HABITAT PREFERENCES OF ARABIAN GAZELLES (*GAZELLA ARABICA*) IN THE FARASAN ISLANDS PROTECTED AREA, SAUDI ARABIA

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ABSTRACT

Habitat preferences are a critical facet in the management of endangered wildlife species, but only recently have wildlife managers begun to fully realize the potential of information on species' habitat selection to solve pressing problems in the conservation and management of protected areas. Habitat choice is particularly important in extreme environments like hyperarid deserts, in which resources like food, water and cover are limited. A number of studies suggested that endangered Arabian gazelles (*Gazella arabica*) prefer wooded, mountainous terrain on the Arabian Peninsula, while avoiding open plains and sand deserts. However, this pattern could also be an artefact created by the tremendous hunting pressure experienced by the species and a retreat into areas inaccessible to humans. We studied habitat choice of the largest indigenous population of Arabian gazelles in the world, persisting on the Farasan Islands in the Red Sea, off the coast of Saudi Arabia. We measured the availability of different habitat types using GIS-based habitat mapping and the degree of utilization by gazelles, assessed via bi-annual transect route counts in the protected area. Our results suggest that former fields (beside *Acacia* grooves) are the preferred habitat type of Arabian gazelles, especially during the hot summer months. Our study further suggests that *Acacia*-wooded habitats are the originally preferred habitat type of this gazelle species (especially during the cooler winter months) rather than secondary habitats in remote mountainous areas on the Arabian Peninsula.

Key words: habitat selection, arid environments, habitat mapping, conservation management, Farasan gazelle

INTRODUCTION

The spatial scale at which ungulates use available space—measured, e.g., as individuals' habitat choice (e.g., Williamson and Williamson, 1988; Bowkett, et al., 2007; Estes et al., 2008; Atickem et al., 2011; Tyowua1 et al., 2012)—has important implications not only for ecological and evolutionary processes but also for the management and conservation of populations and ecosystems (Ofstad et al., 2016). The spatial scale of an ungulate's movement depends on an array of intrinsic and extrinsic factors, including body mass, group size and composition, as well as ecological factors like habitat type, productivity and predation (Leuthold, 1977; Pérez-Barberia et al., 2001; Bro-Jørgensen, 2008; Estes, 2014; Ofstad et al., 2016). Habitat selection by wild ungulates is the process through which individuals (or herds) attain a spatial distribution within the landscape such that they are able to optimise, or at least satisfy their physiological and behavioural requirements (Morrison et al., 2006). In their natural environments, ungulates are expected to distribute themselves in a way that they are able to meet these requirements depending on the distribution and abundance of habitat resources necessary to survive and reproduce.

Ecological factors (including habitat resources) that restrict the population growth and/or density of ungulates in some ecosystems are food (Kagima & Fairbanks, 2013; Schweiger et al., 2015), water (Dunham, 1994; Bleich et al., 2010), cover and shade (Mysterud & Østbye, 1999), breeding sites (Wronski et al., 2006), and other indicators of habitat quality, like presence or density of predators (Theuerkauf & Rouys, 2008), parasites (Telfer, 1970) and competing species (Sinclair, 1985; Fritz et al., 1996; Wronski et al., 2006). Resources should predict habitat choice, especially in species living in resource-limited environments such as the arid lands of the Middle East (Shmida et al., 1986). Ungulates 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 (Shmida et al., 1986; Schmidt-Nielsen, 1979; Feldhamer et al., 1999). Given the scarcity of habitat resources in desert environments, ungulates are expected to congregate in areas in which the limiting resources occur at a maximum and/or competition for such resources is minimized (Noy-Meir, 1973; Lawes & Nanni, 1993; Henley et al., 2007; Stabach et al., 2017).

The Arabian gazelle (*Gazella arabica* Lichtenstein, 1827), an arid to semi-arid adapted gazelle species endemic to the Arabian Peninsula, was reported to prefer wooded, mountainous terrain, while avoiding open plains and sand deserts (Habibi, 1991; Mendelssohn et al., 1995). However, this pattern could also be an artefact created by the tremendous hunting pressure experienced by the species. In recent decades the species has faced a considerable population decline due to illegal hunting and capture for pet trade (Child & Grainger, 1990; Magin & Greth, 1994; Thouless et al., 1991, 1997) leading to a retreat into areas inaccessible to humans. The distribution of extant Arabian gazelles is thus likely to be at the margin of their natural ecological range, confined to peripheral, suboptimal habitats (see H. St. J. B. Philby's reports in Morrison-Scott, 1939; Dunham et al., 1995). In Saudi Arabia, Arabian gazelles are threatened to become extinct on a local and possibly even country-wide scale (Thouless et al., 1991, 1997; Dunham et al., 2001), and the IUCN (2016) classifies its worldwide status as "vulnerable" (still under the previous name *G. gazella*; but see Wronski et al., 2010; Bärmann et al., 2013; Lerp et al., 2013, 2016). For our study, we choose a population that appears to be viable and less affected by anthropogenic influences and presumably represents the largest *G. arabica* population in the world (Wronski, 2013). The presence of Arabian gazelles on the Farasan Archipelago—an assemblage of islands located in the Red Sea—has been known since at least 1825 (Hemprich & Ehrenberg, 1828; Groves, 1983), but information about their ecology and conservation status was gathered only within the last two decades (see unpublished reports cited in Wronski, 2013). Due to the occupational background of local communities on the islands (mainly fishermen), the gazelle population experiences a relatively low human hunting pressure on the three islands (Kebir, Zifaf, Saqid) on which the species naturally occurs (Cunningham & Wronski, 2011).

Previous studies on dietary preferences (Wronski & Schulz-Kornas, 2015) and resource utilisation of Arabian gazelles (Wronski et al., 2017) suggested that fields—established in ancient times to supplement human nutrition (predominantly based on fish) by some carbohydrates—play an essential role for the nutrition of the gazelles. These fields were established wherever some sandy soil could accumulate between coral rocks, but most of them are nowadays entirely neglected and imbruted. Fields provide habitat for a number of plant species that are otherwise rare on the island but strongly preferred by Farasan gazelles (e.g., *Indigofera* spp. and *Prosopis juliflora* (Sw.) DC.; Wronski et al., 2012; Wronski & Schulz-Kornas, 2015). Both studies involved individual-based research that was limited to a small spatial scale, i.e. the southern section of Farasan's main island (Farasan Kebir), and suffered from small sample sizes. In our current study, we adopted a not individual-based approach to investigate how habitat choice affects the spatial distribution of *G. arabica* on a much larger spatial scale (i.e., on the entire island).

The Farasan gazelle population, with no opportunity to migrate, is expected to range close to its dietary limits (Wronski & Schulz-Kornas, 2015). 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). In our study we used gazelle sightings obtained during bi-annual counts (Wronski et al., 2017) to relate them to the seven major habitat types on the island (Fischer, 1988; Gladstone, 1994a, b, c, 2000; Ady,

2000) and identify preferred or avoided areas. We predicted that the distribution of Farasan gazelles is closely linked to the availability of shelter (shade), especially in the form of *Acacia*-thickets (Vesey-Fitzgerald, 1952). Cunningham & Wronski (2011) assumed the occurrence of *Acacia ehrenbergiana* Hayne (Fabaceae) and broken terrain to be the key factors influencing gazelle density in the protected area. A diet mainly consisting of *Acacia* leafs, pods and flowers was confirmed (Wronski & Schulz-Kornas, 2015), while the assumption that broken terrain represents a preferred habitat type still warrants further proof.

