Original article

Does habitat heterogeneity influence taxonomic richness and abundance? A case study from a terrestrial protected area in Abu Dhabi, United Arab Emirates

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A R T I C L E   I N F O

A B S T R A C T

Biodiversity is under enormous pressure from multiple threats including climate change, land use change, habitat alterations and hunting pressure. One way to ease this pressure on biodiversity and to mitigate the effects of above-mentioned threats, is to establish protected areas. Importance of protected increases many folds in regions that are considered as biodiversity poor regions i.e. deserts. Protected areas have long been a major pillar of biodiversity conservation strategies; the Houbara Protected Area (HPA) is one of the 13 terrestrial protected areas in Abu Dhabi Emirate officially declared in 2017. However, no information regarding the status of biodiversity in the HPA has been communicated to the research fraternity. During the present study, surveys were conducted to fill this gap. The survey area was divided in to 50 grids of 5×5 km^2 and monitoring surveys were undertaken from January to December 2016. A total of 14 bi-monthly to monthly surveys were conducted within HPA and 196 species of different taxonomical groups were recorded. A year-long survey yielded highly diversified fauna and flora from 19 different habitat types (H) 1.32, (E) 2.28, Shannon Diversity Index). We looked at the influence of habitat breadth and temperature on the species richness and abundance, results shows that in desert setup heterogeneity of habitat is not an important factor in maintaining the biodiversity as total number of individuals as well as species were similar in the grids that have different number of habitat types (df = 34.3, t = -0.472, P = 0.640). However, we did find a positive impact of mean monthly temperature on species richness (df = 154, t = 2.53, P = 0.012). Our study highlights the importance of temperature in driving species abundance and richness in protected area. Abundance and species richness are similar in protected areas indicating that protection is allowing species to explore the heterogenous habitats. Overall, we can conclude that protection is beneficial for species.

1. Introduction

Uneven distribution of biodiversity on the surface of the Earth has been the focus of thousands of researchers for decades (Hof 2010; Khaliq et al., 2017). Several measures of biodiversity like species richness, species turnover and phylogenetic diversity have been used to quantify biodiversity (Dornelas et al. 2014; Hillebrand et al. 2018).Researchers have identified a plethora of abiotic and biotic drivers directly or indirectly influence distribution of biodiversity (Connolly et al., 2018; McGill and Potochnik, 2018; Nadeau et al. 2017). Among these drivers, climate and habitat has become two most important drivers of biodiversity under

changing anthropogenic world (Parody et al. 2001; Jetz et al. 2007; Hof et al. 2011; Bowler et al. 2017; Methorst et al. 2017). One of the favoured measure of biodiversity has been species richness that has been shown to influenced by climate and habitat at local as well as large scale (Currie 1991; Sanders et al. 2003; Wiens and Donoghue 2004; Gotelli and Chao 2013). However, other studies have also shown that trends in species richness do not influence the changes in the biodiversity (Hillebrands et al 2018).

Species richness has been used to identify the biodiversity hotspots for conservation purposes and to establish the Protected Areas (Brooks et al. 2004; Coad et al. 2008; Butchart et al. 2010). Additionally, these designated areas play a significant role in social and economic development (Coad et al. 2008) and symbolize many practical approaches to participatory and collaborative management. One of the primary causes of biodiversity loss is the destruction of habitat. There is evidence from many studies that greater habitat complexity and heterogeneity facilitate higher species diversity. MacArthur and MacArthur (1961), has demonstrated that higher foliage height diversity supports a greater number of bird species, numerous studies have corroborated the positive relationship between habitat complexity or heterogeneity and species richness in many habitat types (Heck and Crowder 1991, Jeffries 1993, Gee and Warwick 1994, Kelaher and Castilla 2005)

Protected Areas (PAs) have long been regarded as an important tool for maintaining habitat integrity and species diversity (Brooks et al., 2004) and play a vital role in the protection of biodiversity in a given geographical area (Bruner et al 2001). Although terrestrial protected areas herein after (TPAs) only cover 15.4 % of the world's land area (Nelson et al., 2011) they are considered to be vital reservoirs for maintaining biodiversity (Karanth et al. 2010) and reducing deforestation (Nolte et al. 2013). They are often considered the first line of defence for wildlife protection (Bruner et al. 2001) and have important values for biodiversity and community well-being (Leverington et al. 2010).

On a regional scale, the Arabian Peninsula contains approximately 230 protected areas covering an estimated 15 % of the total land area (Holness et al., 2011). Currently, the United Arab Emirates (UAE) has 44 declared terrestrial and marine protected areas with (TPAs) representing 14.93 % of the total land area. Terrestrial protected areas constitute 63% of the all declared protected areas in UAE (MoCCE 2021). Moreover, the largest emirate, Abu Dhabi, accounts for 87% of the UAE's total land area and therefore 68% of the terrestrial protected areas are found in Abu Dhabi. UAE's biodiversity richness is closely attributed to its geographic location being between the Indo-Asian and Afro-European regions resulting in the presence of 731 plant species, 78 mammal species (59 terrestrial & 19 marine) and 72 species of reptiles and amphibian in UAE (CBD, 2021). Moreover, nearly 4,000 species of terrestrial invertebrates have been recorded (Van Harten, 2008). However, rarely influence of habitat heterogeneity and temperature has been assessed on abundance and species richness at the Abu Dhabi HPA.

Environmental heterogeneity and area are the two important fundamentals of the species diversity (Rosenzweig 1995). Moreover, for more than five decades ecologists believe that spatial heterogeneity in habitat types helps species richness by increasing the opportunities for segregating niche (Allouche et al.,2012). Furthermore, habitat heterogeneity hypothesis assumes a correlation between area and the number of different habitats. It also assumes that each habitat is associated with a different set of species. The result is that, as area increases, new habitats are added and thus new sets of species are found (Kallimanis et al., 2008, Hugo and van Rensburg, 2008).

Given the proportion of arid or desert (TPAs) present within the UAE and primarily Abu Dhabi Emirate. Houbara Protected Area (HPA), formerly known as Baynunah Protected Area (BPA) is an important study site that harbour regionally important terrestrial

species and provides an excellent opportunity to evaluate the role of habitat in a desert ecosystem. The objectives of this study are threefold: 1) to test the hypothesis that habitat heterogeneity in HPA has any impact on species richness and abundance 2) to evaluate the impact of temperature and season on species richness and abundance 3) to document the biodiversity profile of HPA using 5x5 km^2 grid-based methodology.

2. Material and methods

2.1. Study area

The study area is inside HPA (N 24.005207°, E 053.086708°), located approximately 163 km from Abu Dhabi city and extending towards the west of the country. Grid-based surveys in HPA were undertaken during 2016, at that time the total area of HPA was 776 km^2 which was expanded to three-fold in June 2019 to a total area of 2,490 km^2 (Fig. A). In the survey area, a total of 19 habitat types were identified: Sand sheets and Sand dunes with Dwarf Shrub Cover was found to be the dominating habitat encompassed 35% of the total habitat types of the protected area, followed by Gravel Plains with Dwarf Shrub Vegetation with 21%, Gravel Plains with Sparse Vegetation 15% and Forestry Plantations with 11%. And all other habitat types comprise 16% in the enitre study area.

