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Research article

Conservation of the Goitered gazelle (*Gazella subgutturosa*) under climate changes in Iraq

Emad Kaky [a,*], Victoria Nolan [b], Mohammed I. Khalil [c], Ameer M. Ameen Mohammed [a], Aram Afrasiaw Ahmed Jaf [c], Saman Mohammed Mohammed-Amin [c], Yadgar Ali Mahmood [d], Francis Gilbert [b]

[a] Kalar Technical College, Sulaimani Polytechnic University, Qirga District, Sulaymaniyah, Iraq
[b] School of Life Sciences, University of Nottingham, Nottingham, UK
[c] Department of Biology, College of Education, University of Garmian, Iraq
[d] Field Crops Department, College of Agricultural and Engineering Science, University of Garmian, Iraq

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ABSTRACT

Climate is a vital factor that shapes habitat suitability for many species across space and time. *Gazella subgutturosa* (Goitered gazelle) is a globally vulnerable mammal already extinct in some areas of Armenia and Georgia and is highly threatened in other areas of its distribution. In this study, new data were gathered for 33 locations in north-eastern Iraq, and then together with literature data, Species Distribution Models (SDMs) were used to explore the geographical distribution of the gazelle under current and future climate change scenarios. We studied the relationship between seven climate variables and 43 occurrence records to predict habitat suitability of the gazelle under the current climate, and also under four future climate scenarios (RCP2.6 and RCP8.5 for both 2050 and 2080). Annual precipitation and isothermality had the most influence on the distribution of *Gazella subgutturosa*. The most suitable habitat in both the current and future scenarios was located in north-eastern Iraq close to the Iranian border near the Zagros Mountains. There was no difference in habitat suitability for the gazelle inside Iraqi Protected Areas (PAs) compared to outside the PAs. Using the occurrence records and IUCN Red List national assessments, we found Iraqi Goitered gazelle populations to be classified as Endangered (EN). Our results suggest urgent conservation planning is needed to save this species, including the establishment of new PAs. These results contribute new baseline information, which was currently missing Goitered gazelle in about Iraq, to the IUCN SSC Antelope Specialist Group, which will hopefully aid with future global assessments and conservation.

1. Introduction

Climate plays an important role in determining the ecological niche of species in space and time. The ecological niche explains much of the geographical distribution of species, and how they persist and compete with co-occurring species [1,2]. Therefore, species are able to survive in a specific environment for the most part because of their responses to climate [3,4]. Persistence in the face of rapid climate change often requires continuous shifts in distribution and range [5], especially for species with narrow ranges and those

* Corresponding author.
E-mail address: emadd.abbas@spu.edu.iq (E. Kaky).

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unable to adapt to unusual climate environments [6,7].

There has been little up–to-date information about Iraqi biodiversity throughout the last few decades because of conflict in the area [8,9]. However, evidence shows that the biodiversity of Iraq is facing a sharp decline compared to data collected even a few decades ago [10]. This decline is likely due to a deficiency in proper and effective PAs, ecosystem degradation, and the lack of action plans or strategies for conservation planning [11]. The total proportion of terrestrial land covered by PAs in Iraq is about 1.5% of the total land area [12], which does not achieve the minimum global requirements of the Aichi Target 11 [13]. To establish a better strategy, Iraq needs more urgent action by decision makers, stakeholders and scientists in regards to expanding the PAs to conserve the most vulnerable species in the area, and to achieve global targets and requirements to mitigate biodiversity loss.

There are several different gazelle species found historically in Iraq, including the Goitered gazelle (*Gazella subgutturosa)*, Arabian oryx (*Oryx leucoryx*), Saudi gazelle (*Gazella saudiya*) and occasionally the Mountain gazelle (*Gazella gazella*) [14–16]. The Saudi gazelle and the Arabian oryx are now extinct in Iraq, while the presence of the Mountain gazelle has apparently not been substantiated [15–17]. However, Goitered gazelles, either Persian Goitered (*Gazella subgutturosa subgutturosa*) or Arabian sand gazelles (*Gazella subgutturosa marica*) or their hybrids, are reported to still be present in Iraq [14].

Gazella subgutturosa is migratory and is therefore impacted by linear barriers such as fences, railways, roads etc., all of which are developing quickly across Asia. Consequently, urbanization and land-use changes may open up more opportunities for hunters via better access to different locations and habitats; it is likely the rate of decline of *Gazella subgutturosa* outside PAs will thus increase further.

The IUCN Red List is a vital tool for assessing species extinction rates [18]. Using the IUCN Red List categories and criteria over the last five decades has helped to assess 116,000 species to date, with a target for 2020 of 160,000 species. Around 27% (31,000) of all assessed species are threatened with extinction (for more details see Ref. [19]. According to the last IUCN Red List assessment *Gazella subgutturosa* is a globally Vulnerable (VU) species, whose current population trend is decreasing [19]. The IUCN SSC Antelope Specialist Group has reported *Gazella subgutturosa* to exist in 11 countries, all of them in the continent of Asia. It has been recorded as extinct in Armenia, and extinct and then reintroduced in Georgia (for more details see Ref. [19]. Data about this species in Iraq was not included in the last assessment, because in Iraq it was assessed as "presence uncertain". According to the Environmental Protection Organization of Garmain (EPOG) and local authorities in the main areas inhabited by the species, the population of *Gazella subgutturosa* has sharply declined by about 50% in the last three decades owing to human activities such illegal hunting, agricultural expansion and urbanization.