MATERIAL AND METHODS

Study area

Our study was carried out on the main island (Farasan Kebir, app. 386 km²) of the Farasan Archipelago in the southern Red Sea, off the coast of Djizan city in southwestern Saudi Arabia (16°20' to 17°20'N, 41°30' to 42°30'E; Figure 1a, b). The islands are formed of raised fossil coral reefs at altitudes of 0–30 m above sea-level. The climate is arid, with unpredictable annual rainfall ranging between 50 and 100 mm, mainly between December and February (Child & Grainger, 1990) and no permanent surface water (Flamand et al. 1988; Habibi & Thouless 1997). The annual mean ambient temperature is 30.2°C (summer daily mean, maximum: 40°C, winter daily mean, minimum: 20°C). The assemblage of islands has been protected since 1988, primarily because of its Arabian gazelle (*Gazella arabica*) population but also for its outstanding biological value as a marine reserve (Child & Grainger, 1990; Gladstone, 2000).

Transect route surveys

The gazelle population was monitored during three surveys (in January 2012 and 2013, i.e., during the cool, wet season, and in June 2012, i.e., during the hot, dry season) along transect routes established to count gazelles on Farasan Kebir (Wronski, 2013). During each survey, a total of 279.2 km was driven along ten predetermined routes (12-44 km long). Due to the difficult terrain on the island, route length varied slightly between surveys. Whenever an individual (or a group of gazelles) was encountered, one of the six habitat types (see below) was assigned to each gazelle, pending on the moment of first sight. During none of the three surveys could the encountered gazelles be identified individually, so that habitat availability and utilization were assessed on population level (Thomas & Taylor, 1990).

All surveys were carried out by two observer teams, each consisting of one driver and two observers, during early morning hours (05:30 h to 9:00 h local time) by driving a 4×4 vehicle at 10–30 km/h. Transect routes were designed to cover the entire island as evenly as possible, including six habitat types described below. Two transect routes were located in the Northwest of the island (Seir area), two in the centre (Al Hesen area), two in the North (north of Farasan city) and two in the South (Miharraq area). Another two routes were situated to the West and the South of the harbour of Farasan Kebir (Figure 1c).

Habitat map

A digital habitat map (Figure 2) was generated using QGIS version 2.14 (QGIS Development Team, 2016), based on the physical map of Farasan Islands (1:100,000; Ministry of Defense and Aviation, 1988) and on aerial images (taken from 2012 to 2014) provided by Google Satellite and Bing Aerial (*Microsoft*). Supporting information, especially regarding the actual vegetation, was collected *in situ* during frequent field visits to Farasan Kebir between 2009 and 2013. Habitat contours are based on the habitat classification proposed on the physical map of Farasan Islands (Ministry of Defense and Aviation, 1988) or on personal observations of the research team. Subsequently, the total area of each habitat type available on Farasan Kebir was calculated in QGIS. Survey routes were recorded during each survey using *Garmin* GPS III devices and subsequently intersected with the habitat map in QGIS to obtain the distance travelled in each habitat type.

Based on management plans for the Farasan Islands Protected Area (Fischer, 1988; Gladstone, 1994a, c, 2000; Ady, 2000) and an unpublished report (Gladstone, 1994b), six terrestrial habitat types were distinguished:

(*a*) Gravel plains (126.9 km^2 surface area in total; Figure 2, 3a) consisting of flat, weathered coral stones represent the top of large ancient reef pavements and are mainly located on the central plateau, stretching like the spinal cord of the island from northwest to southeast. Apart from brief flushes of annual herbs such as *Justicia flava* (Forssk.) Vahl (Acanthaceae) after winter rains, this habitat is barren except where cracks and small gullies in the limestone collect silt and water, forming ravines of denser vegetation. The most conspicuous shrubs and perennial herbs growing in the cracks, gullies and depressions of the plains are *Capparis sinaica* Veillard (Capparaceae), *Indigofera oblongifolia* L. (Fabaceae) and *Aboutilon pannosum* (G. Forst.) Schltdl. (Malvaceae).

(*b*) Sand plains (12.3 km^2) formed either on low-lying gravel plains mainly in the northwest, north and south of Farasan Kebir or as wind-scattered extensions of beaches (Figure 3b). Dominant plants include the small succulent *Desmidorchis retrospiciens* Ehrenb. (Apocynaceae), the herbs *Zygophyllum simplex* L. (Zygophyllaceae), *Blepharis ciliaris* (L.) B. L. Burtt (Acanthaceae) and *Aerva javanica* (Burm. f.) Shult. (Amaranthaceae) as well as the sedge *Cyperus jemenicus* Bernh. ex Kunth (Cyperaceae).

(*c*) Broken terrain (or 'jebals'; 157.0 km^2) form the hills and mountains in the western and eastern parts of the island, consisting mainly of bare coral rock, uplifted and tilted by the underlying salt dome (in the west of Farasan Kebir these faults reach 72 m above sea-level; Bailey et al., 2007). This is the most diverse and abundant habitat type in the protected area and is characterized by an *Acacia-Commiphora* bushland growing mainly in the numerous silt pans and valley bottoms within the rocky outcrops (Figure 3c). The flora is dominated by *Commiphora gileadensis* (L.) C. Chr. (Burseraceae), *Ziziphus spina-christi* (L.) Desf. (Rhamnaceae) and *Maerua oblongifolia* Forssk. (A. Rich.) (Capparaceae) on sandy patches, while *Salvadora persica* L. (Salvadoraceae), *Grewia tenax* Forssk. (Malvaceae) and *Capparis sinaica* can cope with shallow soils accumulating in cracks and fissions in the broken terrain. Prevailing shrubs and woody perennials are *Asparagus flagellaris* (Kunth) Baker (Asparagaceae), the climber *Cissus quadrangularis* L. (Vitaceae), *Pentatropis nivealis* (J. F. Gmel.) Field & Wood (Apocynaceae) and *Ipomea obscura* (L.) Ker Gawl. (Convolvulaceae). Other shrubs and herbs include *Capparis decidua* (Forssk.) Edgew. (Capparaceae), *Kickxia coralliola* D. A. Sutton (Plantaginaceae), *Tephrosia uniflora* Pers. (Fabaceae) and *Cucumis melo* L. (Cucurbitaceae). This habitat type is the richest in terms of food and shelter for Farasan gazelles and birds, especially where the broken land makes access difficult or impossible for humans.

(*d*) Fields (12.4 km^2; Figure 3d) are wall-fenced patches of soft soil formerly used to grow crops, but nowadays often covered by ruderal plants like *Indigofera spinosa* Forsk. (Fabaceae), *Abutilon pannosum*, or invasive mesquite, *Prosopis juliflora* (Sw.) DC. (Fabaceae). Other trees occasionally encountered include *Acacia ehrenbergiana*, *Hyphaene thebaica* (L.) Mart. (Arecaceae), and *Salvadora persica*. The herb layer is sparse and consists of sedges like *Cyperus jemenicus* and *C. conglomeratus* Rottb. (Cyperaceae) as well as the shrub *Corchorus trilocularis* L. (Tiliaceae).