Moreover, mesas and burqas that have cultural importance contribute 1.3% of the total habitat types in the protected area. According to the data gathered from the nearest weather station of HPA, mean average temperature of 28℃ was recorded from January to December 2016 and the highest of 41℃ was recorded during the month of August. Furthermore, average relative humidity was recorded at 57% (NCM, 2021). Limited historic surveys in HPA were undertaken identified the presence of some regionally important species such as 1) Spiny-tailed lizard (Uromastyx aegyptia), 2) Ghaf Tree (Prosopis cineraria) and, 3) Macqueen's Bustard (Chlamydotis macqueenii). Furthermore, the Arabian Sand Cat (Felis margarita thinobia) was recorded after a gap of 10 years in 2015 from HPA and is considered a regionally important species (Ahmed et al. 2016).

2.2. Method

Monitoring surveys occurred during the summer season (April - September) and winter season (October - March) in 2016. The survey area was divided in to 50 grids of 5 × 5 km^2 each and depending upon the logistics and availability of biologists for each taxon bi-monthly to monthly monitoring surveys were undertaken in the survey grids. Each grid sampling was done in the grids midpoint or centroid to improve consistency of data collection and to sample all the grids within the protected area. Trail camera traps were deployed in each grid from January to December 2016 to record the data of crepuscular species of mammals and reptiles in the study area. Because of intense summer heat, monitoring surveys could not be conducted in the HPA during the month of June and July by the biologists, however trail camera traps were not removed from the study area and data retrieved from camera traps for these two months was used in the analysis (Plate.1).

Efforts were made to conduct monitoring surveys twice in each grid during summer and winter season in the protected area. Both diurnal and nocturnal surveys were carried out by a team of trained biologists in each gird. Additionally, 20–25 Trail camera traps were deployed to record the presence and absence of some of the elusive and nocturnal species of mammals, birds and reptiles. All the camera traps were placed at different habitats and were checked every month for battery usage and collection of memory (SD) cards.

Data for each taxonomical group was collected by biologists. Grid based monitoring surveys were carried out using following sampling techniques for each taxon:

Invertebrates: Sampling was carried out using multiple collection techniques including: 1) malaise trapping 2) light trapping, and 3) aerial netting for flying and perching insects based on techniques outlined in (Gullan and Cranston 2010; Van Harten, 2008). The collected invertebrate specimens within each group were identified up to species level and were preserved; dry pinned or preserved in 70% ethanol. Voucher specimens (insect specimens collected from study sites and preserved for future reference) were identified to species level by comparing with identified specimens in the Environment Agency - Abu Dhabi (EAD)'s invertebrate reference collection.

Reptiles: Given the varied behaviour of reptile species, nocturnal and diurnal surveys were conducted via walking and driven transects in accordance with (Hill et al. 2005). Active searching under natural or anthropogenic cover within the grids was conducted that yielded reptile species under cover. Indirect sightings (tracks and burrows) for different species of geckos, lizards and snakes were also recorded during diurnal and nocturnal surveys. Nocturnal reptiles' surveys were conducted concurrently with mammalian surveys.

Birds: To determine avifauna diversity and density in HPA, point count and transects surveys were conducted in accordance with the method outlined in (Bibby et al. 2000). Customised data sheets for point count and random count were prepared in the IOS Collector App using Ipads and were used to record the avian species in each survey grid. Data recorded included number of species and total number of individuals present in each survey grid. Efforts were also made to record other characteristics of birds such as age, sex, and activity. The duration of the point count was 10 min in each grid to record all the avian species. Moreover, randomly encounter birds were also recorded within each grid and while transiting between one grid to another.

Mammals: Small and large terrestrial mammal species were recorded using walking or driven transects. In addition, 20–25 Reconyx Inc. hyperfire (HC500, HC600 and PC800) baited trail camera traps were deployed within each centroid grid were used in accordance with the method outlined in Jones et al. 1996. These cameras run on 12 AA-cell lithium batteries in conjunction with 8–16 GB-SD cards for each camera trap. The cameras were placed with the following settings: (1) advance setting, continuous high-quality images, (2) high sensitivity, (3) three pictures per trigger and (4) infrared illuminator for nocturnal pictures. All the camera traps were checked every month for battery level, positioning and to replace memory (SD) cards. The camera traps were mounted on tripods as well as on specifically designed iron rods to fix in the sandy surfaces to capture small mammalian, bird and reptile species. (Fig. E). All the camera traps were baited using tinned cat food to attract carnivorous species.

Incidental records of all direct mammal species sightings and indirect sightings in the form of burrows, tracks or scats were also recorded. To increase detection rates, nocturnal walking and driving transects of 400 m along established tracks in low dunes were conducted using two million candle power spotlights in car charger power adaptor. Also, headlamps and small handheld torches were used during the nocturnal walks. The nocturnal surveys were conducted after sunset until midnight in all the habitat types. Additionally, camera traps installation in each grid helped to collect data for nocturnal species of mammals and reptiles.

Plants: These were recorded throughout the HPA during the daytime using line transects. The transects involved driving in a straight line of 500 m in each grid and recording the species observed on either side of the line (Hill et al. 2005). Apart from the above, the opportunistic data were also collected from each grid when transiting between survey girds for all flora and fauna groups.

2.3. Data collection and analysis

Data for all the fauna and flora species were collected using the IOS based Collector App using Ipads. The Collector App allows survey teams to use maps for navigation in the field to gather data and to synchronise records directly with the EAD Environmental Database using their mobile devices. This increases the efficiency and accuracy of data collection and helps in eliminating recording errors. Camera traps installation and removal in the study area was done by developing a special feature in the Collator App for navigation purposes.

The whole sampling area within the HPA was divided into 50 grids of 5x5 km^2 each (Fig. 1). Monthly data retrieved from the Collector App was accumulated to report total abundance as well as number of species for each taxon. The habitat type percentage in each grid was calculated using ArcGIS10.5. The species richness was determined by enumerating the number of species observed over the whole year in each grid at class level in case of animals and we pooled all the plant species together. In each grid, we categorized the habitat and to calculate the habitat breadth we counted the number of habitats in each grid cell. There is no data for the abundance for plant species so only richness for plants species was analysed. Mean monthly temperature data for all the surveyed grids was extracted from Chelsa climate data at 1 km resolution (Karger et al. 2016).

We fitted linear mixed effect models to model abundance and richness of species as function of habitat breadth, mean monthly temperature, taxa and month and added grid ID as random factor to account for spatial autocorrelation. For the model for abundance, we added species identity as random factor in addition of grid ID. Also Type III ANOVA with Satterthwaite's method was used to test whether addition of a variables such as habitat, temperature, seasons has significantly improved the model fit.

The data summarisation was carried out in MS Excel, and the analysis were done in R Core Team (2021). Also, Shannon Diversity Index was calculated using a software Biodiversity Pro. Sightings captured by the camera traps were manually recorded along with the date and time stamp of the images and entered in MS excel spreadsheet for further analysis. To visualise the influence of habitat types on species richness in each grid map was developed in ArGIS10.5.

