Resource availability predicts the distribution of Arabian gazelles (*Gazella arabica*) on Farasan Islands

***Torsten Wronski*[1,2,*], *Ping Sun*[3,4] *and Martin Plath*[4]**

[1] King Khalid Wildlife Research Center, Saudi Wildlife Authority, Riyadh, Saudi Arabia
[2] Conservation Programs, Zoological Society of London, London, UK
[3] Department of Biology, University of Rwanda, Huye, Rwanda
[4] College of Animal Science and Technology, Northwest A&F University, Yangling, China

ABSTRACT

Understanding how habitat parameters affect distribution patterns of threatened mammalian species is imperative for their conservation. Arabian gazelles (*Gazella arabica*) are on stark decline, while the population on Farasan Islands seems to be largely unaffected by human pursuit. Here, we asked whether vegetation-related parameters predict their local abundance. We conducted home range analyses, using cumulative kernel density estimates per study quadrant as an estimate of local abundance. We also established several vegetation-related parameters and subjected them to principal component (PC) analysis. Multiple regressions uncovered a statistically significant effect of PC 1 (with high axis loading from several food-related plants like *Acacia ehrenbergiana* Hayne), while PC 2 (*Capparis sinaica* Veill., a presumed source of hygroscopic water) had no effect on abundance estimates, probably because gazelles visit hygroscopic plants only sporadically. Our study is the first to provide empirical evidence that the occurrence of Arabian gazelles is tightly linked to that of *Acacia* spp..

Keywords: *Acacia*, *Capparis sinaica*, desert ungulate, home range, Saudi Arabia

INTRODUCTION

Understanding the distribution and local abundance of endangered species is imperative for the development of effective conservation measures (Caughley & Sinclair, 1994). Environmental factors restricting the population growth and/or density of a given taxon are resources like food (Hubbs & Boonstra, 1998), water (Dunham, 1994), cover and shade (Fabricius & Mentis, 1992), breeding sites like nest holes and dens (Powell & Fried, 1992), and other indicators of habitat quality, like presence or density of predators (Hubbs & Boonstra, 1998), parasites (Hudson et al., 2002) and competing species (Eccard & Ylönen, 2003). Mammals inhabiting desert regions must contend with high solar radiation and ambient temperatures, lack of freely available water, strong winds enhancing evaporative water loss, scarce vegetation cover, unpredictable food resources, and the challenges these factors impose on thermoregulation and water balance (Feldhamer et al., 1999). Desert-dwellers face a constant risk of evaporative and excretory water loss, and strong selection acts on mechanisms to maintain a positive water balance (Macfarlane, 1968; Schmidt-Nielsen, 1979). Still, a surprising number of ruminants live in arid and hyper-arid ecosystems, even though their large body size prevents them from seeking subterranean shelter, and herbivory is typically associated with high rates of water turnover (Nagy & Peterson, 1988). Key requirements of desert-dwelling ruminants are, therefore, shade to escape solar radiation and availability of water, or water-containing (hygroscopic) plants (Williams et al., 2001; Ostrowski et al., 2002).

The presence of Arabian gazelles (*Gazella arabica*) in the Farasan Islands Protected Area—an assemblage of islands located in the Red Sea (N 16°20’ to 17°20’, E 41°30’ to 42°30’)—has been known since at least 1825 (Groves, 1983), but information about their ecology and conservation status became available only one-and-a-half centuries later (see unpublished reports cited in Wronski, 2013). Today

---

[*] Corresponding author’s email address: t_wronski@gmx.de.

Farasan gazelles represent the largest remaining *G. arabica* population in Saudi Arabia (Cunningham & Wronski, 2011b) and probably the second largest in the world (Wronski, 2013). In recent decades *G. arabica* has been drastically decimated by hunting, habitat degradation and competition for food with domestic livestock (Mallon & Kingswood, 2001).

The Farasan population, with no opportunity to migrate, is expected to range close to their dietary limits (Cunningham & Wronski, 2011a). Large parts of the islands are weathered flat gravel plains, bare coral rock, and salt marshes with only a few *Acacia*-thickets or well-vegetated wadis (Flamand et al., 1988). It is, therefore, straightforward to predict that the distribution of Farasan gazelles is tightly linked to the availability of shelter (shade), especially in the form of *Acacia*-thickets (Vesey-Fitzgerald, 1952). Moreover, due to the lack of surface water, we expected access to succulent (hygroscopic) woody plants to represent another major limiting resource (Wronski & Schulz-Kornas, 2015). In our present study, we tested whether more individual home ranges are found (i.e., if more home ranges overlap) in regions with favorable ecological conditions. We focused on females to exclude any confounding effects of male territoriality (Wronski & Plath, 2010).

