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Proximity to urban fringe recreational facilities increases native biodiversity in an arid rangeland

Tamer Khafaga[A], *Greg Simkins*[B] *and David Gallacher*[C,D]

[A]Universidad de Málaga, Avenida de la Estación de El Palo, 4, 29017 Málaga, Spain.
[B]Dubai Desert Conservation Reserve, PO Box 191177, Dubai, United Arab Emirates.
[C]Department of Interdisciplinary Studies, Zayed University, PO Box 19282, Al Ruwayyah, Dubai, United Arab Emirates.
[D]Corresponding author. Emails: david.gallacher@zu.ac.ae; david.gallacher.dr@gmail.com

Abstract. Urban developments affect neighbouring ecosystems in multiple ways, usually decreasing native biodiversity. Arabian arid rangeland was studied to identify the primary causes of biodiversity variation. Al Marmoum is a 990 km^2 area on the urban edge of Dubai, designated for ecological 'enhancement' and outdoor recreational use. The area lacks historical biodiversity data, but is thought to be primarily influenced by Arabian camel (*Camelus dromedarius* Linnaeus, 1758) herbivory. Perennial floral and faunal diversity was assessed at 54 sites. Counts of reintroduced ungulates (Arabian oryx *Oryx leucoryx* (Pallas, 1777), Arabian gazelle *Gazella gazella cora* (C.H. Smith, 1827) and sand gazelle *G. subgutturosa marica* (Thomas, 1897)) were made at 79 separate sites. Correlations of observed biodiversity with substrate type, anthropogenic structures, and ungulate distribution were assessed. Native biodiversity was substantially higher in north-north-west locations near recreational facilities, with the most likely cause being differential browsing pressure. Camel browsing faced greater communal regulation in the north-north-west, whereas oryx and gazelles congregated at feed points in the south-south-east that were farther from human activity. Arid rangeland in this socioecological landscape exhibits greater natural biodiversity at the urban fringe. Human activity reduces ungulate density, enabling a greater diversity of perennial flora, which then attracts non-ungulate fauna. Anthropogenic features can therefore offer conservation value in landscapes where ungulate populations are artificially elevated.

Additional keywords: anthropogenic, browsing, camel, herbivory, peri-urban, ungulate.

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Introduction

Urban fringes are normally associated with a reduction in native biodiversity (Hansen *et al*. 2005; Bekessy *et al*. 2012), and urban expansion is one of the leading causes of local extinctions (Marzluff 2008). However, outer urban fringes sometimes exhibit increased biodiversity, likely due to increased habitat diversity that includes faunal access to resource-rich gardens (McKinney 2002). Total phytomass may increase with groundwater changes, which typically include an increase in both volume and pollutants (Simon 2008). In such cases, the apparent ecological health is controversial because the modified urban–rural transitional landscapes favour immigrant species (Walker *et al*. 2009).

A healthy ecosystem of predominantly native species has value beyond the preservation of natural heritage. High biodiversity has a positive psychological effect (Carrus *et al*. 2015), and people are more connected with the natural ecosystem of the region if that ecosystem reaches close to their homes (McKinney 2006). Community participation is a necessary component of long-term sustainability of conservation efforts (Seddon 2000), but such participation may be problematic in societies that retain a predominance of anthropocentric over ecocentric values (Gagnon Thompson and Barton 1994). Arabian camels (*Camelus dromedarius* Linnaeus, 1758) and dates (*Phoenix dactylifera* L.) are held in high regard within the Arabian culture, and edible species are held in higher regard than species with little or no economic value (Seddon and Khoja 2003). Abu Dhabi Media Co. operates a television station devoted to traditional sports, with camel racing as its primary focus. Societies tend to conserve the species they value, to the extent that the real environment often becomes a partial reflection of social attitudes (Ouis 2003).

Camel herbivory is frequently cited as the main cause of rangeland decline on the Arabian Peninsula (Batanouny 1990; Assaeed 1997; Ferguson *et al*. 1998; Abed and Hellyer 2001; Hegazy and Lovett-Doust 2016). Camels have been present for millennia (Peters 1997), but social, cultural and political effects have resulted in a population explosion (Al-Rowaily 1999) since the end of the Second World War (Heady 1963). Camel herbivory suppresses phytomass and reduces the proportion of more palatable small perennial plants on all land surfaces, but more severely on gravel substrate (Gallacher and Hill 2006). Camel herder settlements are scattered throughout the Dubai rangeland (Gallacher 2010), but camel densities are highest around racetracks and are not directly associated with rangeland provision of feed or water (Yagoub and Hobbs 2003). Land tenure is not always clear and is traditionally based on water access rather than geographical boundaries (Wilkinson 1983). Land tenure in the bordering Abu Dhabi emirate is legally defined (The General Secretariat of the Executive Council of the Emirate of Abu Dhabi 2015), though enforcement is unclear and the emirate boundary is porous. Rangeland access for camel herders is thus regulated communally within Dubai emirate, with few restrictions through unfenced rangeland or across emirate boundaries.