(*e*) Salt marshes (or 'sabkha'; 66.0 km^2) are regularly flooded sand and mud plains at sea level entirely comprising of halophyte shrubs and herbs such as *Arthrocnemum macrostachyum* (Moric.) C. Koch (Amaranthaceae), *Halopeplis perfoliata* Forssk. (Amaranthaceae), *Limonium axillare* (Forssk.) Kuntze (Plumbaginaceae) and *Zygophyllum* spp. (Zygophyllaceae). With increasing distance from the shore line, soil salt content decreases and vegetation progressively impoverishes towards broken terrain and gravel plains (Figure 3e).

(*f*) *Acacia* groves (thickets; 2.2 km^2) occur only at a few locations on Farasan Kebir (e.g., between Miharraq and Al Qiasar Village; Figure 3f, g) and are dominated by *Acacia ehrenbergiana*. Other woody plants include *Prosopis juliflora*, *Phoenix dactylifera* L. (Arecaceae), *Hyphaene thebaica, Ziziphus spina-christi* and *Ficus populifolia* Vahl (Moraceae).

Moreover, mangroves grow on muddy tidal flats and lagoons (Figure 3h), mostly along the well sheltered, eastern shore lines of the island. The dominant species is the black mangrove, *Avicennia marina* (Forssk.) Vierh. (Acanthaceae), while *Rhizophora mucronata* Lam. (Rhizophoraceae) occurs only occasionally in areas that can be reached by higher winter tides. This vegetation type was reported to attract Farasan gazelles searching for fallen leaves and fruits of mangrove trees (Llewellyn, 2008), but since we never observed any gazelle in mangroves during previous research, we made no attempt to cover this habitat type systematically by our transect routes. The habitat assembly on Farasan Kebir includes two additional habitats that were not covered by the course of the transect routes, i.e. human settlements and tidal ponds. Since mangroves (1.7 km^2), tidal ponds (0.95 km^2) and human settlements (6.8 km^2) appear to be irrelevant to the biology of Farasan gazelles, we omitted them from our analysis, i.e., the area covered (9.45 km^2) was not included in the calculations.

Study species

Originally, Farasan gazelles (*G. gazella farasani*, Thouless & Al Basri, 1991) were described as a subspecies of the mountain gazelle (*G. gazella*). Until recently, *Gazella arabica* was thought to be synonymous to its ecologically and behaviorally very similar sister species, the mountain gazelle, which occurs only in the Levant (Wronski et al., 2010; Bärmann et al., 2013; Lerp et al., 2014, 2016). However, phylogenetic evidence suggests that the island population is not genetically distinct from mainland gazelles, shedding doubt on the validity of the subspecies name (Lerp et al., 2014). Arabian gazelles occur along the western edge of the Arabian Peninsula, from the Arava Valley in Israel south into the highlands of Yemen, eastwards through Oman and north into the United Arab Emirates (Child & Grainger, 1990; Lerp et al., 2013). In total, the population on Farasan Kebir nowadays numbers about 800-1000 animals (Wronski, 2013), equaling a population density of 1.4 to 3.2 animals per km^2 (extrapolated from a ground surveys carried out between June 2009 and January 2013; Cunningham & Wronski, 2009; Wronski, 2013).

Statistical analysis

We first determined the proportion of different habitat types, i.e., distance travelled in each habitat type, along the total length of all transect routes (i.e. combining the data from all ten routes). Second, the total number of gazelles seen along the combined transect route was multiplied by the proportion of each habitat type along the combined transect route, resulting in the expected number of gazelles that would have been encountered in different habitat types given a random distribution. We compared the expected occurrence with the observed number of gazelles in each habitat type using χ^2 goodness-of-fit tests. Data from the three surveys were analysed separately.

RESULTS

Chi-squared tests detected significant deviations when comparing the observed distribution of gazelles encountered in different habitat types with the expected encounter rates under the assumption of random distribution patterns (January 2012: $\chi^2 = 690.02$; June 2012: $\chi^2 = 506.04$; January 2013: $\chi^2 = 1213.9$; all: $df = 5, p < 0.001$). Hence, the gazelle population in the Farasan Islands Protected Area showed significant preferences for (and avoidance of) certain habitat types throughout the course of our study.

During all three surveys, the Farasan gazelle population showed a clear predilection for *Acacia* groves, and this habitat preference was more pronounced in both January surveys [11.6-fold (2012) and 13.9-fold (2013) higher encounter rates than expected by chance; Figure 4a, c] compared with the survey during the hot and dry summer, i.e. in June 2012 (4.5-fold higher encounter rates than expected; Figure 4b). Gazelles also showed an overall preference for former fields, and we observed a trend that was contrary to the pattern observed for *Acacia* groves, with a stronger preference during June 2012 (8.2-fold higher encounter rates than expected by chance; Figure 4b) compared with both winter (i.e. January) surveys, when cooler and moister weather conditions prevailed [2.9-fold (2012) and 4.6-fold (2013) higher encounter rates than expected; Figure 4a, c].

Broken terrain was clearly avoided by Farasan gazelles during both January surveys [1.5-fold (2012) and 2.6-fold (2013) lower encounter rates than expected; Figure 4a, c], while a slight preference for this habitat type became apparent in our summer survey (1.1-fold higher encounter rate than expected; Figure 4b).

All other habitat types were avoided by Farasan gazelles. The strongest avoidance was observed in the case of sand plains, in which no individuals were observed in January and June of 2012 (Figure 4a, b), while encounter rates in January 2013 were 2.7-fold lower than expected given a random distribution of the gazelles (Figure 4c). Likewise, salt marshes were clearly avoided [2.3-fold lower encounter rate than expected in January 2012, 6.0-fold lower in June 2012 and 6.5-fold lower in January 2013; Figure 4a-c]. Finally, gravel plains were avoided in January 2012 (1.1-fold lower encounter rates than expected; Figure 4a) and June 2012 (2.7-fold lower encounter rates than expected; Figure 4b), but 1.2 times more gazelles than expected were observed in gravel plains in January 2013 (Figure 4c).

DISCUSSION

As reported by previous studies (Vesey-Fitzgerald, 1952; Cunningham & Wronski, 2011; Wronski & Schulz-Kornas, 2015; Wronski et al., 2017), Arabian gazelles on the Farasan Islands showed a strong preference for *Acacia* groves. *Acacia ehrenbergiana* is the major food plant of gazelles on Farasan Islands, and gazelles consume virtually all plant parts, i.e. leaves, pods, flowers and even bark (Wronski & Schulz-Kornas, 2015). Apart from serving as food, *Acacia* groves provide shelter from intense sun radiation, strong wind and predators. Unexpected was the finding that the preference for *Acacia* groves was stronger during winter—paired with a weaker preference for fields, while a stronger preference for fields—coupled with a weaker preference for *Acacia* groves—was observed in the hot and dry summer months. This shift in habitat choice goes along with a pronounced shift in the gazelles' diet (Wronski & Schulz-Kornas, 2015). In winter, the proportion of grass and herbs in the diet of the gazelles is three-times higher than during the hot, dry season, when indigenous, wild grass and herb species inside the *Acacia* groves are eaten or dried up. The only herbs surviving well into the hot summer are woody perennials, such as *Indigofera spinosa*, *I. oblongifolia* or *Abutilon pannosum*, which are dominant on anthropogenically modified, sandy silts forming the soils of fields. These ruderals, and the invasive tree *Prosopis juliflora*, thrive on the disturbed soils and supposedly cause the observed seasonal shift in habitat preferences.