MATERIAL AND METHODS

Our study area (3 × 5 km) was situated on the main island, Farasan Kebir west of Al Qisar and Miharraq Village, and comprised abandoned gardens (wall-fenced patches of soft soil formerly used to grow crops, but nowadays often covered by ruderal plants like *Indigofera spinosa* Forsk. or invasive mesquite, *Prosopis juliflora* (Sw.) DC. (Wronski et al., 2012), open gravel plains, bare coral rock and an extensive *Acacia*-thicket (Wadi Matr; Figure 1). We divided the study area into 60 quadrants (each 500 × 500 m; Figure 1) and established the abundance of five major resources. Within each quadrant we assessed those parameters in five equidistant plots (each measuring 10 × 10 m) along a transect line from East to West and used mean values per quadrant for the statistical analyses. We collected data from 07 to 18 October 2008 (dry season, when availability of green plants was lowest; Figure 2) and from 26 January to 07 February 2013 (wet season, after Farasan Islands had received above-average rains in early 2013; Figure 3).

Vegetation-related variables were: (*i*) the *Acacia*-index (*Acacia ehrenbergiana* Hayne is the major woody food plant; Wronski & Schulz-Kornas, 2015), and (*ii*) the *Capparis*-index (*Capparis sinaica* Veill.). The maximum browsing height in our study area was estimated as 1.4 m (Figure 4). Therefore, we established both indices as the Green Leaf Frequency (GLF; Kent & Cocker, 1992) up to a height of 1.4 m, multiplied by the number of trees with available food within each plot. Available food was defined not only as green leaves, but also included pods and flowers, while pods, flowers and leaves fallen on the ground were not considered (Wronski & Schulz-Kornas, 2015). We leaned a 1 × 1.4 m sampling rectangle, divided into 140 sampling grids (each 10 × 10 cm), onto the greenest bush or tree in each plot at the side where maximum greenness was observed, and recorded presence or absence of green leaves in all sampling grids to establish the fraction of measuring grids containing green leafs. (*iii*) We established the frequency of seasonally growing annual herbs (including only those species known to be consumed by gazelles; see Tables 1, 2 in Wronski & Schulz-Kornas, 2015). The 1 × 1.4 m sampling rectangle was laid arbitrarily on the ground, and we once recorded the presence of herb species in each sampling grid to establish the fraction of grids containing palatable herbs. (*iv*) The *Indigofera*-density was established as the number of *I. spinosa* plants per quadrant, which is the major perennial herb consumed by gazelles (Wronski & Schulz-Kornas, 2015). (*v*) We established the *Acacia*-tree density as numbers of trees per quadrant.

The population density in the southern part of Farasan Kebir equals approximately 3.2 gazelles per km^2 (extrapolated from ground surveys between June 2009 and May 2011; see unpublished reports cited in Wronski, 2013). Our study area harbored about 110 females, organized in two large groups (see unpublished reports cited in Wronski, 2013). Fifty-one individuals could be individually distinguished by external bodily characteristics such as horn length and shape (Farasan gazelles have a high degree of horn deformations in females; Thouless & Al Basri, 1991; Lerp et al., 2016), facial marks, blood vessel patterns inside the ears or ear cuts, fur color, and scars, compiled in a photographic file card system (see Walther et al., 1983). Contrary to gazelles in areas with lower population densities due to human pursuit (Wronski & Plath, 2010), female groups on Farasan Islands are much larger and probably not entirely based on relatedness, but rather on the use of communal resting sites such as Wadi Matr (Figure 1). Group

---

[*] Corresponding author's email address: t_wronski@gmx.de.

membership and sizes were largely consistent over time, but some females occasionally visited other thickets and gardens.

A sufficient—but admittedly, relatively low—number of location fixes to calculate home range estimates could be collected for 17 females (i.e., 11 females in group one, 6 females in group two; 6 to 23 sample points per individual). We conducted daily patrols between 5:00 and 11:00 a.m. and occasionally between 5:00 and 7:00 p.m. from 26 March to 22 April, 03 June to 02 July and 07 to 18 October 2009, and from 10 to 19 February, 07 to 16 May and 14 to 20 June 2010 (in total 93 days). Patrols were carried out along existing tracks (app. 20 km) covering the entire study area. Individually distinguishable gazelles were haphazardly encountered and positional data recorded at the spots where the animal was first sighted (usually after it had moved away) using a Garmin GPS 12.