In the present study, the ecological status of an arid rangeland zone on the southern edge of Dubai emirate was assessed as part of a proposal for extending an ecological recreation zone. There appeared to be more plant growth in areas bordering recreational facilities, and it was hypothesised that proximity to an urban fringe recreational facility influences the biodiversity of native faunal and floral species. Possible mechanisms for increased biodiversity might include the provision of resources (gardens, groundwater), the distribution of seeds, and the suppression of browsing by livestock (camels) and native ungulates (Arabian oryx *Oryx leucoryx* (Pallas, 1777), Arabian gazelle *Gazella gazella cora* (C.H. Smith 1827) and sand gazelle *G. subgutturosa marica* (Thomas, 1897)).

Materials and methods

Study site

Al Marmoum is a 990 km^2 open-access, protected area of interspersed gravel plains and sand dunes on the inland fringe of Dubai metropolitan area (Fig. 1). The area is hyper-arid, with high summer temperatures, low rainfall of ~80 mm annually, and lying in the humid coastal zone of the United Arab Emirates (Böer 1997). Al Marmoum is bordered by the fenced 225 km^2 Dubai Desert Conservation Reserve (DDCR), a 62 km^2 fenced military area, and the open-access arid rangelands of Abu Dhabi emirate. Two unfenced, sealed roads cross the area, intersecting perpendicularly. Camels and ungulates can move freely within the United Arab Emirates, but cannot cross major roads or enter fenced spaces such as the DDCR. Approximately 120 camel enclosures are scattered throughout Al Marmoum. Enclosures are comprised of one or more fenced areas, usually of ~200 m^2 each, and may include buildings. Information on the ownership of camel enclosures in Dubai Emirate is lacking, though