3. Results

During the course of the study, 14 monitoring surveys were undertaken within HPA over the duration of eight months in 2016 to collect data on all the taxa present. Moreover, 289 trapping days occurred within study area over 365 days to collect data on terrestrial mammals, birds & reptiles using trail camera traps. We recorded highly diversified fauna and flora in 19 different habitat types in HPA (H) 1.32, (E) 2.28, Shannon Diversity Index.

Recorded species occurrence for all the taxonomic groups was greatest (40%) in three major habitats in HPA: 1) Sheets and Dunes with Dwarf Shrub Cover, 2) Forestry plantations, and 3) Gravel Plains with Dwarf Shrub Vegetation, whereas 60% of the total species were found in all 16 habitats in HPA (Fig. B). Areas with Sand Sheets and dunes had the higher habitats heterogeneity as compared to other habitat types in HPA.

Our results indicate that total number of individuals as well as species are similar in the grids that have different number of habitat types (df = 34.3, t = -0.472, P = 0.640) (Table A). The highest number of 25 species of different taxa were recorded from Gird
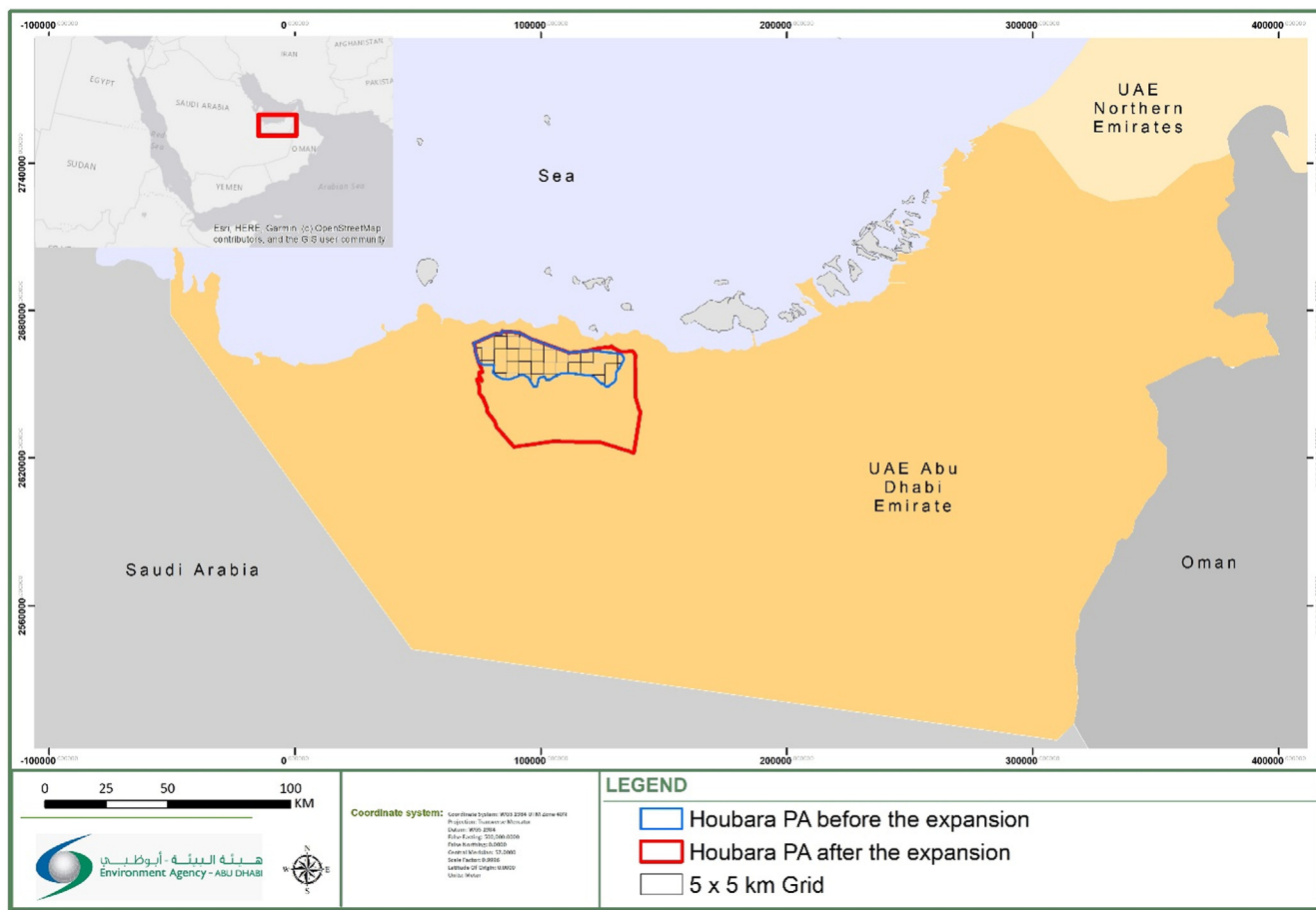
Fig. A. Map Showing the boundary of the HPA and survey grids within the protected area in Abu Dhabi Emirate.

No. 6 and a total of seven habitats types are present (Fig. B). On the other hand, Grid No. 9 had 15 different types of habitats and only 13 species were recorded. However, we did find a positive impact of mean monthly temperature on species richness (df = 154, t = 2.53, P = 0.012) (Table A) (Fig. C). The number of species of different taxonomical groups recorded to have decreased with increase of the atmospheric temperature (Fig. C) Also, overall number of species were recorded more in winter months January, February and December as compared to summer months, but the results were not statistically substantiated (df = 11, F = 235, P = 0.17, Type III ANOVA) (Table C). Moreover, we found that the species abundance did not vary significantly across the months (df = 11, CI = 0.14, P = 0.99, Type III ANOVA) and across the different habitats (df = 1, CI = 1.68, P = 0.20, Type III ANOVA) (Table. D). Also, rise in atmospheric temperature had no impact on species abundance in the HPA (df = 1, CI = 0.48, P = 0.48, Type III ANOVA) (Table B) (Fig. D).

During the grid-based surveys in HPA, a total of 116 species of invertebrates of which the Arabian Darkling Beetle (*Pimelia arabica*) and Urchin Beetle (*Prionotheca coronata*) were found to be the most frequently recorded species. Moreover, 13 species of reptiles were recorded; the Schmidt's Fringe-toed Lizard (*Acanthodactylus schmidti*) was found to be the most commonly occurring species in terms of numbers in HPA followed by the Arabian Toad-headed Agama (*Phrynocephalus arabicus*). There were no amphibian species recorded from the protected area as it is not in the known distribution range. In addition, 30 species of avifauna were recorded in the entire study area. Muscicapidae (wheatears, pipits) was found to be the most dominating family with six

species followed by Columbidae (doves, pigeon) with four species only. Over a period of one year, 10 species of small to large mammals were encountered in the HPA. Desert Hare (*Lepus capensis*) was recorded to be the most widespread and commonly occurring species in the protected area followed by Arabian Sand Gazelle (*Gazella marica*). Arabian Sand Cat (*Felis margarita thinobia*) was sighted 44 times at 13 different locations within the study area. Our results showed that total 27 plant species were documented in the HPA, *Tetraena qatarensis* and *Haloxylon salicornicum* were the most widespread species in the study area.