We used individual location fixes to generate kernel density estimations in ARCVIEW (version 3.0a) in combination with the Animal Movement Analysis Arcview Extension (Hooge, 1998) for each female. We used a fixed kernel density estimation (Worton, 1989), applying a grid of 300 × 300 m, reference smoothing and isolines plotted to the location density distribution. Since raw data on home-range overlap (see below) were not normally distributed (Kolmogorov–Smirnov test, $P < 0.05$), a bandwidth was chosen using least squares cross validation with a smoothing factor suggested by the *ad hoc* default (Silverman, 1986; Horner & Powell, 1990; Seaman & Powell, 1996). Independence and site fidelity tests were applied as described by Kenward (1987) and Spencer et al. (1990). We determined home range contours of individual females for the 90%, 70% and 30% home-range sections. We calculated an index of utilization frequency for each quadrant as follows: for each individual whose home range overlapped at least partially with the quadrant, the percentage of home range overlap with the respective quadrants was calculated, and percentage values of all females encountered in a given study quadrant were summed.

Vegetation-related variables showed a high degree of inter-correlation, as Spearman rank correlations found nine out of ten pair-wise correlations in the wet season and eight out of ten in the dry season to be significant (Table 1). Therefore, we subjected the five variables to a factor reduction (correlation matrix-based Principal Component Analysis, PCA) using varimax rotation and for both analyses retrieved two PC axes with Eigenvalues >1 (for axis-loadings see Table 2), cumulatively explaining 82.3% (wet season) and 73.4% (dry season) of the total variance, respectively. To test for effects of the vegetation-related ecological variables on home range distributions we used multiple regression analyses using the index expressing utilization frequencies for 30%, 70% and 90% home range cores as the dependent variables and PC 1 and 2 (see Table 2) as predictor variables. Wet and dry seasons were analyzed separately.

Results

Multiple regression analysis uncovered statistically significant effects of PC 1 on utilization frequencies. This pattern was apparent for both dry and wet seasons, and for 30%, 70% and 90% kernel home range cores (Table 3). PC 1 received strong positive axis loadings (i.e., ≥ 0.58) from the *Acacia*-index, herb frequency, *Indigofera*-density, and *Acacia*-tree density. PC 2, which received strong (≥ 0.93) loadings from the *Capparis*-index (Table 2), had no significant effect (Table 3). However, both PCAs explained only a small, albeit significant, portion of the total variance, namely 11.2% to 18.8% in the wet season and 11.2% to 21.7% in the dry season (wet season: $R^2 = 0.11$ to 0.19; regression ANOVA: $F_{2,59} =$ 3.59 to 6.58, $P = 0.003$ to 0.034; dry season: $R^2 = 0.11$ to 0.22; $F_{2,59} = 3.59$ to 7.91, $P = 0.001$ to 0.034). Exemplary scatter plots showing the relationship between utilization frequencies (cumulative 90% kernel home range cores) and PC 1 during the wet and dry seasons are presented in Figure 5. Notably, considerable variation in utilization frequency could be seen at sites with low vegetation cover (i.e., small values for PC 1 in Figure 5).

DISCUSSION

As a crepuscular species seeking shelter from predation in impenetrable terrain such as rocky slopes or dense vegetation, the local abundance of Arabian gazelles was predicted to be linked to the occurrence of *Acacia*-thickets (Vesey-Fitzgerald, 1952), which was confirmed in our present study on Arabian gazelles living on the Farasan Islands. Similarly, a recent investigation using observational data on the feeding

---

[*] Corresponding author's email address: t_wronski@gmx.de.

behavior as well as mesowear analysis highlighted the importance of *Acacia ehrenbergiana* Hayne as the primary food source for this gazelle population (Wronski & Schulz-Kornas, 2015).

Preformed water provides a significant portion of the total water intake in arid-adapted ungulates and is related to the ability of some species to survive extended periods of time without access to surface water (Taylor, 1968, 1972; Schmidt-Nielsen, 1979; Cain III et al., 2006). Given the absence of surface water, we predicted Farasan gazelles to be reliant on hygroscopic water contained in *Capparis sinaica* Veill. leaves and buds, and so the distribution of gazelles should coincide with the occurrence of *Capparis*-stands, which was not confirmed in our present study. We argue that other ecological factors (e.g., occurrence of *Acacia*-trees) are more important in determining home range locations and -overlap and that sporadic visits of *Capparis*-bushes (and possibly uptake of morning dew; Habibi, 1992) may suffice to secure proper water balance.

