Which is a stronger predictor of the abundance of Dorcas Gazelle, *Gazella dorcas* in the Eastern desert of Egypt: human or natural factors?

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The Dorcas Gazelle, *Gazella dorcas*, has lost 86% of its global historical range, and is regionally categorized as endangered by the IUCN. The factors that caused this decline have never been quantified. In this work, field and remotely sensed data were used to examine the ecological and anthropogenic factors affecting the abundance of Dorcas Gazelle within Wadi El-Gemal Protected Area in the Eastern desert of Egypt, using Generalized Linear Mixed Models (GLMM). The species’ abundance is shaped by anthropogenic activities (number of car trails and proximity to the coastal road) more than ecological factors (vegetation and wetness indices). Dorcas Gazelle is avoiding more humid and greener areas because of human disturbance. Such suitable habitats may be perceived by gazelles as too dangerous, and the animals therefore prefer less suitable but safer habitats that are further away or less frequented by humans. Moreover, an easy to conduct, cheap monitoring tool, the Kilometric Abundance Index (KAI), was devised and implemented for baseline information to be used for future monitoring of Dorcas Gazelle.

**Keywords:** Conservation; anthropogenic activities; protected areas

**Introduction**

The Sahara’s large mammals are collapsing due to habitat degradation and loss caused by human activities such as urbanization, use of off-road vehicles, oil exploration, armed conflicts, and poaching (Brito et al., 2018; Duncan et al., 2014; Newby et al., 2016). In the Eastern Desert of Egypt, the speed at which human landscape use occurs is exceeding the slow resilience of the ecosystem (Andersen, 2012). This region used to be a cultural landscape but is now experiencing intense tourism and mining development. Dorcas Gazelle is one of the largest herbivores remaining in this area. It has vital interaction with trees, especially *Vachelia* trees, and enhances seed dispersal, germination success and can reduce bruchid infestation (Or & Ward, 2003). However, *Vachelia* trees are now declining in the Eastern Desert due to intense harvesting by humans for firewood (Andersen & Krzywinski, 2007; Grettenberger, 1987; Hobbs et al., 2014).

Dorcas Gazelle is believed to have lost 86% of its historical global range, and is regionally categorized as endangered (Durant et al., 2014; Temple & Cuttelod, 2009). Dorcas Gazelle represents an excellent species for studying the response of gazelles to
the increasing anthropogenic activities in the Saharan desert. Dorcas Gazelle is considered a flagship species (Attum & Mahmoud, 2012), habitat generalist (Chammem et al., 2008), and is widespread across northern Africa (El Alqamy & Baha El Din, 2006). Despite the ecological importance of Dorcas Gazelle, there are no quantification of the factors that caused such declines.

In Egypt, more than half of Dorcas Gazelle’s range occurs in the Eastern Desert (El Alqamy & Baha El Din, 2006). Understanding how the species responds to anthropogenic pressures is essential to implement effective conservation plans. Dorcas Gazelle is very sensitive to human disturbance and is known to become nocturnal when threatened by humans (Yom-Tov et al., 1995), making direct observations difficult. The use of Kilometric Abundance Index (KAI) has been used to monitor Dorcas Gazelle when they are secretive and difficult to observe (El Alqamy, 2003). Previous studies on gazelles reported a positive correlation between the number of Cuvier’s Gazelles and its tracks and dung, suggesting that tracks and dungs (thereafter: indirect signs) could be used as a proxy to determine gazelle abundance (Gil-Sánchez et al., 2017). The KAI of indirect signs can be calculated using minimal resources and can be done in any season at any time of the day (El Alqamy, 2003; Preatoni et al., 2012).

This study explored the relationship between Dorcas Gazelle abundance (KAI, i.e. number of individual or even indirect signs such as dung piles or tracks per kilometer surveyed) and human disturbance through factors such as livestock grazing, coastal development, and off-road vehicle use and ecological factors such as landscape greenness, topographic ruggedness, and topographic wetness. We also established a quantitative baseline information via KAI for future monitoring purposes.