4. Discussion

Our main goals were to test the role of habitat heterogeneity and temperature and we found a strong influence of temperature on species richness. Overall, we observed around 196 species of different taxonomical groups in all the survey grids, however, contradictory to our expectation we found that species richness is similar in grids with different habitats. Our results indicate that in a desert setup, heterogeneity of habitats is not an important factor in maintaining biodiversity in deserts.

The effect of habitat breadth and temperature was not significant for species abundance. Also, at taxa level we did not find a significant positive effect of habitat heterogeneity on richness of birds and mammalian fauna, However, the richness of invertebrates and reptiles were found to be significantly different (Table A).

The previous studies have reported habitat heterogeneity to be an important determinant of maintaining biodiversity (Tews et al 2004, Fahrig et al 2011). In arid environments species aggregations
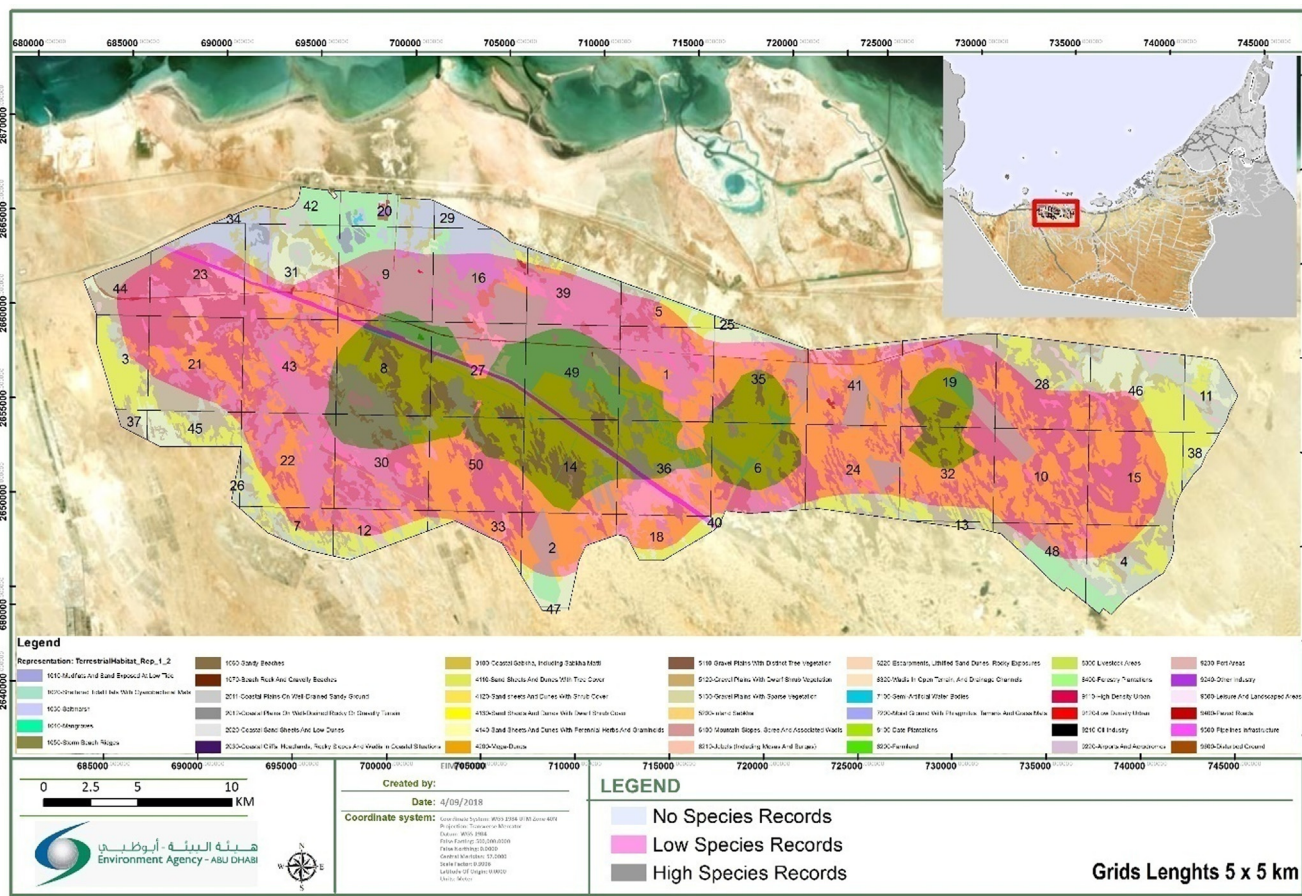
Fig. B. Study site showing species ocrruance in different habitat types in 5x5 km grids in HPA.

Table A

Table showing results of Linear mixed effect model - Species richness was used as response variable and habitat, mean monthly temperature, months and taxa as fixed factor and survey grids as random factor.

Variables	Estimate	Std. Error	df	t value	P
Intercept	−31.46607	14.97626	169.30503	−2.101	0.03712 *
Habitats	−0.03413	0.07234	34.31420	−0.472	0.64009
Mean Monthly Temperature	2.03645	0.80349	154.42995	2.535	0.01226*
October	−24.37279	8.21618	145.87433	−2.966	0.00352 **
November	−17.01264	5.79055	160.52846	−2.938	0.00379 **
December	−8.54966	2.97751	218.08736	−2.871	0.00449 **
February	−2.86334	2.24510	288.55794	−1.275	0.20320
March	−12.59525	4.32733	180.43616	−2.911	0.00406 **
April	−19.61943	6.70711	156.51283	−2.925	0.00395 **
May	−30.96076	11.15609	152.44638	−2.775	0.00621 **
June	−33.35742	11.68821	152.89822	−2.854	0.00492 **
July	−38.89234	13.91989	153.61998	−2.794	0.00587 **
August	−38.24421	13.89222	147.17608	−2.753	0.00665 **
September	−32.97045	11.79059	141.66773	−2.796	0.00589 **
Invertebrates	1.42848	0.45385	274.85482	3.147	0.00183 **
Mammals	0.35354	0.40169	278.09471	0.880	0.37954
Plants	0.39450	0.44404	273.37944	0.888	0.37509
Reptiles	−1.48391	0.58509	283.16791	−2.536	0.01174 *

Notes Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '1.'