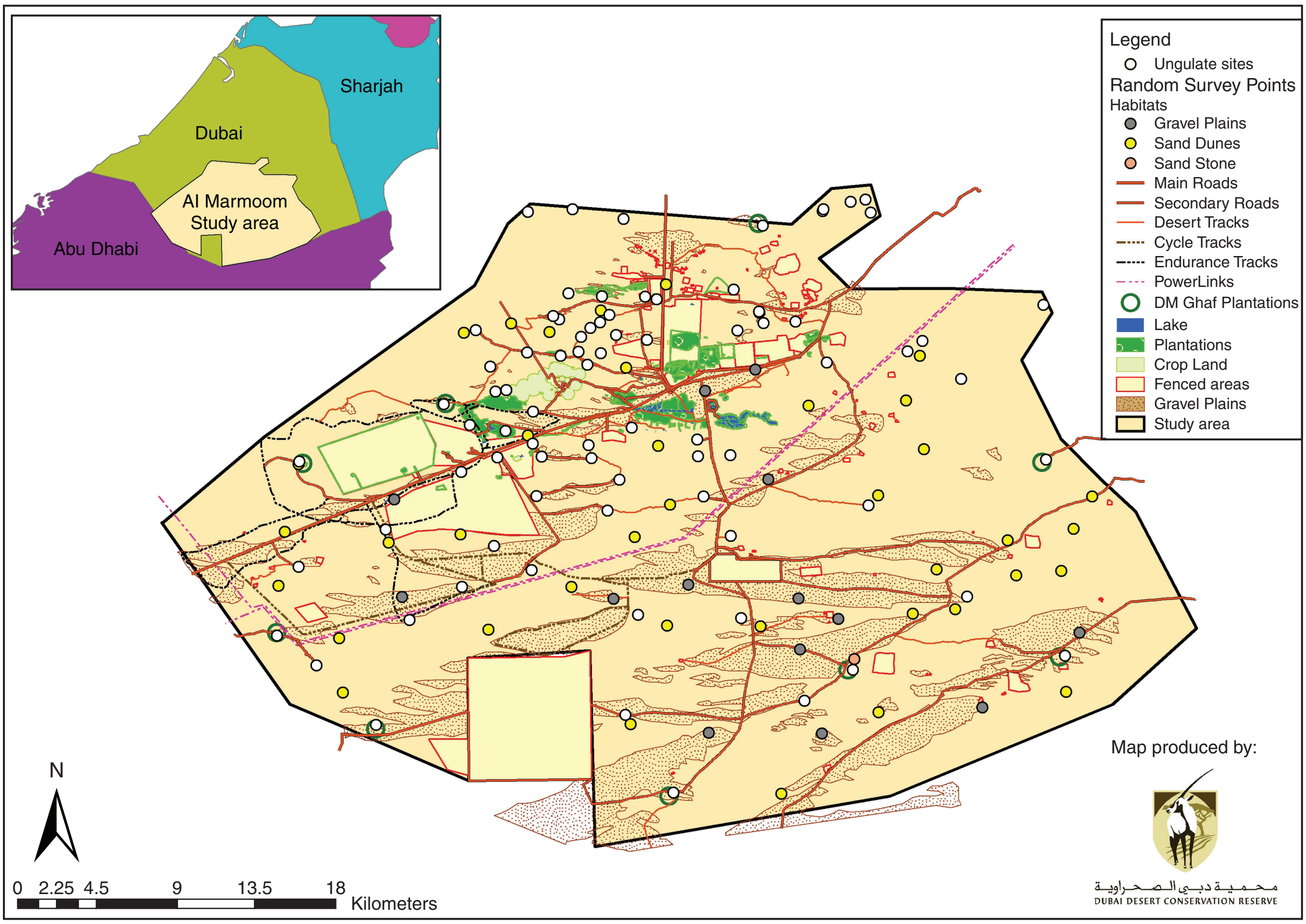


Fig. 1. Map of the Al Marmoum open-access nature reserve, and its location within the United Arab Emirates (inset).

a general description of rangeland farms and livestock enclosures has been published (Gallacher 2010). Camel diets are only partially provided by rangeland, with the primary source being provided within the enclosure from non-rangeland sources. Hence, rangeland browsing pressure is strongly influenced by animal husbandry practices and is significantly lower than would be surmised from camel density estimates.

Several recreational facilities are provided within Al Marmoum, with more being proposed. Currently available are:

- Dubai International Endurance City; includes soil-graded equestrian circuits, the longest being 160 km, and 15 km^2 of stables and other facilities for the Dubai Equestrian Club.
- Al Qudra Cycle Track; includes tarmac cycle circuits, the longest being 100 km, and facilities for patrons (bicycle hire, cafeteria, changing rooms).
- Al Qudra Lakes; includes 14 km^2 of irrigated forests and lakes, developed for day trips and overnight camping. Forest species are mostly indigenous, though the high tree density and placement on gravel substrate do not mimic natural systems. The 40 lakes contain a mix of native and introduced fauna, with a notably large population of ducks. Note that the singular term 'Al Qudra Lake' refers confusingly to a separate, older lake associated with the Bab Al Shams Resort.
- Bab Al Shams Desert Resort and Spa; a 113-room hotel with a 3 km^2 footprint.
- The Dubai Camel Racing Club is located on the area's perimeter, with race tracks (the longest being 8 km) and 35 km^2 of stables and other facilities.

A further 6 km^2 is used for pivot-irrigated forage production of *Medicago sativa* L., and 10 km^2 for the Mohammed bin Rashid Al Maktoum Solar Park. The area encompasses three archaeological sites, but there are currently no plans to open these to tourism.

Herbivore populations are encouraged to reside in the area via 67 fixed feeding points, at which hay, water and shade are provided *ad libitum*, and camels are exclosed via razor wire at and above 1.5 m. Translocation has established populations of three native ungulate and one bird species. Details were unavailable regarding dates, numbers and sources of translocations, but likely began around 2005. Arabian gazelle and sand gazelle were likely introduced from a mix of captive and wild populations, and Arabian oryx from captive populations only. *Chlamydotis macqueenii* (J.E. Gray, 1832), the Asian houbara bustard, have been released annually from captive-bred populations as part of an ongoing release program at locations throughout the United Arab Emirates. There have been unofficial reports of houbara breeding colonies within Al Marmoum.