Generally, the effects detected in this study were weak, i.e. vegetation-related parameters explained only a small amount of the total variance when considering numbers of individuals whose home ranges overlapped in a given area. More specifically, pronounced variation in numbers of gazelles per study quadrant was observed at sites with low vegetation cover. A part of this variance may be explained by rather low numbers of individual positional data (see above) and thus, errors in the calculation of home range contours. However, this finding could also suggest that cover and structural heterogeneity may be more important determinants of gazelle home ranges than food availability per se, and it is well conceivable that gazelles seek shelter in rugged terrain and *Acacia*-thickets in the daytime but visit open plains and gardens for foraging at sunset and dawn. An alternative, not mutually exclusive explanation is that high population densities of the Farasan population lead to an increased resource competition, and so some individuals may be forced to occupy sub-optimal micro-habitats. In fact, the Farasan population remained rather stable, ranging in size between 1,013 animals in 1993 and 1,048 animals in 2013 (Wronski, 2013), suggesting that the carrying capacity may have been reached.

Our behavioral observations were carried out between dusk and dawn and included midday resting phases in shelter as well as activity phases at dusk and dawn when animals move to marshes and former gardens (Wronski et al., 2013; Wronski & Schulz-Kornas, 2015). This foraging in open terrain (marshes, gravel plains) is another important factor that needs to be considered when interpreting the small percentage of variance explained by vegetation-related variables in our current study. Overall then, our current study is the first to provide empirical evidence for the long-standing notion that the distribution of *G. arabica* on the Arabian Peninsula may be tightly linked to the occurrence of *Acacia*-dominated habitats (Vesey-Fitzgerald, 1952). Our findings could have important implications for the selection of suitable sites for future reintroduction programs using captive stock, e.g., from King Khalid Wildlife Research Center, in areas where the species has been locally eradicated (Wronski et al., 2011b).

ACKNOWLEDGEMENTS

We would like to thank H. H. Prince Bandar bin Saud bin Mohammed al Saud (President, Saudi Wildlife Authority, Saudi Arabia) for his permission and support to conduct scientific research on wildlife in the Kingdom. Special thanks are rendered to Mohammed Hassan Khairi who collected a large part of vegetation data on the Farasan Islands.

REFERENCES

Cain III, J.W., Krausman, P.R., Rosenstock, S.S. & Turner, J.C. (2006). Mechanisms of thermoregulation and water balance in desert ungulates. *Wildlife Society Bulletin* 34, 570-581.

Caughley, G. & Sinclair, A.R.E. (1994). *Wildlife Ecology and Management*. Cambridge: Blackwell.

Cunningham, P.L. & Wronski, T. (2011a). Population structure of Farasan gazelle. *Mammalia* 75, 157-161.

Cunningham, P.L. & Wronski, T. (2011b). Twenty years of monitoring of the Farasan gazelle *Gazella gazelle farasani* on the Farasan Islands, Saudi Arabia: an overview. *Oryx* 45, 50-55.

Dunham, K.M. (1994). The effect of drought on the large mammal population of Zambesi riverine woodlands. *Journal of Zoology (London)* 234, 489-526.

---

[*] Corresponding author's email address: t_wronski@gmx.de.

Eccard, J.A. & Ylönen, H. (2003). Who bears the costs of interspecific competition in an age structured population? *Ecology* 84, 3284-3293.

Fabricius, C. & Mentis, M.T. (1992). Modelling the habitat relations of kudu in arid savanna. *South African Journal of Animal Science* 88, 280-284.

Feldhamer, G.A., Drickamer, L.C., Vessey, S.H. & Merritt, J.F. (1999). *Mammalogy: adaptation, diversity, and ecology*. Boston, Massachusetts: WCB McGraw-Hill,.

Flamand, J.R.B., Thouless, C.R., Tatwany, H. & Asmode, J.-F. (1988). Status of the gazelles of the Farasan Islands, Saudi Arabia. *Mammalia* 52, 608-610.

Groves, C.P. (1983). Notes on the gazelles IV: the Arabian gazelles collected by Hemprich & Ehrenberg. *Zeitschrift für Säugetierkunde* 48, 371-381.

Habibi, K. (1992). Reproductive strategy of the Farasan gazelle *Gazella gazella farasani*. *Journal of Arid Environments* 23, 351-353.

Hooge, P.N. (1998). Animal movement analysis ArcView extensions. Glacier Bay Field Station, Alaska: USGS-BRD, Alaska Biological Science Center.

Horner, M.A. & Powell, R.A. (1990). Internal structure of home ranges of black bears and analysis of home range overlap. *Journal of Mammalogy* 71, 402-410.

Hubbs, A.H. & Boonstra, R. (1998). Effects of food and predators on the home-range sizes of Arctic ground squirrel (*Spermophilus parryii*). *Canadian Journal of Zoology* 76, 592-596.

Hudson, P.J., Dobson, A.P., Cattadori, I.M., Newborn, D., Haydon, D.T., Shaw, D.J., Benton, T.G. & Grenfell, B.T. (2002). Trophic interactions and population growth rates: describing patterns and identifying mechanisms. *Philosophic Transactions of the Royal Society, London B* 357, 1259-1271.