are mostly found in dominating habitats such as Sand sheets and sand dunes, Gravel Plains and forestry plantations. In HPA we have found that 40% of the total species occurred in Sand sheets and sand dunes which comprises 35 % of all the habitat types present in the study area followed by Gravel Plains and forestry planta-tions, but the positive influence of habitat complexity on species
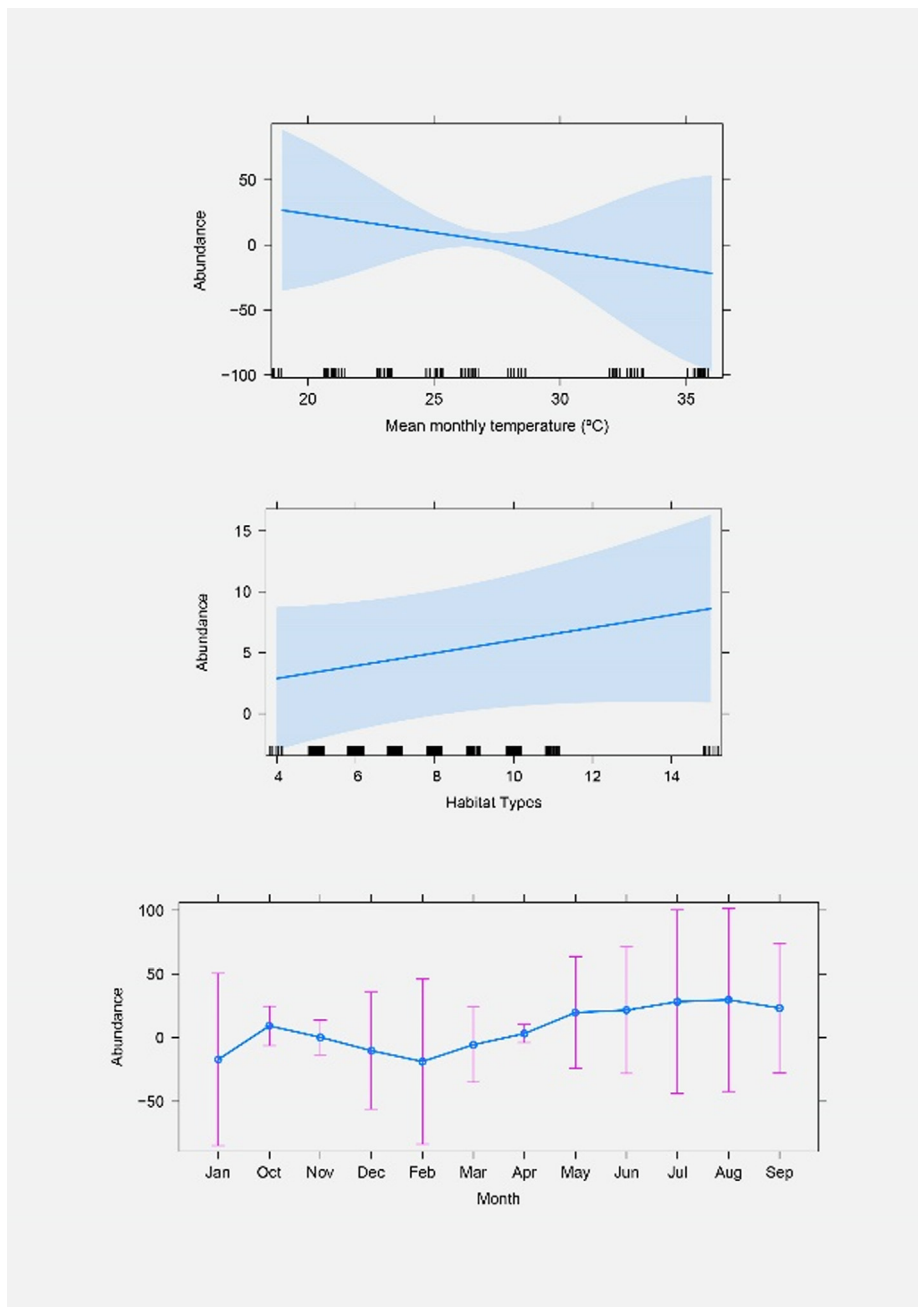
Fig. C. Influence of Atmospheric temprature, Habitats and Month on species abundance in HPA.

diversity and abundance could not be statistical substantiated. Furthermore, the grids with high species richness and abundance had a less number of habitat types, whereas those grids with low species records had the higher number of habitat types. The species occurrence and habitat types for each grid can be visualised in Fig. B.

Although positive relationships between habitat heterogeneity and animal species diversity is well documented (Davidowitz & Rosenzweig, 1998), but pragmatic and hypothetical studies have produced contradictory results. Depending on the taxonomic group, the structural parameter of the vegetation, species diversity may also decrease with an increase in habitat heterogeneity (Ralph, 1985; Sullivan & Sullivan, 2001). We are reporting that habitat complexity has least impact on species richness and abundance. However, our finding shows that, rise in monthly temperature

significantly affect the local species richness in desert environments. It has been found in the previous studies that high-temperatures primarily alter the relationship between biodiversity and ecosystem functioning. Moreover, impacts of temperature change on ecosystem functioning is directly linked to species' thermal traits (García et al., 2018). For conservation purposes, this is also very important to keep the diverse habitat intact in the protected areas otherwise many species might be under threat. Our results also indicate that in a desert ecosystem there is not much shift in community structure across the seasons. Presence of large number of species in desert ecosystem indicate the importance of protected areas.

Protected areas are places where conscious efforts are made to preserve not only wild species, but also the ecosystems in which species live (Stoltonet al. 2015). Physical expansion of the pro-

Table B
Table showing Linear mixed effect model - Species abundance was used as response variable and habitat, mean monthly temperature, months and taxa as fixed factor and survey grids as random factor.

	Estimate	Std. Error	df	t-value	P
(Intercept)	53.2938	75.6112	106.1786	0.705	0.4825
Habitats	0.5213	0.4014	23.3911	1.299	0.2067
Mean monthly Temperature	−2.8544	4.1002	99.8984	−0.696	0.4879
October	26.404	41.2633	95.0062	0.64	0.5238
November	17.4543	28.3498	103.2588	0.616	0.5395
December	6.9457	12.1768	116.7032	0.57	0.5695
February	−1.6215	5.8863	521.3262	−0.275	0.7831
March	11.5841	20.0528	112.6451	0.578	0.5646
April	20.3427	33.2959	102.8925	0.611	0.5426
May	36.8205	56.3513	100.4249	0.653	0.515
June	38.74	59.1842	101.073	0.655	0.5142
July	45.3808	70.5705	100.9677	0.643	0.5216
August	46.8795	70.6974	96.3867	0.663	0.5088
September	40.4119	59.9705	93.8451	0.674	0.5021
Invertebrates	6.5968	3.9209	172.4042	1.682	0.0943.
Mammals	−0.3127	5.8058	137.6602	−0.054	0.9571
Reptiles	−1.2183	6.6146	188.5381	−0.184	0.8541

Notes: Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table C
Type III Analysis of Variance Table with Satterthwaite's method for species richness – Temperature are Taxa are significant factor.

	Sum sq. Mean	Sq. Number	DF	F value	CI	>P
Habitat	1.039	1.039	1	34.314	0.2226	0.64009
Temp	29.999	29.999	1	154.430	6.4237	0.01226 *
Month	71.343	6.486	11	235.766	1.3888	0.17878
Taxa	135.227	33.807	4	276.420	7.2391	1.47805 ***

Notes: Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

tected area means giving attention to the local biodiversity, in 2019 the boundary of the HPA was expanded three-fold (Fig. A). Our findings in this paper represents 31% of the total area of the HPA.