Data collection

Fifty-four sites were selected randomly within the existing and proposed extension areas of Al Marmoum, using XTools Pro 16.1 plugin for ArcGIS to ensure representative sampling of gravel and sand substrates. Perennial floral and faunal counts were made from 7 to 16 August 2016 within a circle of 50 m radius. Ephemeral plant species were absent during data collection, but their distribution is not affected by ungulate herbivory (Gallacher and Hill 2008). Perennial floral counts were made on five 10 × 10 m plots within the circle, including one central, and one randomly selected within each quartile of 50 m radius. This sampling method is time efficient for heterogeneously distributed sparse vegetation (McAuliffe 1990). Faunal counts of tracks, burrows, faeces, skeletons and living individuals were made in the entire circle. Ungulates and sighted individuals were classified to species, but other artefacts were classified broadly (rodent, lizard, etc.). Vertebrates comprised 93% of observations. Sites were further ranked based on ground observations of the substrate and included 9 stable and 24 active dunes, 17 gravel and 3 sandy plains, and 1 sandstone site.

In addition to counts made at study sites, live ungulates (Arabian oryx, Arabian and sand gazelles) were counted once during August 2016 at each of the 67 fixed feed points, 9 forested locations where feed had been provided, and elsewhere when observed.

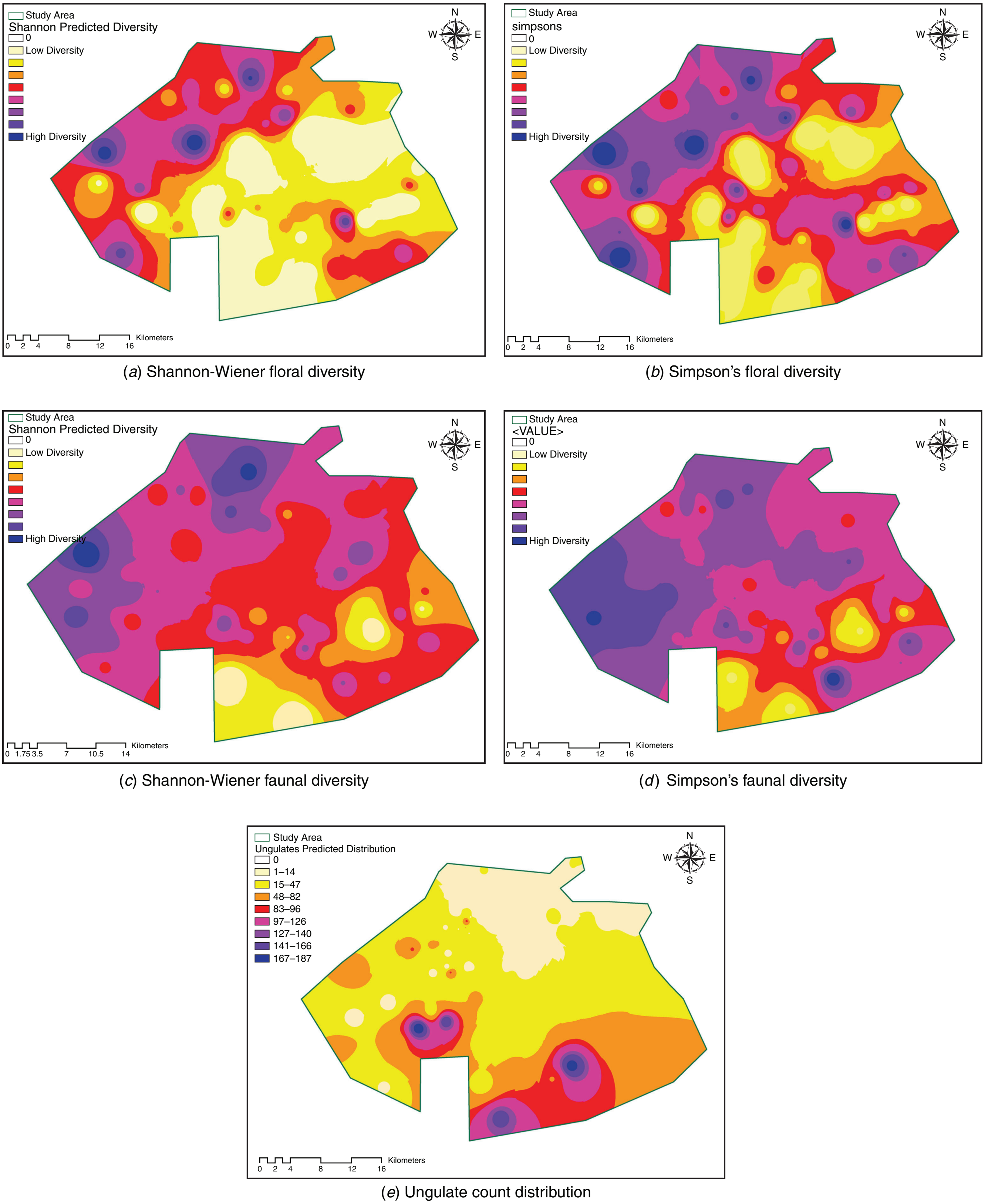
Data analysis

The Shannon–Wiener, Simpson and Margalef indices were calculated for floral and faunal observations at each of the 54 sites. The first two indices represent Types I and II diversity (Peet 1974), which are more sensitive to variation in abundant and rare species respectively. The third is an estimate of actual species richness from observed data. Inverse distance weighting (IDW) was used to generate heat maps of the predicted diversity throughout the study area. The relative importance of each species was estimated using the importance value index (IVI), in which relative density, frequency, abundance and cover are given equal weighting (Curtis and McIntosh 1951). The IVI provides a broader assessment of a species presence within a community than single measures do (Shukla and Chandel 1989; Sharma 2003).