Another habitat type, i.e., rocky, broken terrain, was significantly preferred only during the summer, but the preference was comparatively weak. During winter, this habitat type was clearly avoided. Previous studies on Farasan Islands (Flamand et al., 1988; Habibi & Thouless, 1997; Cunningham & Wronski, 2011) or in other areas on the Arabian Peninsula (Morrison-Scott, 1939; Vesey-Fitzgerald, 1952) suggested that Arabian gazelles not only occurred in the valleys of foothills, but also in open gravel or sand plains. Today, rocky, mountainous habitats may thus represent the main retreat area for gazelles seeking shelter from illegal hunting and life capture (see supplementary material in Lerp et al., 2014). During the hot summer months on Farasan islands, this habitat type provides lower temperatures and continued access to green vegetation (T. W., pers. observ.). Altogether then, our current data, in combination with previous studies (Morrison-Scott, 1939; Flamand et al., 1988; Habibi & Thouless, 1997; Dunham et al., 1995), support the hypothesis that Arabian gazelles on the Arabian mainland are indeed forced into suboptimal habitats (mountainous broken terrain) but would prefer well vegetated wadis and plains if hunting was effectively prevented (see also Wronski et al., 2017).

Even though several halophytic plant species represent a substantial part of the gazelle's diet (e.g. *Zygophyllum* spp.; Wronski & Schulz-Kornas, 2015), salt marshes and sand plains are avoided throughout the year. This may be attributed to the prevailing soft soils (sand, clay) in these habitats, representing an obstacle to the gazelles' movements. Gravel plains, on the other hand, provide as little shelter as sand plains and salt marshes, but offer the gazelles a solid substrate to walk or escape predators. Moreover, several plant species consumed by Farasan gazelles grow on the gravel plains, such as *Corchorus depressus* (Linn.) Stocks (Tiliaceae), *Justicia flava*, and the succulent caper *Capparis sinaica*, whose leaves are consumed because of the hygroscopic water (leaves contain more than 80% of water; Wronski & Schulz-Kornas, 2015). However, gazelles did not adjust their small scale distribution (assessed as the extent of home range overlap) according to the occurrence of this hygroscopic plant (Wronski et al., 2017). Nevertheless, gazelles use this habitat throughout the year approximately as much as predicted if the gazelles would be randomly distributed; in other words, neither did they avoid nor did they prefer this habitat type. Contrary to claims that Farasan gazelles visit mangroves regularly to brows on the fallen fruits and leaves of mangrove trees (Llewellyn, 2008), this was neither observed during our study nor during a five-year conservation project carried out by field ecologists of King Khalid Wildlife Research Centre on the Farasan Islands (see unpublished reports cited in Wronski, 2013). Our current study in conjunction with Wronski et al. (2017) provides empirical evidence for the claim that the ecology of *G. arabica* is closly linked to the occurrence of *Acacia*-dominated habitats (Vesey-Fitzgerald, 1952). However, a word of caution is required when interpreting our data, as our surveys were carried out in the daytime. While Arabian gazelles from the mainland (Arava Valley) were reported to be mainly active during the day and to rest at night (Shalmon, 1987), gazelles on Farasan are active at dusk and dawn, but visit certain areas (habitats) to browse at night (Wronski et al., 2017).

Information on habitat choice by Farasan gazelles as provided here will help conservation managers and local authorities to sustainably develop the islands for the growing tourism industry without putting further threats to the gazelle population. Specifically, the new tourist resort at Kharij as Sailah bay, the expansion of Farasan port, as well as the planned Farasan airport represent some examples of where data obtained during our study will help to mitigate threats arising to the Farasan gazelle population (Robinson et al., 2001). Moreover, our findings may also provide important information of where to invest in eco-tourism projects (e.g., a nature trail in the Miharraq *Acacia* groves) or what areas of Farasan Kebir should be completely free of any utilisation (e.g., jebals between Al Hesen and Seir).

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References

Ady, J. (2000). *Farasan Islands Protected Area Master Management Plan*. Riyadh, Saudi Arabia: Unpublished report, National Commission for Wildlife Conservation and Development.

Atickem, A., Loe, L. E., Langangen, Ø., Rueness, E. K., Bekele, A. & Stenseth, N. C. (2011). Estimating population size and habitat suitability for mountain nyala in areas with different protection status. *Animal Conservation* 14, 409-418.

Bärmann, E. V., Wronski, T., Lerp, H., Azanza, B., Börner, S., Erpenbeck, D., Rössner, G. E. & Wörheide, G. (2013). A morphometric and genetic framework of the genus *Gazella* de Blainville, 1816 with special focus on Arabian and Levantine mountain gazelles. *Zoological Journal of the Linnean Society* 169, 673-696.

Bailey, G., Al Sharekh, A., Flemming, N., Lambeck, K., Momber, G., Sinclair, A. & Vita-Finzi, C. (2007). Coastal prehistory in the southern Red Sea Basin, underwater archaeology, and the Farasan Islands. *Proceedings of the Seminar for Arabian Studies* 37, 1-16.

Bleich, V. C., Marshal, J. P. & Andrew, N. G. (2010). Habitat use by a desert ungulate: Predicting effects of water availability on mountain sheep. *Journal of Arid Environments* 74, 638-645.

Bowkett, A. E., Rovero, F. & Marshall, A. R. (2007). The use of camera-trap data to model habitat use by antelope species in the Udzungwa Mountain forest, Tanzania. *African Journal of Ecology* 46, 479-487.

Bro-Jørgensen, J. (2008). Dense habitats selecting for small body size: a comparative study on bovids. *Oikos* 117, 729-737.

Child, G., & Grainger, J. (1990). *A system plan for protected areas for wildlife conservation and sustainable rural development*. Riyadh, Saudi Arabia: National Commission for Wildlife Conservation and Development.

Cunningham, P. L. & Wronski, T. (2009). *Farasan Island Survey–June 2009. Determining Farasan gazelle (*Gazella gazella farasani*) numbers on Farasan Kebir and As Saqid Islands, 26 to 29 June 2009*. Thumamah, Saudi Arabia: Unpublished report, King Khalid Wildlife Research Centre.

Cunningham, P. L. & Wronski, T. (2011). Twenty years of monitoring of the Farasan gazelle *Gazella gazella 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.

Dunham, K., Robertson, F. & Wacher, T. (1995). *Proposed re-introduction of mountain gazelle in the Uruq Bani Ma'arid Protected Area*. Thumamah, Saudi Arabia: Unpublished report, King Khalid Wildlife Research Centre.