During the grid-based monitoring exercise within the HPA, we recorded the representative species at both national and regional levels from five taxonomic groups. A total of 19 habitat types were identified in the Houbara Protected Area, Sand sheets and dunes with dwarf shrub representing 35% of the total habitat types and being utilised by 40% of the species of all the taxonomic groups. Results show that species occurrence was recorded higher in the mosaic habitats such farmland and forestry, gravel plains and sand sheets and dunes within survey grids and lower species occurrence was recorded in the less diversified habitat types (Fig. B) but the results were not statistically substantiated.

There were limitations with surveying the entire study area, since some areas within the protected area have a restricted access thus some of the grids could not be properly surveyed for habitat and species assessments. Furthermore, some of the survey grids with coastal sabkhas had poor access for vehicles to approach the targeted grids. It has been found that local communities within Abu Dhabi Emirate have extensive knowledge about the local species and awareness on ensuring the local biodiversity is protected: especially the carnivore species and birds of prey. During the study period, protected area rangers, mainly from the surrounding communities, were interviewed from time to time for presence and absence of the locally threatened and extinct species in different habitat types of HPA.

The HPA contains a diversity of habitats and species of regional and global conservation importance such as the Arabian Sand Cat that was thought to be extinct in the wild in Abu Dhabi. The systematic monitoring studies in HPA not only rediscovered this iconic species after a gap of 10 years (Ahmed et al. 2016) but also produced more than 40 new records at 13 different locations in the HPA. Moreover, Arabian Sand Cat was sighted 91 times at different locations within the Protected area using trail camera traps till the end of year 2019 (Al Zaabi et al 2020). The findings highlight the conservation importance of a terrestrial protected area in the arid environments and emphasize the need to expand the protected area network at the national and regional level.

After the rediscovery of the Arabian Sand Cat, the HPA was selected for extensive monitoring surveys as it has a history of supporting species of high ecological importance, is strictly governed, and is deemed the most representative of ecological conditions within the region. Record of Darkling Beetles, Spiny-tailed Lizard, Macqueen's Bustard, European Turtle Dove and particularly Short-eared Owl (*Asioflammeus*) and Pharaoh Eagle-Owl (*Bubo ascalaphus*) in HPA make this region very important for conservation of biodiversity.

Habitat loss is considered a major threat to global biodiversity (Fahrig 2003; Brooks et al. 2002), increasing the extinction rate of species in most ecosystems. During the gird-based monitoring surveys, we have recorded plant species that have conservation importance nationally as well as regionally. Such as *Haloxylon persicum* (locally known as *Ghada*) occupy a geographically distinct and well-delineated area in the south of Abu Dhabi city and has conservation value because this is the only natural occurrence in the UAE (Richard 2008). *Haloxylon persicum* was also recorded from HPA. Floral diversity mainly in Sand sheets and sand dunes habitat supports wide variety of vertebrate and invertebrate fauna. Conserving
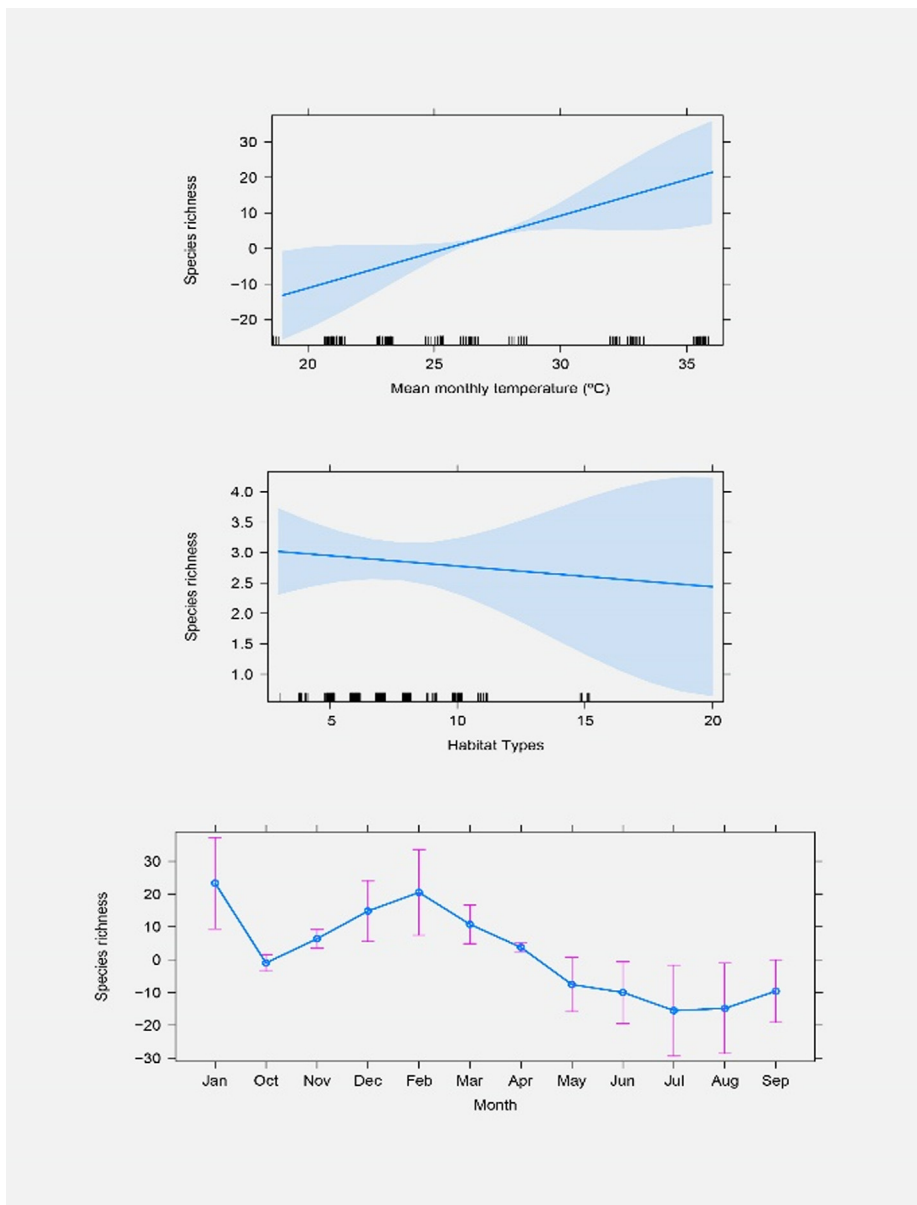
Fig. D. Influence of Atmospheric temprature, Habitats and Month on species richness in HPA.

biodiversity through protected areas has been at the core of global conservation strategies for more than a century (Pimm et al. 2001).