Direct distances from each sample site were measured (using Google Earth) to the closest anthropogenic fixture for several categories (sealed road, graded dirt road, plantation and/or lake, a feeding point, cycle track, equestrian track, overhead power line, camel enclosures, and non-farm buildings). Camel enclosures were identified using Google Earth imagery, and ranged from itinerant, small, fenced areas with a structure providing shade, to permanent buildings with gardens and livestock pens. The number of camels was assumed to vary substantially from farm to farm.

Results

Perennial floral diversity was considerably higher in the north-north-west (Fig. 2*a*, *b*), where recreational facilities are located (horse stables, equestrian and cycle tracks, resort facilities and day/night camping areas), and was lower in the central zone. Higher diversity on the southern edges of the reserve bordered the township of Al Faqa and a worker accommodation/industrial facility in Abu Dhabi emirate (24.6788°N, 55.1631°E), though it was not consistently higher near the town of Murqquab or a southern afforestation project (24.6245°N, 55.4027°E). All plant species observed within sites were native. Faunal diversity was also higher in the north-north-west and displayed greater homogeneity than floral diversity, though this may be an artefact of the sampling method. No evidence of non-native animal species was detected.



(*a*) Shannon-Wiener floral diversity

(*b*) Simpson's floral diversity

(*c*) Shannon-Wiener faunal diversity

(*d*) Simpson's faunal diversity

(*e*) Ungulate count distribution

Fig. 2. Inverse distance weighted heat maps for Types I and II floral (*a*, *b*) and faunal (*c*, *d*) diversity indices and for ungulate counts (Arabian oryx, sand gazelles and Arabian gazelles; *e*) in the Al Marmoum open-access reserve.

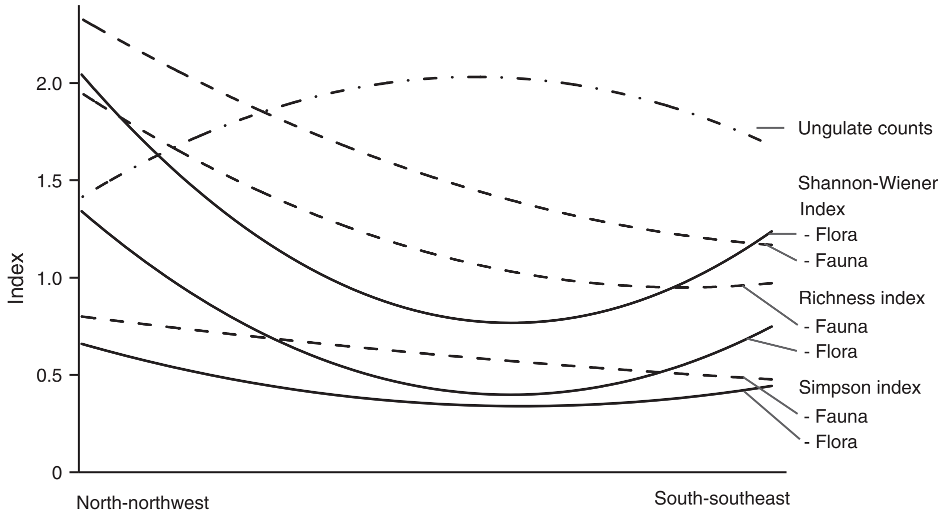


Fig. 3. Quadratic correlations for floral (solid lines) and faunal (dashed lines) diversity indices, and ungulate counts (dot–dash lines; 8% of average count per site) along a gradient from the nor-north-west (north-north-west) to the sou-south-east (south-south-east) of Al Marmoum reserve.