Methods

Study area. The study area is located in the Egyptian Eastern Desert within Wadi El-Gemal Protected Area (WGPA), west to the Red Sea (Figure 1). The landscape is hyper-arid and precipitation is highly variable both spatially and temporally, falling mostly in November and December. Mean annual rainfall is approximately 17 mm and the monthly mean temperature varies between 24 and 38°C during summer and 12 and 26°C during winter (Abdalla et al., 2014; Attum et al., 2014; Mahmoud, 2010). Wadis bisect the igneous mountains, in which trees such as *Vachellia*, *Balanites*, and *Tamarix* and shrubs such as *Zilla spinosa*, *Ochradenus baccatus* and *Leptadenia pyrotechnica* are interspersed. The local Ababda people typically leave their camels to graze freely in the wadis but sheep and goats are escorted by a herder.

Survey design. Four wadis (‘Eraier, Um Ramareem, El-Gemal and Um El-Abbas) in WGPA were chosen because they historically contained large gazelle populations (Attum & Mahmoud, 2012). The four wadis were mapped into polygons, and random points were laid every two kilometres on one side of the wadi polygon using QGIS software. From those points, we drew a line transect obliquely to the opposite wadi’s bank. We conducted 33 walking transects (mean length: 557 m) along the random points in March 2021 and recorded the number of indirect signs for gazelles, camels, and goats/sheep in each transect. We also recorded the number of off-road vehicle tracks that bisected each transect and recorded the length of each transect. KAI for each wadi was calculated as average indirect signs per km.

Factors related to gazelle abundance. The Normalized Difference Vegetation Index (NDVI) was used as a proxy for landscape greenness. NDVI was calculated from Landsat 8 imagery in March 2021 using Google Earth engine (Gorelick et al., 2017). We used the Topographic Ruggedness Index (TRI) as a proxy for landscape ruggedness and Topographic Wetness Index (TWI) for landscape wetness, as it indicates the tendency of an area to retain water (Mattivi et al., 2019). TRI and TWI were derived from digital elevation model of ALOS-PALSAR Radiometric Terrain
Correction 12.5 m using SAGA software (Conrad et al., 2015). TRI, TWI and NDVI values were then averaged within a 100-metre radius around midpoints of each line transects. We quantified the effects of roads by measuring the distance to the coastal road along the Red Sea coast in the east and the Shazly desert road in the west for each midpoint of the line transect. All the factors were tested for correlation prior the analysis (Table S1). Distance to Shazly and coastal roads were highly correlated (r=0.8) and therefore only the distance to the coastal road was used.

Modelling factors related to Dorcas Gazelle abundance. We fitted a negative binomial generalized linear mixed model (GLMM) because of the overdispersion in our count data, i.e. the variance is larger than the mean (Touchon, 2021). GLMM handles abnormally distributed data and accounts for random effects (Bolker et al., 2009). We fitted a GLMM with number of off-road vehicles tracks, NDVI, TRI, TWI, camel, goats/sheep (presence/absence of indirect signs), and distance to coastal road as fixed effects. Count of gazelle indirect signs was included as a response variable. Transect ID was included as random effect and transect length in km was included as an offset term (Coxe et al., 2009). All the continuous fixed effects were scaled and centered \((x–\bar{x})/\sigma\). The global model was simplified by discarding the least significant effects to reach the minimal adequate model (Crawley, 2007; Touchon, 2021); Quasi-Akaike information criterion corrected (QAICc) was used to select from the competing models (Bolker et al., 2009). The final minimal adequate model was evaluated for its predictive performance and fit using Pseudo \(R^2\) (Nakagawa & Schielzeth, 2013) and Hosmer-Lemeshow Goodness of Fit Test, respectively. Modelling was implemented using glmmTMB R package (Brooks et al., 2017).
Figure 2. Relationship between distance to coastal road (m) and gazelle abundance. Abundance is given as the number of indirect signs/km. The red line represents the mean of the estimate, while the shaded area represents the confidence interval.