During monitoring surveys in the HPA, we found that protected areas with more restrictive management objectives are expected to retain more biodiversity. HPA represented 3% of the total invertebrate fauna recorded from the UAE followed by 25% of reptiles, 7% birds, 23% mammals and 6% plant species. Geographically small terrestrial protected area holds diversified fauna and flora. Moreover, grid-based monitoring surveys in the HPA yielded four globally threatened and 12 regionally and locally important species of conservation concern.

5. Conclusion

Temperature is the main driver of species richness in our study. The habitat structural diversity in a protected area in arid environments does not influence the taxonomic richness and abundance. Our findings reinforce the conservation importance of the Houbara Protected Area and suggest that protection consistently benefit species with narrow distribution ranges such as Arabian Sand Cat and the protected areas have important roles to play in securing species populations. Furthermore, grid-based methodology to study different taxonomical groups can be used as template to for-

Plate 1. Species (Arabian Red Fox, Arabian Sand Gazelle, Arabian Sand Cat) captured by camera traps in HPA during the grid-based survey in 2016.

mulate conservation action plans for the regionally and locally important species within the terrestrial protected areas in desert ecosystems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Ahmed, S., Zaabi, R., Soorae, P., Shah, J.N., Hammadi, H., Pusey, R., Al Dhaheri, S., 2016. Rediscovering the Arabian sand cat (*Felis margarita harrisoni*) after a gap of 10 years using camera traps in the Western Region of Abu Dhabi. United Arab Emirates, European Journal of Wildlife Research 62 (5), 627–631. https://doi.org/10.1007/s10344-016-1035-8.

Allouche, Omri., Kalyuzhny, Michael., Moreno-Rueda, Gregorio., Pizarro, Manuel., Kadmon, Ronen. 2012. Area–heterogeneity tradeoff and the diversity of ecological communities (in proceedings of the national academy of science (2012): PNAS 109:43:17495-17500.

Al Zaabi, R., Gubiani, R., Soorae, P., 2020. Current distribution of Arabian Sand Cat Felis margarita harrisoni in Abu Dhabi, United Arab Emirates, via camera trapping. Tribulus 27, 8–10.

Bibby, C.J., Burgess, N.D., Hill, D.A., Mustoe, S., 2000. Bird census techniques. Academic Press, London, Pp, p. 302.

Brooks, T.M., Bakarr, M.I., Boucher, T., Da Fonseca, G.A.B., Hilton-Taylor, C., Hoekstra, J.M., Moritz, T., Olivieri, S., Parrish, J., Pressey, R.L., Rodrigues, A.S.L., Sechrest, W., Stattersfield, A., Strahm, W., Stuart, S.N., 2004. Coverage provided by the global protected-area system: is it enough? Bioscience 54 (12), 1081. https://doi.org/10.1641/0006-3568(2004)054[1081:CPBTGP]2.0.CO;2.

Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., Hilton-Taylor, C., 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16 (4), 909–923.

Bruner, A.G., Gullison, R.E., Rice, R.E., da Fonseca, G.A.B., 2001. Effectiveness of parks in protecting tropical biodiversity. Science 291 (5501), 125–128.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vié, J.-C., Watson, R., 2010. Global biodiversity: indicators of recent declines. Science 328 (5982), 1164–1168.

Bowler, D.E., Hof, C., Haase, P., Kröncke, I., Schweiger, O., Adrian, R., Baert, L., Bauer, H.-G., Blick, T., Brooker, R.W., Dekoninck, W., Domisch, S., Eckmann, R., Hendrickx, F., Hickler, T., Klotz, S., Kraberg, A., Kühn, I., Matesanz, S., Meschede, A., Neumann, H., O'Hara, R., Russell, D.J., Sell, A.F., Sonnewald, M., Stoll, S., Sundermann, A., Tackenberg, O., Türkay, M., Valladares, F., van Herk, K., van Klink, R., Vermeulen, R., Voigtländer, K., Wagner, R., Welk, E., Wiemers, M., Wiltshire, K.H., Böhning-Gaese, K., 2017. Cross-realm assessment of climate change impacts on species' abundance trends. Nat Ecol Evol 1 (3). https://doi.org/10.1038/s41559-016-0067.

CBD, Convention on Biological Diversity. 2021. 6th National Report 2016, Ministry of Water and Environment United Arab Emirate [internet]. [cited 2021 August 02]. Avaiable from: https://www.cbd.int/.

Coad, L., Burgess, N.D., Fish, L., Ravillious, C., Corrigan, C., Pavese, H., Granziera, A., Besançon, C., 2008. Progress towards the convention on biological diversity terrestrial 2010 and marine 2012 targets for protected area coverage. Parks 17, 35–42.

Connolly S.R., Keith S.A., Colwell R.K., Rahbek, C. 2017. Mechanism, Process, and Causation in Ecological Models: A Reply to McGill and Potochnik. Trends Ecol Evol xx:2–3. doi: 10.1016/j.tree.2017.11.009

Currie, David J., 1991. Energy and large-scale patterns of animal and plant species richness. Am Nat 137 (1), 27–49.

Davidowitz, G., Rosenzweig, M.L., 1998. The latitudinal gradient of species diversity among North American grass hoppers within a single habitat: a test of the spatial heterogeneity hypothesis. Journal of Biogeography 25, 553–560.

Dornelas, Maria, Gotelli, Nicholas J., McGill, Brian, Shimadzu, Hideyasu, Moyes, Faye, Sievers, Caya, Magurran, Anne E., 2014. Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss. Science 344 (6181), 296–299.

Fahrig, Lenore, 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution, and Systematics 34 (1), 487–515. https://doi.org/10.1146/ecolsys.2003.34.issue-1.

Fahrig L., Baudry. J, Brotons L., Burel, F.G., Crist, T.O et al. 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14: 101–112.

Gee, JM, Warwick, RM, 1994. Metazoan community structure in relation to the fractal dimensions of marine macroalgae. Marine Ecology Progress Series 103, 141–150.

Gotelli, N.J., Chao, A., 2013. Measuring and Estimating Species Richness, Species Diversity, and Biotic Similarity from Sampling Data. Elsevier Ltd..

García, Francisca C., Bestion, Elvire, Warfield, Ruth, Yvon-Durocher, Gabriel, 2018. Changes in temperature alter the relationship between biodiversity and ecosystem functioning. PNAS 115 (43), 10989–10994.

Gullan, P.J., and Cranston, P.S. 2010. The Insects: An Outline of Entomology 4th Edition (1444317679) Wiley-Blackwell. ISBN: 978-1-4443-1767-1,pp 584.

Van, Harten.A. (Ed).2008. Arthropod Fauna of the UAE. Volume I. Dar Al Ummah, Abu Dhabi, UAE. 1-754.

Heck, K. L. J., Crowder B. 1991. Habitat structure and predator-prey interactions in vegetated aquatic systems. Pages 281–299 in S. S. Bell, E. D. McCoy, and H. R. Mushinsky, editors. Habitat structure: the physical arrangement of objects in space. Chapman and Hall, London, UK.

Hill, D., Fasham, M., Tucker, G., Shewrg, M., Shaw, P., 2005. Handbook of biodiversity methods. Cambridge University Press, Survey, Evaluation and Monitoring.