Dunham, K. M., Williamson, D. T. & Joubert, E. (2001). Saudi Arabia. In R. East (Ed.), *Global Survey and Regional Action Plans*, *Antelopes. Part 4: North Africa, the Middle East, and Asia*. (pp. 55-62). Gland, Switzerland: IUCN.

Estes, L. D., Okin, G. S., Mwangi, A. G. & Shugart, H. H. (2008). Habitat selection by a rare forest antelope: A multi-scale approach combining field data and imagery from three sensors. *Remote Sensing of Environment* 112, 2033-2050.

Estes, R. D. (2014). *The Gnu's World. Serengeti wildebeest ecology and life history*. Berkley, CA, USA: University of California Press.

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.

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

Fischer, R. (1988) *Management Plan for the Farasan Islands, Gizan, Saudi Arabia*. Riyadh, Saudi Arabia and London, UK: Unpublished report, National Commission for Wildlife Conservation and Development College, University of London.

Fritz, H., de Garine-Wichatitsky, M. & Letessier, G. (1996). Habitat Use by Sympatric Wild and Domestic Herbivores in an African Savanna Woodland: The Influence of Cattle Spatial Behaviour. *Journal of Applied Ecology* 33, 589-598.

Gladsone, W. (1994a). *Management Plan for the Farasan Marine Protected Area*. Riyadh, Saudi Arabia: Unpublished report, IUCN/ National Commission for Wildlife Conservation and Development.

Gladstone, W. (1994b). *The Farasan Marine Protected Area: biological resources, conservation values, human use and impacts*. Riyadh, Saudi Arabia: Unpublished report, IUCN/ National Commission for Wildlife Conservation and Development.

Gladstone, W. (1994c). *The Farasan Islands Marine Protected Area Plan: Implementation and Amendments to the Management Plan*. Riyadh, Saudi Arabia: unpublished report, National Commission for Wildlife Conservation and Development.

Gladstone, W. (2000). The ecological and social basis for management of a Red Sea marine-protected area. *Ocean and Coastal Management* 43, 1015-1032.

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

Habibi, K. (1991). *Arabian gazelles*. Riyadh, Saudi Arabia: National Commission for Wildlife

Conservation and Development.
Habibi, K., & Thouless, C. R. (1997). Ecology of sand and mountain gazelles in Saudi Arabia. In K. Habibi, A. Abu-Zinada & I. A. Nader (Eds.), *The gazelles of Arabia* (pp. 88-110). Riyadh, Saudi Arabia: National Commission for Wildlife Conservation and Development.
Hemprich, F. G., Ehrenberg, C. G. (1828). Symbolae physicae. pars zoologica I. Officine Academica, Berlin.
Henley. S. R., Ward, D. & Schmidt, I. (2007). Habitat selection by two desert-adopted ungulates. *Journal of Arid Environments* 70, 39-48.
IUCN (2016): *Gazella gazella*. IUCN Red List of Threatened Species v. 2010.2, www.iucnredlist.org [last accessed 21 May 2013].
Kagima, B. & Fairbanks, W. S. (2013). Habitat selection and diet composition of reintroduced native ungulates in a fire-managed tallgrass prairie reconstruction. *Ecological Restorations* 31, 79-88.
Lawes, M. J. & Nanni, R. F. (1993). The density, habitat use and social organisation of dorcas gazelles (*Gazella dorcas*) in Makhtesh Ramon, Negev desert, Israel. *Journal of Arid Environments* 24, 177-196.
Lerp, H., Wronski, T., Plath, M., Schröter, A. & Pfenninger, M. (2013). Phylogenetic and population genetic analyses suggest a potential species boundary between Mountain (*Gazella gazella*) and Arabian Gazelles (*G. arabica*) in the Levant. *Mammalian Biology* 78, 383-386.
Lerp, H., Plath, M., Wronski, T., Bärmann, E. V., Malczyk, A., Resch, R. R., Streit, B. & Pfenninger, M. (2014). Utility of island populations in reintroduction programs—relationships between Arabian gazelles (*Gazella arabica*) from the Farasan Archipelago and endangered mainland populations. *Molecular Ecology* 23, 1910-1922.
Lerp, H., Klaus, S., Allgöwer, S., Wronski, T., Pfenninger, M. & Plath, M. (2016). Phylogenetic analyses of gazelles reveal repeated transitions of key ecological traits and provide novel insights into the origin of the genus *Gazella*. *Molecular Phylogenetics and Evolution* 98, 1-10.
Leuthold, W. (1977). *African Ungulates—A Comparative Review of Their Ethology and Behavioral Ecology*. Berlin, Germany: Springer.
Llewellyn, O. (2008). *Farasan Islands Protected Area Action Plan*. Riyadh, Saudi Arabia: Unpublished report, National Commission for Wildlife Conservation and Development.
Magin, C. D. & Greth, A. (1994). Distribution, status and proposals for the conservation of mountain gazelles *Gazella gazella cora* in the southwest of Saudi Arabia. *Biological Conservation* 70, 69-75.
Mendelssohn, H., Yom-Tov, Y. & Groves, C. P. (1995). *Gazella gazella*. *Mammalian Species* 490, 1-7.
Ministry of Defence and Aviation (1988) *Map of Farasan Islands (scale: 1:100.000).* Riyadh, Saudi Arabia: Military Survey Department, Ministry of Defence and Aviation.
Morrison, M.L., Marcot, B.C. & Mannan, R.W. (2006). Wildlife-habitat relationships: concepts and applications. Island Press, Washington, D.C.
Morrison-Scott, T. C. S. (1939). Some Arabian mammals collected by Mr H. St. J. B. Philby. *Novitates Zoologicae* 41, 181-211.
Mysterud, A. & Østbye, E. (1999). Cover as a habitat element for temperate ungulates: effects on habitat selection and demography. *Wildlife Society Bulletin* 27, 385-394.
Noy-Meir, E. (1973). Desert ecosystems: Environment and producers. *Annual Review of Ecology, Evolution, and Systematics* 4, 25-51.
Ofstad, E. G., Herfindal, I., Solberg, E. J. & Sæthe, B.-E. (2016). Home ranges, habitat and body mass: simple correlates of home range size in ungulates. *Proceedings of the Royal Society B, Biological Science* 283, 20161234, doi: 10.1098/rspb.2016.1234.
Pérez-Barberia, F. J., Gordon, I. J. & Nores, C. (2001). Evolutionary transition among feeding styles and habitat in ungulates. *Evolutionary Ecology Research* 3, 221-230.
Quantum GIS Development Team (2016). *Quantum GIS Geographic Information System*. Open Source Geospatial Foundation Project, http://qgis.osgeo.org [last accessed 06.06.2017].
Robinson, E., Wacher, T., Al Toum, M., Al Mathami, H., Al Assaf, A., Al Huneish, L. & Moustapha, H.