Kent, M. & Coker, P. (1992). *Vegetation description and analysis–a practical approach*. New York: Whiley & Sons.

Kenward, R. (1987). *Wildlife radio tagging, equipment, field techniques and data analysis*. London: Academic Press.

Lerp, H., Klaus, S., Allgöwer, S., Wronski, T., Pfenninger, M. & Plath, M. (2016). Phylogenetic analysis of true gazelles reveals repeated transitions of key ecological traits and provides novel insights into the origin of the genus *Gazella*. *Molecular Phylogenetics and Evolution* 98, 1-10, doi: 10.1016/j.ympev.2016.01.012.

Mallon, D.P. & Kingswood, S.P. (2001). *Antelopes, Part IV, North Africa, the Middle East and Asia. Global Survey and Regional Action Plans*. Gland and Cambridge: IUCN/SSC Antelope Specialist Group.

Nagy, K.A. & Peterson, C.C. (1988). *Scaling of water flux rates in animals*. Berkeley: University of California Press,.

Ostrowski, S., Williams, J.B., Bedin, E. & Ismail, K. (2002). Water influx and food consumption of free living oryxes (*Oryx leucoryx*) in the Arabian desert in summer. *Journal of Mammalogy* 83, 665-673.

Powell, R.A. (2000). Animal home ranges and territories and home range estimators. In L. Boitani & T.K. Fuller (Eds.), *Research techniques in animal ecology, controversies and consequences* (pp. 65-110). New York: Columbia State University Press.

Powell, R.A. & Fried, J.J. (1992). Helping by juvenile pine voles (*Microtus pinetorum*) growth and survival of younger siblings, and the evolution of pine vole sociality. *Behavioural Ecology* 4, 325-333.

Schmidt-Nielsen, K. (1979). *Desert animals: physiological problems of heat and water*. New York: Dover Publications,.

Seaman, D.E. & Powell, R.A. (1996). Accuracy of kernel estimators for animal home range analysis. *Ecology* 77, 2075-2085.

Silverman, B.W. (1986). Kernel methods for estimating the utilization distribution in home range studies. *Ecology* 70, 164-168.

Spencer, S.R., Cameron, G.N. & Swihart, R.K. (1990). Operationally defining home range: temporal dependence exhibited by hispid cotton rats. *Ecology* 71, 1817-1822.

Taylor, C.R. (1968). Hygroscopic food: a source of water for desert antelopes? *Nature* 219, 181-182.

Taylor, C.R. (1972). The desert gazelle: a paradox resolved. *Symposium of the Zoological Society of London* 31: 215-227.

---

[*] Corresponding author's email address: t_wronski@gmx.de.

Thouless, C.R. & Al Bassri, K. (1991). Taxonomic status of the Farasan island gazelle. *Journal of Zoology (London)* 223, 151-159.

Vesey-Fitzgerald, D.F. (1952). Wildlife in Arabia. *Oryx* 1, 232-235.

Walther, F.R., Mungall, E.C. & Grau, G.A. (1983*). Gazelles and their relatives. A study in territorial behavior*. Park Ridge, New Jersey: Noyes Publications.

Williams, J.B., Ostrowski, S., Bedin, E. & Ismail, K. (2001). Seasonal variation in energy expenditure, water flux and food consumption of Arabian oryx *Oryx leucoryx*. *Journal of Experimental Biology* 204, 2301-2311.

Worton, B.J. (1989). Kernel methods for estimating the utilization distribution in home range studies. *Ecology* 70, 164–168.

Wronski, T. (2013). Population development of Arabian Gazelles (*Gazella arabica*) on the Farasan Islands, Saudi Arabia. *Zoology in the Middle East* 59, 189-195.

Wronski, T. & Plath, M. (2010). Characterisation of the spatial distribution of latrines in mountain gazelles (*Gazella gazella*): Do latrines demark female group home ranges? *Journal of Zoology (London)* 280, 92-101.

Wronski, T. & Schulz-Kornas, E. (2015). The feeding ecology of Arabian gazelles (*Gazella arabica*) on the Farasan Islands, Saudi Arabia. *Mammalian Biology* 80, 87-95.

Wronski, T., Sandouka, M.A. & Butynski, T.M. (2011b). Twenty years of conservation and monitoring of re-introduced mountain gazelle in the Ibex Reserve, Saudi Arabia. In P.S. Soorae (Ed.), *Global Re-introduction Perspectives: 2011. More case studies from around the globe* (pp. 175-179). Gland and Abu Dhabi, Switzerland and UAE: IUCN/SSC Re-introduction Specialist Group and Environment Agency Abu Dhabi.