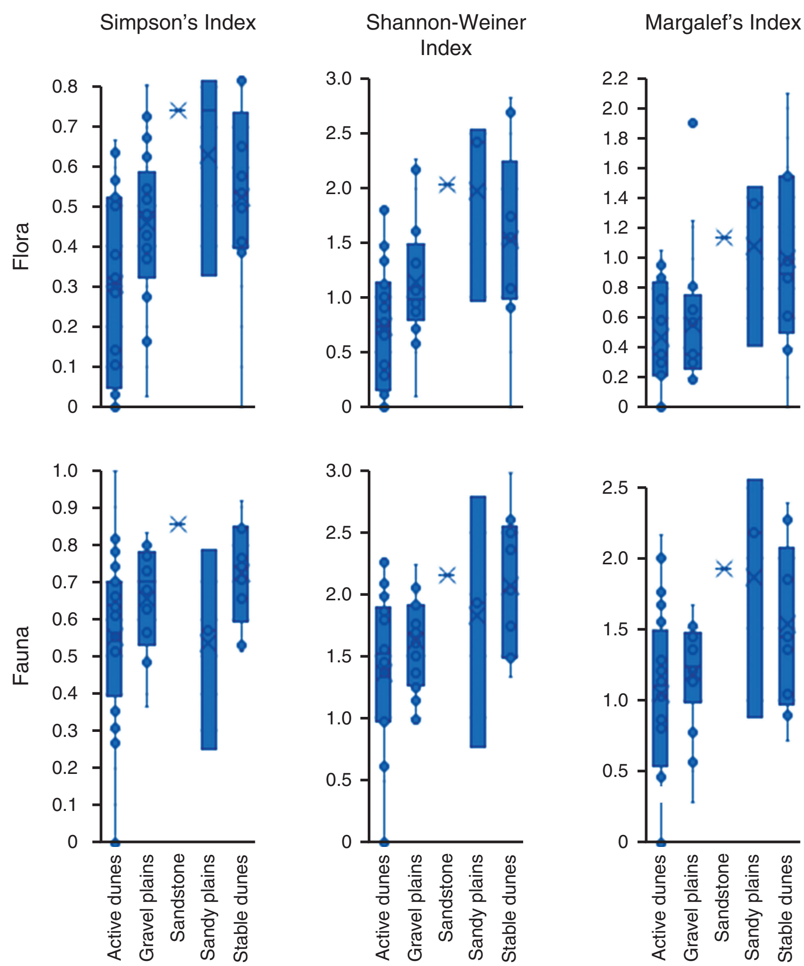


Fig. 4. Box-and-whisker plots of diversity indices for each of the five vegetation types, including stable (9) and active (24) dunes, sandy (3) and gravel (17) plains, and sandstone (1).

Table 1. Plant species observed among the five habitat types, with life form (Raunkiær 1934), Importance Value Index (IVI) and frequency (percentage of plots in which the species was observed)