Hillebrand, Helmut, Blasius, Bernd, Borer, Elizabeth T., Chase, Jonathan M., Downing, John A., Eriksson, Britas Klemens, Filstrup, Christopher T., Harpole, W. Stanley, Hodapp, Dorothee, Larsen, Stefano, Lewandowska, Aleksandra M., Seabloom, Eric W., Van de Waal, Dedmer B., Ryabov, Alexey B., Cadotte, Marc, 2018. Biodiversity change is uncoupled from species richness trends: Consequences for conservation and monitoring. J Appl Ecol 55 (1), 169–184.

Hof, C. 2010. Species distributions and climate change : current patterns and future scenarios for biodiversity.

Hof, C., Araújo, M.B., Jetz, W., Rahbek, C. 2011. Additive threats from pathogens, climate and land-use change for global amphibian diversity. Nature, 480:516–9

Holness, S., Knight, M. H., Sorensen, M. & Othman, Y.R.A. 2010. Towards a systematic conservation plan for the Arabian Peninsula. – Zoology in the Middle East Supplementum 3 (Biodiversity Conservation in the Arabian Peninsula):197-207.

Hugo, S., van Rensburg, B.J., 2008. The maintenance of a positive spatial correlation between South African bird species richness and human population density. Global Ecology and Biogeography 17, 611–621.

Jeffries, Michael, 1993. Invertebrate colonization of artificial pondweeds of differing fractal dimension. Oikos 67 (1), 142. https://doi.org/10.2307/3545104.

Jetz, W., Wilcove, D.S., Dobson, A.P. 2007. Projected impacts of climate and land-use change on the global diversity of birds. PLoS Biol 5:e157.

Jones, C., McShea, W.J., Conroy, M.J., Kunz, T.H., 1996. Capturing mammals. In 'Measuring and Monitoring Biological Diversity: Standard Methods for Mammals in (Eds D. E. Wilson, F.R.Cole, J.D. Nichols, R. Rudran and M. S. Foster):115–155. Washington, DC, Smithsonian Institution Press.

Kallimanis, Athanasios. S., Mazari, Antonis. D., Tzanopoulos, Joseph, Halley, John. M., Pantis, John. D., Sgardelis, Stefanos. P. 2008. How does habitat diversity affect the species–area relationship? Global Ecology and Biogeography, 17:532-538.

Karanth, K.K., Nichols, J.D., Karanth, K.U., Hines, J.E., Christensen, N.L., 2010. The shrinking ark: patterns of large mammal extinctions in India. Proc. R. Soc. B Biol. Sci 277, 1971–1979.

Karger, D.N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R.W., Zimmermann, N.E., Linder, P., Kessler, M., 2016. CHELSA climatologies at high resolution for the earth's land surface areas (Version 1.0). World Data Center for Climate.http://dx.doi.org/doi:10.1594/WDCC/CHELSA_v1.

Kelaher, B.P., Castilla, J.C., 2005. Habitat characteristics influence macrofaunal communities in coralline turf more than mesoscale upwelling on the coast of northern Chile. Estuarine, Coastal and Shelf Science 63, 155–165.

Khaliq, I., Bohning-Gaese K., Prinzinger, R. et al. 2017The influence of thermal tolerances on geographical ranges of endotherms. Glob Ecol Biogeogr, 26:650–668.

Leverington, F., Costa, K.L., Pavese, H., Lisle, A., Hockings, M.A., 2010. Global analysis of protected area management effectiveness. Environ. Manag 46, 685–698.

McGill, B.J., Potochnik, A. 2017. Mechanisms Are Causes, Not Components: A Response to Connolly et al. Trends Ecol Evol xx:1–2. doi: 10.1016/j.tree.2017.11.010

MacArthur, R. H. 1961. On Bird Species Diversity. Ecology 42: 594-598.

MoCCE, 2021. Ministry of Climate Change and Environment, UAE [internet], [cited 2021 March] Avaiable from: https://www.moccae.gov.ae/en/home.aspx

Methorst, Joel, Böhning-Gaese, Katrin, Khaliq, Imran, Hof, Christian, 2017. A framework integrating physiology, dispersal and land-use to project species ranges under climate change. J Avian Biol 48 (12), 1532–1548.

Nadeau, Christopher P., Urban, Mark C., Bridle, Jon R., 2017. Climates Past, Present, and Yet-to-Come Shape Climate Change Vulnerabilities. Trends Ecol Evol 32 (10), 786–800.

Nelson, A. and Chomitz, K.M. 2011. Effectiveness of Strict vs. Multiple Use Protected Areas in Reducing Tropical Forest Fires: A Global Analysis Using Matching Methods. PLoS ONE, 6(8): e22722. https://doi.org/10.1371/journal.pone.0022722.

NCM, National Centre of Meterology, Ministry of Presidential affiars, UAE [internet], [cited 2021 March] Avaiable from: https://www.ncm.ae

Nolte, C., Agrawal, A., Silvius, K.M., Soares-Filho, B.S. 2013. Governance regime and location influence avoided deforestation success of protected areas in the Brazilian Amazon. Proc. Natl. Acad. Sci. USA, 110:4956–4961.

Parody, J.M., Cuthbert, F.J., Decker, E.H., 2001. The effect of 50 years of landscape change on species richness and community composition. Glob Ecol Biogeogr 10, 305–313.

Pimm, S. L. et al. 2001. Environment – can we defy nature's end? – Science 293: 2207 – 2208.

Richard, J. Perry, 2008. In: Terrestrial Environment of Abu Dhabi Emirate, publishers: Environment Agency –, pp. 184–187.

Ralph, C. John, 1985. Habitat association patterns of forest and steppe birds of Northern Patagonia, Argentina. The Condor 87 (4), 471–483.

Rosenzweig, Michael L. (Ed.), 1995. Species Diversity in Space and Time. Cambridge University Press.

Sanders, N.J., Moss, J., Wagner, D., 2003. Patterns of ant species richness along elevational gradients in an arid ecosystem. Glob Ecol Biogeogr 12, 93–102.

Stolton, S., Dudley, N., Avcıoğlu Çokçalışkan, B., Hunter, D., Ivanić, K.-Z., Kanga, E., Kettunen, M., Kumagai, Y., Maxted, N., Senior, J., Wong, M., Keenleyside, K., Mulrooney, D., Waithaka, J., 2015. Values and benefits of protected areas. In: Worboys, G.L., Lockwood, M., Kothari, A., Feary, S., Pulsford, I. (Eds.), Protected Area Governance and Management. ANU Press, Canberra, Australia, pp. 145–168.

Sullivan, T.P., Sullivan, D.S., 2001. Influence of variable retention harvests on forest ecosystems. II. Diversity and population dynamics of small mammals. Journal of Applied Ecology 38, 1234–1252.

Tews, J.U, Grimm, B.V, Tielbörger, K., Wichmann, M.C, Schwager, M. et al. 2004 . Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. J Biogeogr, 31: 79–92. 2.

Wiens, John J., Donoghue, Michael J., 2004. Historical biogeography, ecology and species richness. Trends Ecol Evol 19 (12), 639–644.