Wronski, T., Mosfer, A.N. & Plath, M. (2012). Endemic Farasan gazelle (*Gazella gazella farasani*) enhance the dispersal of invasive *Prosopis juliflora* on Farasan Islands, Saudi Arabia. *Terre et la vie – Revue d'Ecologie* 67, 329-337.

Wronski, T., Apio, A., Plath, M. & Ziege, M. (2013). Sex-difference in the communicatory significance of localized defecation sites in Arabian gazelles (*Gazella arabica*). *Journal of Ethology* 31, 129-140.

[*] Corresponding author's email address: t_wronski@gmx.de.

TABLES

Table 1. Correlation matrix (Spearman rank correlations) for all vegetation-related ecological variables considered in our present study. Significant effects are marked in bold.

A. Wet season	*Acacia*-index	*Capparis*-index	Herb frequency	*Indigofera*-density	*Acacia*-tree density
Acacia-index		$r = 0.27$ **$P = 0.037$**	$r = 0.63$ **$P = 0.000000027$**	$r = 0.44$ **$P = 0.00048$**	$r = 0.99$ **$P = 0.00000020$**
Capparis-index			$r = 0.29$ **$P = 0.023$**	$r = 0.22$ $P = 0.099$	$r = 0.30$ **$P = 0.021$**
Herb frequency				$r = 0.44$ **$P = 0.00050$**	$r = 0.63$ **$P = 0.00000051$**
Indigofera-density					$r = 0.42$ **$P = 0.00084$**
B. Dry season					
Acacia-index		$r = 0.37$ **$P = 0.0043$**	$r = 0.39$ **$P = 0.0021$**	$r = 0.49$ **$P = 0.000071$**	$r = 0.96$ **$P = 0.00000020$**
Capparis-index			$r = -0.055$ $P = 0.68$	$r = 0.0088$ $P = 0.95$	$r = 0.41$ **$P = 0.0012$**
Herb frequency				$r = 0.39$ **$P = 0.0025$**	$r = 0.38$ **$P = 0.0033$**
Indigofera-density					$r = 0.50$ **$P = 0.000062$**

---

[*] Corresponding author’s email address: t_wronski@gmx.de.

Table 2. Axis loadings for principal component (PC) 1 and 2 of vegetation-related ecological variables, calculated for the wet and dry seasons separately.

	Wet season		Dry season	
Variable	PC 1	PC 2	PC 1	PC 2
Acacia-index	0.89	0.22	0.95	0.14
Capparis-index	0.03	0.93	-0.01	0.98
Herb frequency	0.82	-0.261	0.69	-0.11
Indigofera-density	0.86	-0.24	0.58	-0.14
Acacia-tree density	0.91	0.21	0.95	0.15

---

[*] Corresponding author's email address: t_wronski@gmx.de.

Table 3. Results from multiple regression analyses using an index expressing the utilization frequency (cumulative home range overlap with a given quadrant) for 30%, 70% and 90% home range cores as the dependent variable and PC 1 and 2 (see Table 2) as predictor variables.

A. wet season	Factor	B ± SE	β	*t*	*P*
30%	PC 1	13.60 ± 4.07	0.40	3.34	0.001
	PC 2	-5.78 ± 4.07	-0.17	-1.42	0.16
70%	PC 1	16.23 ± 6.58	0.31	2.47	0.017
	PC 2	-6.93 ± 6.58	-0.13	-1.05	0.30
90%	PC 1	19.04 ± 7.73	0.31	2.46	0.017
	PC 2	-9.32 ± 7.73	-0.15	-1.21	0.23
B. dry season					
30%	PC 1	14.45 ± 4.00	0.42	3.61	0.001
	PC 2	-6.65 ± 4.00	-0.20	-1.66	0.10
70%	PC 1	17.22 ± 6.516	0.33	2.64	0.011
	PC 2	-8.03 ± 6.52	-0.15	-1.23	0.22
90%	PC 1	19.56 ± 7.69	0.32	2.54	0.014
	PC 2	-10.02 ± 7.69	-0.16	-1.30	0.20

---

[*] Corresponding author's email address: t_wronski@gmx.de.