Family Species	Life form; Raunkiær plant life-form[1]		IVI	Frequency (%)	Habitats (number of sites) Sand stone (1)	Gravel plains (17)	Sandy plains (3)	Stable dunes (9)	Active dunes (24)	Total habitat number
Asclepiadaceae										
Leptadenia pyrotechnica (Forsk.) Decne.	Perennial shrub	Ph	109	9				×	×	2
Boraginaceae										
Arnebia hispidissima (Lehm.) DC.	Annual herb	Th	30	0.1		×	×	×		3
Heliotropium digynum (Forsk.) Aschers. ex C. Christ.	Perennial shrublet	Ch	11	6			×	×	×	3
Heliotropium bacciferum var. crispum (Desf.) Sauvage and Vindt.	Perennial shrublet	Ch	7	6		×		×		2
Moltkiopsis ciliata (Forsk.) I. M. Johnst.	Perennial shrublet	Ch	41	7			×	×		2
Capparaceae										
Dipterygium glaucum Decne.	Perennial shrublet	Ch	10	2				×		1
Chenopodiaceae										
Cornulaca monacantha Delile	Perennial shrublet	Ch	45	0.04		×		×		2
Cruciferae										
Eremobium aegyptiacum (Spreng.) Asch.	Annual herb	Th	6	2		×				1
Farsetia linearis Decne.	Perennial shrublet	Ch	13	2		×				1
Cyperaceae										
Cyperus conglomeratus Rottb.	Perennial sedge	Ge	153	65	×	×	×	×	×	5
Fabaceae										
Crotalaria aegyptiaca Benth.	Perennial shrublet	Ch	5	2				×		1
Indigofera colutea (Burm.f.) Merr.	Perennial shrublet	Ch	52	17		×	×	×	×	4
Indigofera intricata Boiss.	Perennial shrublet	Ch	21	9		×	×	×	×	4
Prosopis cineraria (L.) Druce	Perennial tree	Ph	72	6					×	1
Fumariaceae										
Limeum arabicum Friedrich	Perennial shrublet	Ch	47	30	×	×	×		×	4
Geraniaceae										
Monsonia nivea (Decne.) Decne. ex Webb	Perennial shrublet	Ch	46	13		×			×	2
Poaceae										
Centropodia forsskaolii (Vahl) Cope	Perennial grass	Th/He	25	0.2		×	×	×	×	4
Coelachyrum pierceii (Benth.) Bor	Perennial grass	He	42	0.04					×	1
Panicum turgidum Forssk.	Perennial grass	He	51	19	×		×	×	×	4
Pennisetum divisum (J.F.Gmel.)	Perennial grass	He	16	7			×	×		2
Stipagrostis plumosa (L.) Munro ex T.Anderson	Perennial grass	He	55	46	×	×	×	×	×	5
Rosaeceae										
Neurada procumbens L.	Annual herb	Th	18	4		×	×			2

Salvadoraceae										
Chrozophora oblongifolia (Delile) A.Juss. ex Spreng.	Perennial shrub	Ch	8	2			×			1
Solanaceae										
Lycium shawii Roem. and Schult.	Perennial shrub	Ph	9	2				×		1
Zygophyllaceae										
Fagonia indica Burm. fil.	Perennial shrublet	Ch	121	37		×	×	×	×	4
Tetraena qatarensis (Hadidi) Beier and Thulin	Perennial shrublet	Ch	65	11	×		×	×	×	4
Tribulus macropterus var. arabicus (Hosni) F. Al-Hemaid and Jacob Thomas	Perennial herb	Ch	54	4			×	×		2
Tribulus pentandrus Forsk.	Perennial herb	Ch	15	15		×		×		2
Zygophyllum simplex L.	Perennial herb	Th/Ch	127	33		×				1

[1]Ch Chamaephyte; Ge Geophyte; He Hemicryptophyte; Ph Phanerophyte; Th Therophyte.

A total of 615 Arabian oryx, 1098 Arabian and 650 sand gazelles were observed, mainly in areas that were distant from anthropogenic features, other than a road near the southern border (Fig. 2*e*). Numbers were higher in the central-west and south-south-east, approximately the opposite of both floral and faunal diversity (Fig. 3).

Biodiversity was higher in stable than on active dunes, and on sandy than on gravel plains (Fig. 4). This represented an observed site richness difference of 2.5 and 3.8 on active dunes, to 7.0 and 10.3 on sandy plains, for plant species and animal artefacts. Three of the 29 observed plant species were ephemeral, despite the timing of the study in summer. Correlation between floral and faunal diversity among sites was low ($R^2 = 0.075$, 0.122 and 0.045 for the Simpson, Shannon–Weiner and Margalef indices respectively), but among habitat types was high ($R^2 = 0.374$, 0.728 and 0.945). *Cyperus conglomeratus* Rottb. was the most widespread plant species, with the highest IVI, frequency, and appearance across all five substrates (Table 1). *Zygophyllum simplex* L. was common on gravel and *Fagonia indica* Burm. fil. on sandy substrates. Gazelle and rodent tracks were observed at many active dune and gravel plain sites, and at all other sites.

Plant diversity was significantly higher within 1 km of tree plantations and lakes ($P < 0.003$ for all three indices) and within 2.5 km of major roads ($P < 0.006$ for all three indices). However, anthropogenic features are clustered in the north–north-west along the east–west main road, which follows a gravel plain, and correlations became insignificant when this was taken into account. Proximity to feeding points and camel farms showed no correlation with diversity measures.

