases may promote *Acacia* growth (Oba, 1998; Seymour, 2008). It is unknown if the gazelle population is large enough to maintain moderate grazing pressure without the presence of livestock. The availability of seed pods on the ground suggest there is not overgrazing or exploitative competition for seed pods between livestock/feral donkeys and Dorcas gazelles in Wadi Gemal at the time of this study.

The feral donkey population is probably more detrimental to gazelles than livestock. Whereas livestock may compete with gazelles over food, the feral donkeys may be contributing to tree mortality by sometimes consuming *Acacia* tree bark (pers. observ). In addition, feral donkeys also degrade water quality at waterholes used by gazelles and may discourage native ungulates from utilizing some waterholes (Attum et al., 2009). We therefore advocate that the feral donkey population needs to be reduced through regular culling (Carrion et al., 2007). However, donkeys should not be removed without the consultation of the local community. Although the donkeys are feral, the local community view the population as a potential resource in which a donkey could be caught and either eventually domesticated or sold in the market during economic distress.

Charcoal production from *Acacia* trees may also negatively impact Dorcas gazelle populations. The local pastoralists historically produced charcoal from burning dead *Acacia* trees (Andersen and Krzywinski, 2007). However, it is believed that some people may resort to burning live trees to produce charcoal during economic distress (Andersen and Krzywinski, 2007). The loss of large *Acacia* trees negatively impacts gazelle populations by reducing food and refuge availability. In addition, the loss of large trees may indirectly affect social the behavior of Dorcas gazelles because animals are losing conspicuous landmarks that could be used for midden sites. Prominent landmarks are often used to delineate territorial borders, which reduce the costs associated with territoriality such as time and energy spent establishing and defending territories (LaManna and Eason, 2003). The disruption of the social structure for a territorial species can affect the population dynamics by indirectly impacting survival and reproduction (Manor and Saltz, 2003).

We propose a conservation framework for Egypt's deserts in which *Acacia* trees are recognized as the keystone species and gazelles considered an umbrella and flagship species. Dorcas gazelle conservation will require maintaining viable *Acacia* populations that are characterized by recruitment and a variation of tree sizes and ages. Our study provides additional evidence showing the value of large *Acacia* trees as keystone species. Dorcas gazelles can be considered umbrella species due to their large activity ranges, whose protection would also include protecting *Acacia* populations. In addition, Dorcas gazelles can be considered a flagship species due to their anthropogenic attributes of being considered 'cute' and 'attractive' to humans, who would presumably be more likely to support gazelle conservation initiatives.

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