(2001). Conservation Zones of Farasan Kebir. Thumamah, Saudi Arabia: Unpublished Report, King Khalid Wildlife Research Centre.
Schmidt-Nielsen, K. (1979). *Desert animals: physiological problems of heat and water*. New York, USA: Dover Publications.
Schweiger, A. K., Schütz, M., Anderwald, P., Schaepman, M. E., Kneubühler, M., Haller, R. & Risch, A. C. (2015). Foraging ecology of three sympatric ungulate species – Behavioural and resource maps indicate differences between chamois, ibex and red deer. *Movement Ecology* 3, 6, DOI: 10.1186/s40462-015-0033-x.
Shalmon, B. (1987). The Arava gazelle. *Israel Land & Nature* 13: 15-18.
Shmida, A., Evenari, M. & Noy-Meir, I. (1986). Hot desert ecosystems: an integrated view. In M. Evenari, I. Noy-Meir & D. W. Goodall (Eds.), *Ecosystems of the World, Vol. 12b, Hot Deserts and Arid Shrublands* (pp. 379-387). Amsterdam, Netherlands: Elsevier.
Sinclair, A. R. E. (1985). Does Interspecific Competition or Predation Shape the African Ungulate Community? *Journal of Animal Ecology* 54, 899-918.
Stabach, J. A., Rabeil, T., Turmine, V., Wacher, T., Mueller, T. & Leimgruber, P. (2017). On the brink of extinction—habitat selection of addax and dorcas gazelle across the Tin Toumma desert, Niger. *Biodiversity Research* 23, 581-591.
Telfer, E. S. (1970). Winter Habitat Selection by Moose and White-Tailed Deer. *Journal of Wildlife Management* 34, 553-559.
Theuerkauf, J. & Rouys, S. (2008). Habitat selection by ungulates in relation to predation risk by wolves and humans in the Białowieża Forest, Poland. *Forest Ecology and Management* 256, 1325-1332.
Thomas, D. L. & Taylor, E. Y. (1990). Study designs and tests for comparing resource use and availability. *Journal of Wildlife Management* 54, 322-330.
Thouless, C. R. & Al Bassri, K. (1991). Taxonomic status of the Farasan island gazelle. *Journal of Zoology (London)* 223, 151-159.
Thouless, C. R, Grainger, J. G., Shobrak, M. & Habibi, K. (1991). Conservation status of gazelles in Saudi Arabia. *Biological Conservation* 58, 85-98.
Thouless, C. R, Habibi, K., Magin, C. D. & Wacher, T. (1997). Status and distribution of gazelles in Saudi Arabia. In K. Habibi, A. Abu-Zinada & I. Nader (Eds.), *The Gazelles of Arabia* (pp. 163-172). Riyadh, Saudi Arabia: National Commission for Wildlife Conservation and Development.
Tyowua1, B. T., Orsar, J. T. & Agbelusi, E. A. (2012). Habitat preference of Roan Antelope (*Hippotragus equinus*, Desmarest, 1840) in Kainji Lake National Park, Nigeria. *Journal of Research in Forestry, Wildlife and Environment* 4, 13-21.
Vesey-Fitzgerald, D. F. (1952). Wildlife in Arabia. *Oryx* 1, 232-235.
Williamson, D. & Williamson, J. (1988). Habitat use and ranging behaviour of Kalahari Gemsbok (*Oryx gazella* Linneus, 1758). In A. Dixon, & D. Jones (Eds.), *Conservation and Biology of desert antelopes* (pp. 114-118). London, UK: Christopher Helm.
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. & 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., Sun, P. & Plath, M. (2017). Resource availability predicts the distribution of Arabian gazelles (*Gazella arabica*) on Farasan Islands. In: C. Ward (Ed.), *Wildlife: Perceptions, Threats and Conservation* (pp. 1-16). Hauppauge, NY: Nova Science Publishers.
Wronski, T., Tiedemann, R., Apio, A. & Plath, M. (2006). Cover, food, competitors and individual densities within bushbuck *Tragelaphus scriptus* female clan home ranges. *Acta Theriologica* 51, 319-326.
Wronski, T., Wacher, T., Hammond, R. L., Winney, B., Blacket, M. J., Hundertmark, K., Mohammed, O.

B., Flores, B., Omer, S., Macasero, W., Plath, M., Tiedemann, R., Bleidorn, C. (2010). Two reciprocally monophyletic mtDNA lineages elucidate the taxonomic status of Mountain gazelles (*Gazella gazella*). *Systematics and Biodiversity* 8, 119-129.

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.

FIGURE LEGENDS

Figure 1. (A) Location of Farasan Islands in the Red Sea, (B) the position of Farasan Kebir within the archipelago and (C) the course of ten transect routes established to assess the habitat choice of gazelles on Farasan Kebir.

Figure 2. Habitat map showing six habitat types (gravel plain, sand plain, broken terrain, former fields, salt marshes and *Acacia* grove) included in our analysis, as well as three additional habitats (mangrove, tidal ponds, human settlements) that were not used by gazelles and therefore omitted from our analysis.

Figure 3. Habitat types on Farasan Kebir: (A) gravel plain with female Farasan gazelle, (B) sand plain with Jebal al-Boten in the background, (C) broken terrain with lush perennial growth after rain, (D) field (fallow) with fresh grass growth located in broken terrain, (E) salt marshes (sabkha), (F) aerial view of *Acacia* grove surrounded by bare gravel plain, (G) dense shrub and tree vegetation inside *Acacia* grove during the dry season, and (H) aerial view of *Avicennia marina* mangroves.

Figure 4. Predicted and observed numbers of Farasan gazelles encountered in six habitat types (gravel plain, sand plain, broken terrain, former fields and fields, salt marshes (sabkha) and *Acacia* groves) during three surveys on Farasan Kebir.