To date, there are no studies investigating the ecological niche of *Gazella subgutturosa* in Iraq, and therefore little is known about their geographical distribution or predicted habitat suitability under climate change. Species Distribution Models (SDMs) are one of the most useful approaches to examine relationships between species occurrence and their environment [20,21], in order to predict habitat suitability. SDMs are widely used in ecology, conservation biology, and biogeography, and their applications are rapidly expanding [22,23]. SDMs have been shown to perform well when modelling species from data-sparse countries with limited spatial records [24], and when there are no up-to-date range maps and no local expert knowledge [25,26]. Users of SDMs are confronted with a wide variety of options, and it is not generally evident whether selecting one choice over an alternative has a significant impact on model execution. Among all the possible methods, Maximum Entropy (MaxEnt) has become the standard method of choice in many studies due to its ease of use and robust predictions [20,27]; Phillips et al., 2006). Recently, SDMs have been used for IUCN (International Union for Conservation of Nature) Red List criteria to create species range maps [24,28–31]. In addition, SDMs have been used to assess the effectiveness of Protected Areas (PAs), and to establish new reserve networks to halt biodiversity decline [8,32].

Protected Areas (PAs) are key in reducing biodiversity loss and extinction rates. Currently, human activities and land-use changes are the most powerful factors driving environmental changes and increasing rates of extinctions [33,34]. Previous conservation plans aimed to halt this, such as the Aichi targets to protect 10% of marine and 17% of terrestrial's lands by 2020 (an international agreement adopted by the Convention Biological Diversity [CBD] in 2010). Species extinction rates are a thousand times higher than before the Anthropocene [35], and to reduce these rates and protect biodiversity, wilderness areas and PAs are still the best way to support and conserve high levels of species richness [36–38]. The current lack of PAs and loss of wild regions across the planet will have disastrous consequences for accomplishing worldwide climate mitigation objectives [39,40].

In this study, we modelled the distribution of *Gazella subgutturosa* using MaxEnt [20]. We address the following objectives: 1) map the distribution of *Gazella subgutturosa* based on current and future habitat suitability; 2) identify the most important climate refuges for future conservation; 3) test the effectiveness of Iraqi PAs to conserve this species; 4) apply IUCN Red List criteria at a national scale; and finally 5), add Iraq to the IUCN Red List map data for future global assessments.

2. Methods

2.1. Study area and species data

Iraq is located between 33.2° N and 43.7° E, and has a total area of 437,831 km^2 [12]. The climate is mainly subtropical semi-arid, Mediterranean in the north and north-east [41]. During the last assessment by the Antelope Specialist Group in 2016, records from Iraq were not included because it was not one of the countries noted as containing populations of this species [42]; perhaps there were just no up-to-date information on this species in Iraq.

We carried out new surveys of *Gazella subgutturosa* in north-eastern Iraq, supported by The Rufford Foundation. The survey focused on three main areas (around the towns of Kalar [Sulaymaniyeh Governorate], Kifri, and Khanaqeen [both Diyala Governorate]), chosen because the opinions of local experts suggested that these were the best places for this species. We visited 33 locations in random order around the three towns over five different periods between March 2018 and April 2019, recording the presence/absence of *Gazella subgutturosa* at least once in each location, "using both direct and indirect signs. Every survey day, were led by two groups of 2–5 people using two 4 × 4 vehicles. Ten expeditions were achieved in the spring of 2018 (March and April), 10 in the autumn of 2018 (October), and ten in the spring of 2019 (March and April). Because of the hot weather we avoided carrying out any surveys in the summer season. Therefore, in total 8 weeks of survey done between 2018 and 2019, and every group were done between 5 and 12 km walking in each day of survey looking for the Goitered gazelle". This information is from Kaky et al., 2022 unpublished paper: we used Garmin GPSMAP 78 Handheld GPS Units. We also used 7 records from the literature [14] and 3 records from online open resources such as GBIF (www.gbif.org) to locate records in Iraq. In total, we noted 43 occurrence records for *Gazella subgutturosa* in Iraq (see Fig. 1 A and B).

2.2. Current and future climate data

The environmental predictors used in this study comprised 19 variables downloaded from the WorldClime v2 dataset at a resolution of 2.5 arc-minutes [43]; http://www.worldclim.org). We down-scaled the pixels for the current and future scenarios to a pixel size of 4 km^2 in order to apply the IUCN Red List assessment, as recommended by IUCN guidelines [18]. We retained seven of the 19 environmental variables (see Table 1) after removing 12 to reduce the impact of collinearity, based on the Variance Inflation Factor (VIF) calculated using the *sdm* package in R [44] (see Table 1).