Discussion

Native biodiversity was ~3-fold higher near established anthropogenic facilities in the north, and somewhat higher near some but not all communities in the south. Plant biodiversity is low across the United Arab Emirates (Hegazy and Lovett-Doust 2016), and observed diversity is lower in summer, when ephemeral species are mostly present only in seed form. Some perennial species of ecological significance in the area did not appear in sampling, including *Acacia ehrenbergiana* Hayne and *Calotropis procera* (Ait.) Ait. fil. Hence, the true plant species richness may be higher than observed.

Historical data is unavailable to determine whether biodiversity distribution pre-dates anthropogenic structures. Location of anthropogenic structures has been influenced by substrate and proximity to the coast, and is unlikely to have also been significantly influenced by biodiversity. Camel and horse stables, towns, and solar facilities are located on gravel plains, whereas forage production and the desert resort are located on stable dunes. Variation in community self-regulation of camel browsing throughout Al Marmoum could have caused the observed spatial variation in biodiversity. Camel herders in the north suggested the south has been, and continues to be, overgrazed by intraday Abu Dhabi–based herders.

Proximity to camel enclosures did not affect plant diversity at the scale observed in this study, though we expect that a specifically designed transect study would find differences at smaller scales (tens of metres from enclosures). Moderate browsing can sometimes increase plant diversity through the reduction of dominant species, but heavy browsing typically reduces the richness of palatable species (Holechek *et al*. 2010). Observations of increaser and decreaser plant species were mixed. The palatable grasses *Panicum turgidum* Forssk. and *Pennisetum divisum* (J.F.Gmel.) Henrard were found only in the north-north-west, and the palatable tree *Calligonum comosum* L'Hér was not observed during the study, indicating heavier browsing in the central and south-south-east regions. However *Calotropis procera*, known to flourish under heavy camel browsing (Gallacher 2010), was also not observed, perhaps due to the presence of gazelles. Distribution of the sedge *Cyperus conglomeratus* followed a similar pattern to the Shannon–Wiener floral diversity (Fig. 2*a*), despite being an early recoloniser of stressed habitats.

This study found no correlation between study-site biodiversity and proximity to feeding points, but oryx and gazelle densities were negatively correlated with site biodiversity and proximity to human activity. These ungulates had *ad libitum* access to non-rangeland food, water and shade sources at feed points throughout Al Marmoum. It therefore appears they preferentially inhabited areas away from people, using feed points as their primary food source, and browsing on rangeland vegetation nearby. Diurnal movement patterns of oryx and gazelles were disrupted by reliance on feed points that provided all their needs (food, water and shade) at a single location. In the neighbouring DDCR, oryx utilised feed points, whereas gazelles preferred rangeland vegetation if available. Oryx tend to disperse uniformly during daytime and night-time browsing hours and regroup at sunrise and sunset (Gallacher 2015). Ungulate densities likely far exceed historical levels, but their level of dependence on rangeland vegetation has not been measured.

Differential browsing is the most likely cause of the observed spatial variation in biodiversity, due to camel herders using areas that are less communally regulated, and other ungulates avoiding human activity. Nevertheless, several other factors could be contributing, including changes to groundwater, seed bank production and dispersal, and faunal consumption of irrigated vegetation. Groundwater distribution in the United Arab Emirates has been substantially modified over the last few decades through increased extraction and added recharge sources (Murad *et al*. 2007).

Protection from large herbivores is available for plants in many anthropogenic structures, some of which also have increased water availability. These areas may be important for seed bank recharge of palatable species. Plants can grow far larger with protection, and thus produce far more seeds than plants without protection. Seed dispersal might also be affected by faunal visits to irrigated spaces, and to anthropogenic activity throughout the reserve. Equestrian tracks are regularly graded, and on- and off-road vehicles of all sizes move throughout the reserve. Higher site biodiversity appeared to be more associated with fenced irrigated spaces than unfenced irrigated forests, which is indicative that seed bank recharge might be significant.

Conclusions

A primary cause of rangeland degradation in Arabia is open-access livestock herbivory. Ungulates and herders tend to avoid peri-urban rangeland. This study found native biodiversity to be higher in arid rangeland that bordered Dubai urban developments, compared with rangeland further inland. Whether this represents an increase over historical levels or a reduced decline, is not known. The likely mechanism is the influence of anthropogenic fixtures on browsing pressure by camels, oryx and gazelles. Within the study area, camel browsing faced greater communal regulation in locations bordering anthropogenic fixtures, whereas oryx and gazelles selectively avoided these areas. Anthropogenic fixtures can therefore offer conservation value in this landscape by reducing the impact of elevated ungulate populations.

Conflicts of interest

The authors declare no conflicts of interest.

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