FIGURES

Figure 1

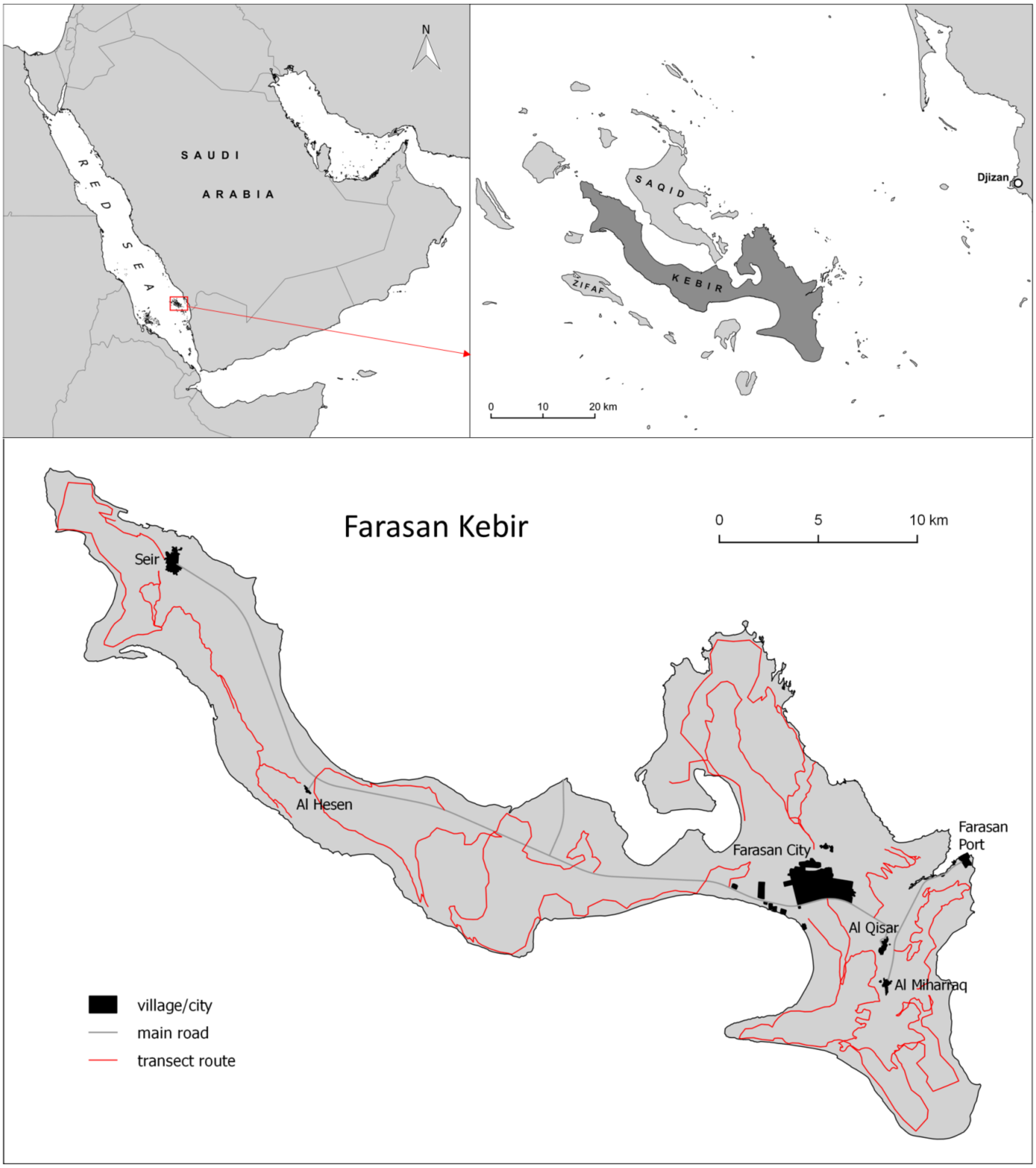
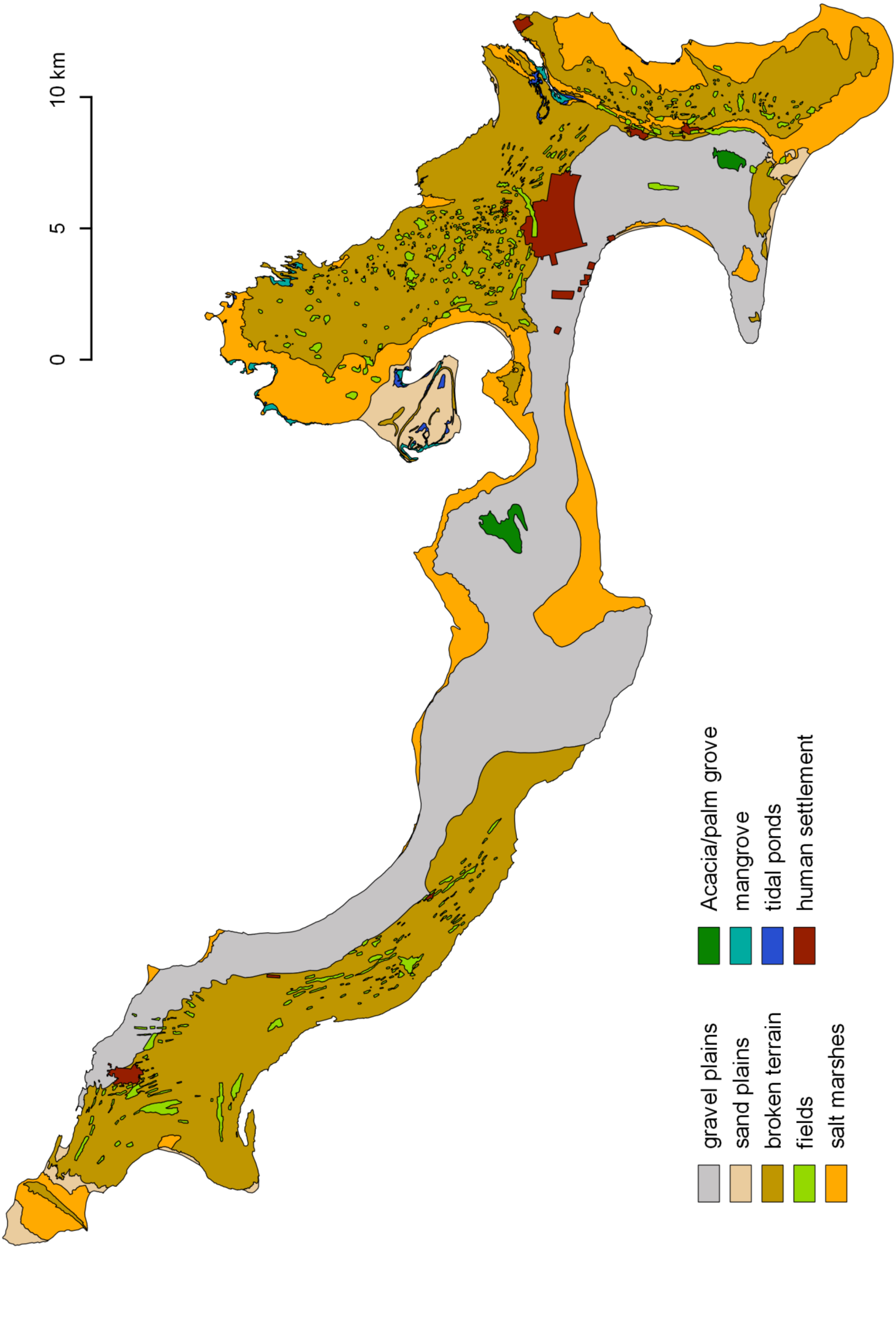


Figure 2.



10 km
5
0
gravel plains
sand plains
broken terrain
fields
salt marshes
Acacia/palm grove
mangrove
tidal ponds
human settlement

Figure 3.