Results

A total 18.3 km of transects were surveyed with an average transect length of 557 m (range 61.5–1779.8 m). Wadi Um Ramarem had the highest KAI of all areas surveyed (Table 1), while Wadi Um El-Abas had no signs of gazelle and the highest density of off-road vehicle use (Figure S1).

The best fit model had a QAICc score of 111.9 (Table S2), which encompasses the distance to the coastal road and its quadratic term, number of off-road vehicles tracks, NDVI and TWI. The model had a very high accuracy (Hosmer-Lemeshow test, $\chi^2 = -21.741$, df=8, $P=1$) and exceptional predictive accuracy (conditional $R^2=0.94$). The distance from the coastal road was the strongest negative predictor of gazelle abundance in WGPA (Table 2). The abundance of Dorcas Gazelles was confined to 10–20 km from the coastal road (Figures 1–2). The number of off-road vehicles was the second strongest predictor of gazelle abundance. Off-road vehicles had a negative impact on abundance with more than six off-road vehicle tracks/transect being associated with the absence of gazelles (Figure 3). There was significant relationship between landscape greenness (NDVI), landscape wetness (TWI) and gazelle abundance but this effect was weaker than the distance from the coastal road and the number of off-road vehicle tracks (Table 2). This relationship was negative (Figure S2, S3).

Discussion

Our results suggest that the strongest predictor of gazelle occurrence in Egypt’s Eastern Desert is now human disturbance instead of natural factors. Our findings are similar to other studies which suggested that human presence and land use are now limiting the
Table 1. Kilometric abundance indices of Dorcas Gazelle in Wadi El-Gemal Protected Area, sum of indirect signs are in brackets.

| Average sign/km            | Um El-Abas | Um Ramarem | El-Gemal | 'Eraiier |
|----------------------------|------------|------------|----------|----------|
| Track density              | 0 (0)      | 25.58 (20) | 1.61 (21)| 5.01 (5) |
| Dung density               | 0 (0)      | 4.85 (6)   | 0.51 (7) | 2.57 (2) |
| Midden density             | 0 (0)      | 3.22 (3)   | 0.16 (2) | 0.96 (1) |
| Total transects length (km)| 5.18       | 1.24       | 10.59    | 1.37     |

Table 2. Results of the GLMM (with lowest QAICc) for the human and ecological effects on Dorcas Gazelle’s abundance.

|                        | Coefficient | SE      | z value | P value |
|------------------------|-------------|---------|---------|---------|
| (Intercept)            | -1.1094     | 0.8294  | -1.337  | 0.18105 |
| Distance to costal road| 7.9978      | 2.5376  | 3.152   | 0.00162 |
| Distance to costal road 2| -11.1935    | 3.5765  | -3.13   | 0.00175 |
| Off-road vehicles      | -1.9269     | 0.9057  | -2.127  | 0.03338 |
| NDVI                   | -0.984      | 0.3789  | -2.597  | 0.00939 |
| TWI                    | -0.7653     | 0.3742  | -2.045  | 0.04084 |

distribution and abundance of gazelle populations (Chammem et al., 2008; Soultan et al., 2021; Stabach et al., 2017). The distance to the costal road was the strongest predictor of gazelle abundance, as roads represent a human access point for disturbance (tourism, settlement, mining, and grazing). Gazelle distribution was essentially found between the coastal and the Shazly road, as disturbance is high along both roads.

The number of off-road tracks was the second strongest factor associated with gazelle abundance. Our results suggest that gazelles are avoiding areas that are more accessible to off-road vehicles due to the associated disturbance listed previously and illegal hunting, as has been suggested in the past (Mallon & Kingswood, 2001; Newby et al., 2016). The poaching of gazelles now almost always occurs using off-road vehicles, which permits access to gazelle habitat and chasing of gazelles (Soultan et al., 2021). Nowadays, local people depends on pick-up trucks for transportation instead of camels. Even in the absence of illegal hunting, the Dorcas gazelle might still be avoiding the areas due to the perceived danger (Ross et al., 2019; Soultan et al., 2021). Moreover, off-road vehicles are known to degrade desert vegetation and cause a decline in floral species richness (Marei et al., 2004) which would explain why gazelles avoid this areas.