FIGURES

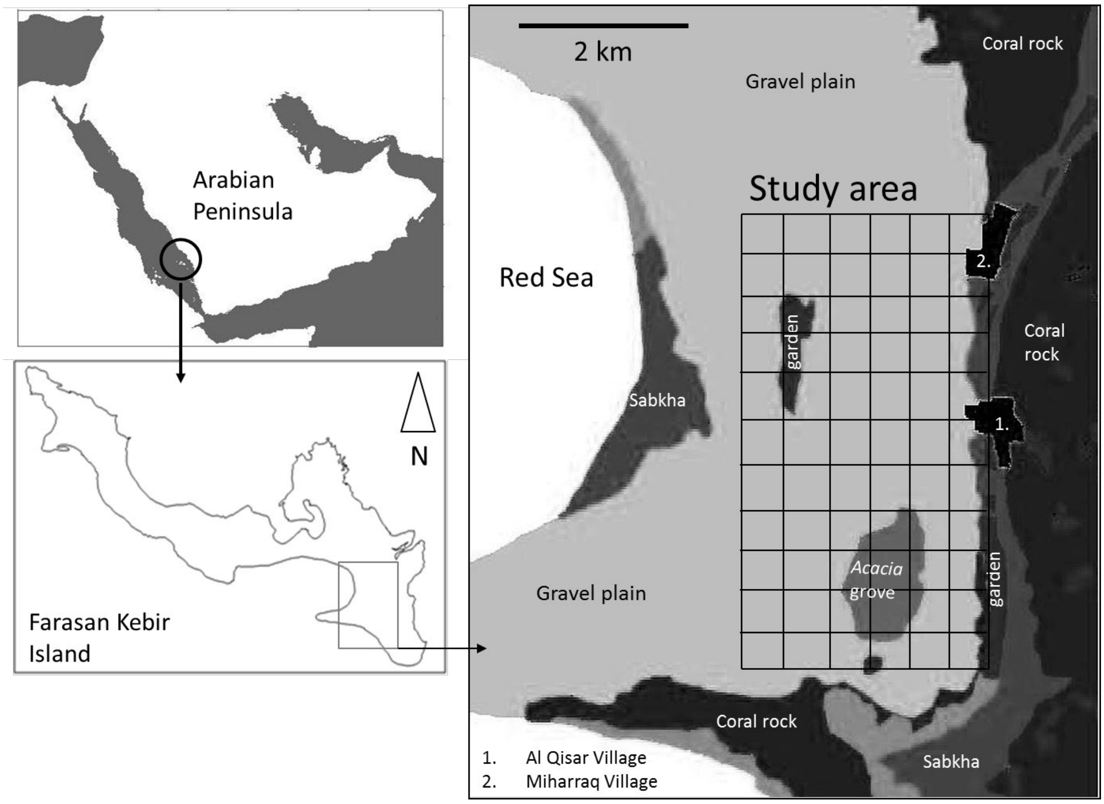

Figure 1. Location of the Farasan Archipelago in the Red Sea and location of our study area within the southern part of Farasan Kebir. The study area mainly comprises gravel plains, gardens and an extended *Acacia*-grove, and is overlaid with a 500 × 500 m grid, resulting in eleven study quadrants measuring 0.25 km^2 each. Vegetation-related variables were collected in five sampling plots per quadrant along transect lines extending from East to West (lower line of each section).

[*] Corresponding author's email address: t_wronski@gmx.de.

Figure 2. Exemplary group composition of female Farasan gazelles (a female with her last and second last female offspring—i.e., a matriline), resting inside the *Acacia* grove during the dry season.

---

[*] Corresponding author's email address: t_wronski@gmx.de.

Figure 3. Typical group composition of female Farasan gazelles (a female with her last and second last female offspring), browsing on various herbs during the wet season.

---

* Corresponding author's email address: t_wronski@gmx.de.

Figure 4. *Capparis sinaica* Veill. bush, a succulent species containing a high amount of hygroscopic water. The level pole indicates the maximum feeding height of Farasan gazelles (1.4 m).

---

[*] Corresponding author's email address: t_wronski@gmx.de.