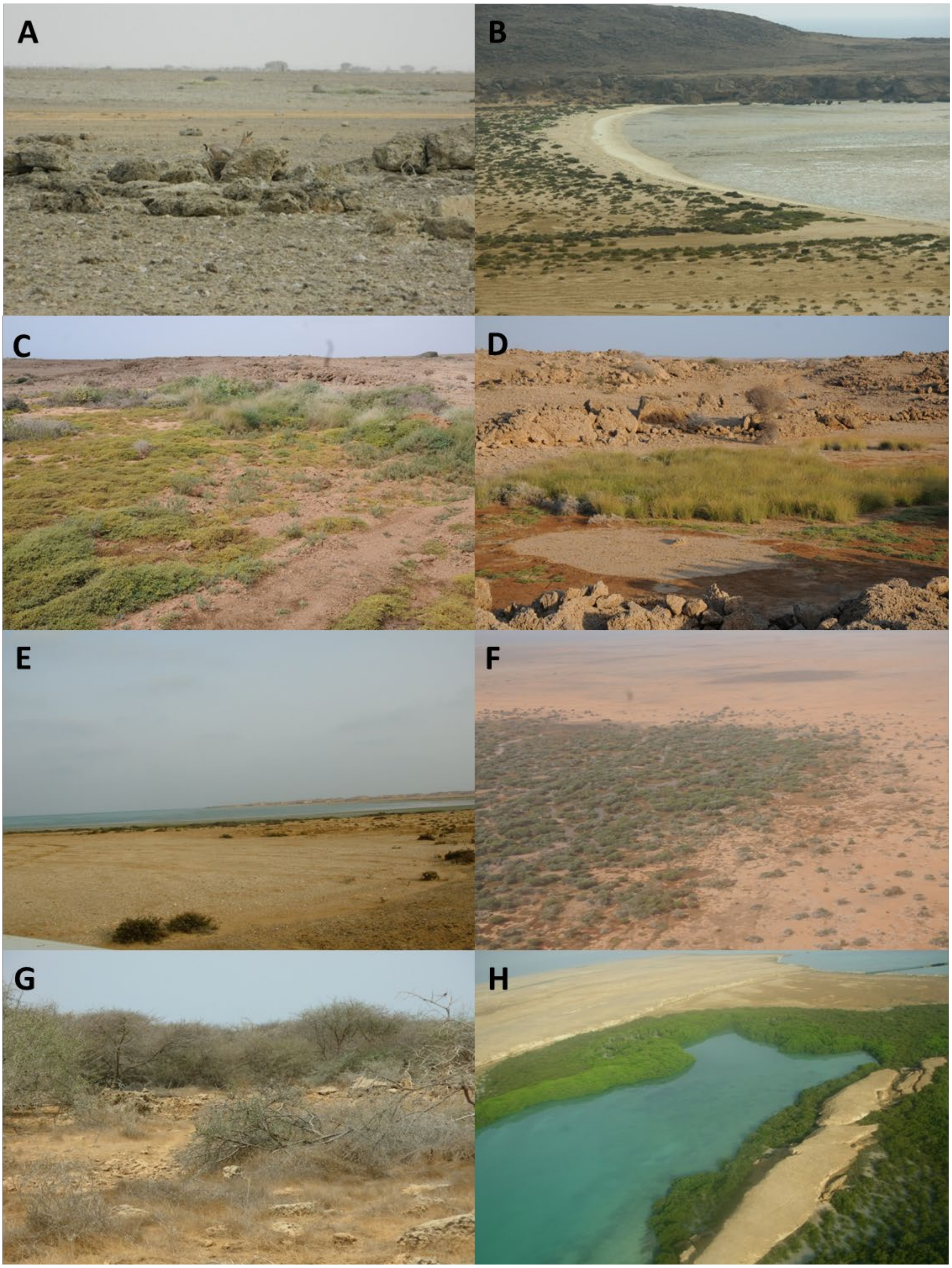
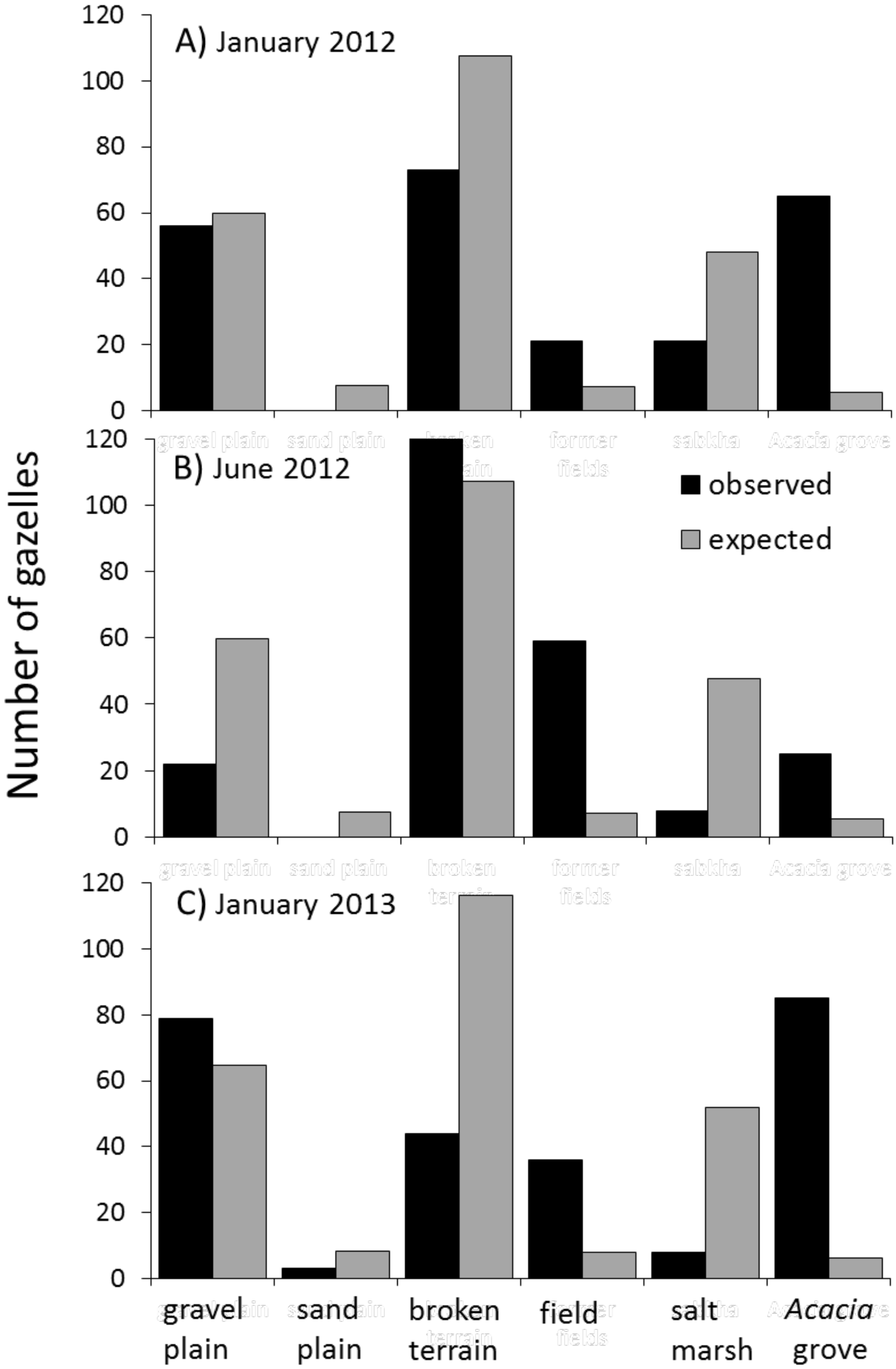


Figure 4.



A) January 2012
B) June 2012
C) January 2013
observed
expected
Number of gazelles
120
100
80
60
40
20
0
gravel plain
sand plain
broken terrain
field
salt marsh
Acacia grove