Unexpectedly, we found a negative relationship between NDVI and gazelle abundance (Figure S3), unlike other studies (Creech et al., 2016; Pettorelli et al., 2009; Ross et al., 2019; Stabach et al., 2017). There are several possible explanations for this negative relationship. Despite NDVI being often used as a surrogate for food availability (Attum et al., 2022; Marshal et al., 2006; Pettorelli et al., 2009, 2011; Ross et al., 2019), NDVI may not accurately reflect food availability for wildlife that preferentially selects plants that have little contribution to overall vegetation greenness values (Gautam et al., 2019). For instance, Dorcas Gazelle food items such as *Ochradenus baccatus* has a NDVI value of 0.05 (Khdery et al., 2019).
Figure 3. Relationship between the number of off-road tracks/transect and gazelle abundance. Abundance is given as the number of indirect signs/km. The red line represents the mean of the estimate, while the shaded area represents the confidence interval.

The negative relationship between NDVI values and gazelle abundance could be from the higher NDVI values in our study that are associated with large canopy cover species *Tamarix aphyla*, *T. nilotica* and *Salvadora presca*, species that are not used for food by Dorcas Gazelle (Attum & Mahmoud, 2012). The negative relationship could also be the result of anthropogenic disturbances as a result of which gazelles avoid utilizing larger trees typically used for food and refuge, e.g. *Vachelia* and *Balanites* species. Soultan et. al. (2021) found that Dorcas Gazelles avoid larger food and refuge trees due to the intensive human use of these trees. It is possible that humans are competitively excluding gazelles from these greener areas as gazelles perceive these areas as being too dangerous (Soultan et al., 2021).

Similarly, the negative relationship detected between TWI and gazelle abundance was unexpected. Gazelles were confined to areas with a TWI score between 5 and 10 (Figure S2), suggesting that gazelles are avoiding wider wetter wadis and prefer narrower drier wadis. This could be due to gazelles avoiding potentially wetter areas that are visited by livestock and humans and are more accessible for off-road vehicles. Gazelles may perceive these areas that would retain more water and presumably have more food availability as too dangerous and may thus use less suitable habitat as found in other populations (Soultan et al., 2021). Similar findings were reported by Stabach et al. (2017) in which gazelles were forced into rougher terrain due to disturbance by humans.

Livestock and TRI were not included in our final model as they decreased model accuracy. The presence of camels did not affect the distribution of Dorcas Gazelle, in fact camel numbers were positively associated with gazelles occurrences (Chammem et al., 2008). Camels did not appear to be a threat to gazelles’ midden selection (Soultan et al., 2021). Furthermore, there was no significant relationship between the number of goats
and the occurrence of gazelles (Chammem et al., 2008). It is therefore possible that camel, sheep, and goats in WGPA could pose less of a threat to Dorcas Gazelle (Attum & Mahmoud, 2012). Dorcas Gazelle is known to be habitat generalist (Chammem et al., 2008) using variety of habitats such as flat plains (Yom-Tov et al., 1995), open areas, dry wadis, vegetated coasts (Helmy & Osborn, 1980) rugged wadis (Attum & Mahmoud, 2012) avoiding very sandy areas (Mallon & Kingswood, 2001), therefore TRI was not found to be a significant predictor of gazelle’s distribution. However, it was noted that Dorcas Gazelle could be confined to rugged terrains due to human disturbances (Stabach et al., 2017).

This study suggests that even within protected areas, gazelle distribution is limited by human presence or perceived danger from humans. Gazelles may not be using suitable habitat as these habitats may be perceived by gazelles as too dangerous, and gazelles are therefore using less suitable but safer habitats that are further away or less frequented by humans.

Supplementary Material
Supplementary Material is given as a Supplementary Annex, which is available via the “Supplementary” tab on the article’s online page.

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No potential conflict of interest was reported by the authors.

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