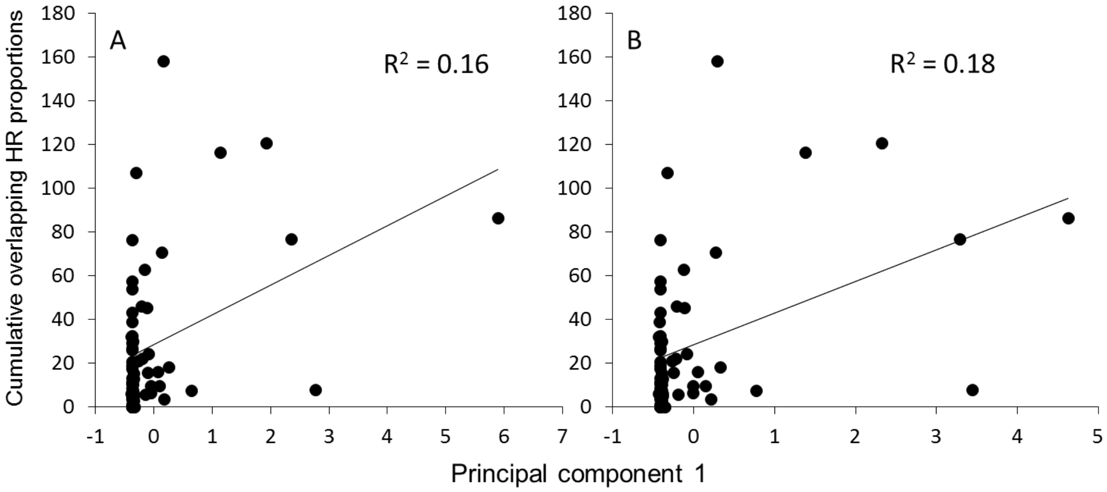

Figure 5. The relationships between cumulative overlapping 90% kernel home range (HR) proportions per quadrant (our measure of utilization frequency) and vegetation-related ecological variables (PC 1, see main text) for wet (A) and dry seasons (B). Note pronounced variation of gazelle abundances at low values of PC 1. Linear regression lines are shown.

---

[*] Corresponding author's email address: t_wronski@gmx.de.

BIOGRAPHICAL SKETCH

Lead author **Torsten Wronski** began his academic education in Hamburg, Germany, where he obtained his Bachelor of Science degree in 1997, followed by a Master of Science in 1999. His MSc study was carried out in cooperation with the German Technical Cooperation (GTZ) and the Integrated Pastoralist Development Program (IPDP) in Lake Mburo NP, Uganda, to develop a scheme for the sustainable utilization of impala antelopes in the adjacent Ankole Ranching Scheme. Here, Wronski focused on fire-induced changes in the foraging behavior of impala (*Aepyceros melampus*), comparing the relatively undisturbed National Park and the heavily used ranchlands surrounding the park.

In 2004, he obtained a PhD in Behavioral Ecology from the University of Hamburg. The study was carried out in Queen Elisabeth National Park, in Uganda, and was supported by the German Academic Exchange Service (DAAD). The study aimed at explaining why the bushbuck, the most common ungulate species in Africa, does not suffer from human impact while other antelope species are driven to the brink of extinction. The bushbuck is a generalist species, surviving in a number of human-modified habitats and is believed to be so successful because of his crepuscular and secretive lifestyle. Hence, Wronski studied the social and spatial organization of this overlooked antelope species.

Following his time as a PhD student, he became a postdoctoral fellow at the Zoological Museum in Hamburg. Together with Prof. B. Hausdorf, he implemented a long-term research project on the phylogeography and ecology of terrestrial gastropods in the tropical montane rain forests along the Albertine Rift Valley in East Africa (Uganda, Rwanda and DRC). The project is still ongoing and is funded by a research grant from the German Research Foundation (DFG) and several smaller grants from the Zoological Museum in Hamburg. Since land snails are easy to collect and due to their important role as decomposers in the ecosystem, they are believed to be good indicator species to assess the degree of deforestation and disturbance in tropical rain forests.

After his time as a postdoctoral fellow, Wronski moved to Saudi Arabia, where he headed the Field Conservation Department at King Khalid Wildlife Research Centre (KKWRC). Working with the Zoological Society of London (ZSL), he was involved in the management of several protected areas in Saudi Arabia and advised the Saudi Wildlife Authority (SWA) on wildlife reintroduction and conservation management. His work included scientific breeding of endangered ungulates, project planning and reporting, budgeting, and capacity building of Saudi rangers and protected area managers. He implemented ranger-based camera trapping surveys, carried out the post-release monitoring of reintroduced ungulates and conducted regular game counts in several protected areas.

In early 2013, Wronski started teaching Ecology and Wildlife Management at the University of Rwanda. As a Senior Lecturer in the Department of Wildlife and Aquatic Resources Management, he educated future Rwandan wildlife managers and decision makers. In cooperation with the Rwanda Development Board (RDB), he established a project, monitoring the effect of fencing on the larger wildlife species in Akagera National Park. Furthermore, he designed and implemented the ecological monitoring of the degazetted Mutara Game Reserve, a protected area that was rendered to returning refugees and their cattle after the civil war and genocide in Rwanda. The study is still ongoing and supported by a research grant from the Swedish International Development Agency (SIDA). The monitoring program involves the local people in community-based resource management activities that improve the understanding of sustainable agriculture, promote traditional pastoralism and reduce human-wildlife conflicts.

During his time in Rwanda he was invited to become a visiting Professor at the Northwest A&F University in Yangling, Shaanxi, P.R. China to teach Zoology and Wildlife Management. During his one year visit, he also engaged in the study of stress reduction in captive musk deer, an ungulate species that is kept in China for the production of musk, an extremely precious substance used as a carrier of odor and thus important for the cosmetic industry, but also in traditional Chinese medicine.

---

[*] Corresponding author's email address: t_wronski@gmx.de.