To forecast the impact of future climate change on the distribution of *Gazella subgutturosa* in Iraq, the current prediction was projected into two different future times (2050 and 2080) under two "representative concentration pathway" scenarios (RCP 2.6s and RCP 8.5s). The future climate data came from the Intergovernmental Panel on Climate Change's (IPCC) 5th assessment data [45,46], downloaded from the WorldClim portal at the same resolution for two time slices (2050s and 2080s) under the two scenarios (RCP2.6s and RCP8.5s): the data were generated by the UK Hadley Centre for Climate Prediction and Research (Hadgem2_es). Under the RCP2.6 climate scenario, we expect that the levels of CO_2 emission will not increase much because human population growth will be slower and there will be fewer changes in land use. In contrast, under the RCP8.5 climate scenario, we expect a high level of CO_2 emissions because of high human population growth and more changes in land use by the end of 2100 [47].

2.3. Ecological niche modelling

MaxEnt version 3.4.1 k (Phillips et al., 2006) was used to run the models because MaxEnt can produce reliable models using presence-only data, even with relatively few records [8,20,48–51]. The default settings were used to create the models (i.e. 10,000 background points, 1000 iterations, cross-validation [K = 10] with 10 replications, and logistic output format). Model accuracy was evaluated based on two statistics, the Area Under the Curve (AUC) [52] and the True Skill Statistic (TSS) [53]. AUC values range between 0 and 1, with values close to 1 implying an excellent model, and values close to 0.5 meaning that the model is no better than

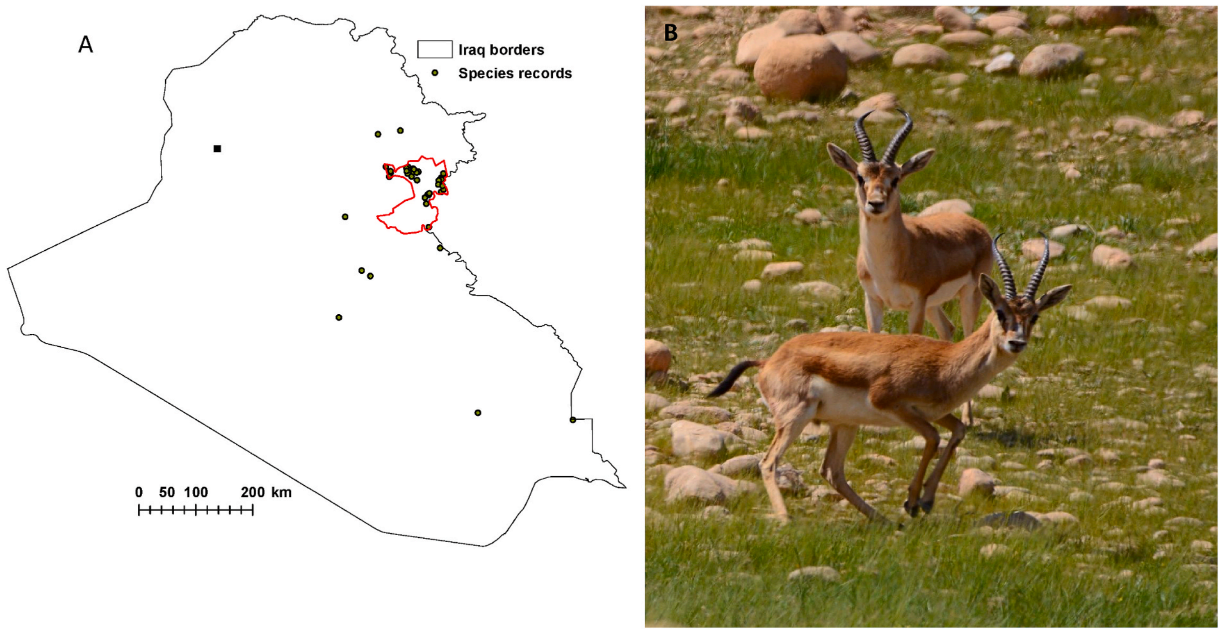

Fig. 1. (A) Occurrence records of the species (43 records) (green dots) and red polygon show the survey areas; (B) *Gazella subgutturosa* from recent field work 2018 © Najeeb Omar. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Environmental variables used to run MaxEnt. The highlighted one were used after reducing collinearity using Variation Inflated Factors (VIF) to build the model.

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

random (Phillips et al., 2006). TSS values range between +1 and −1: values close to +1 mean excellent model performance, whereas values close to −1 show model performance no better than random [53].

We classified each pixel of the MaxEnt habitat suitability maps into four categories: unsuitable (0–0.2), marginally suitable (0.2–0.5), suitable (0.5–0.7), and highly suitable (0.7–1), following [54] and [5]. MaxEnt can also produce binary (suitable and non-suitable) maps from probability maps by choosing a threshold. There are many approaches to selecting an appropriate threshold based on the data and assumptions (see Liu et al., 2005). Here, we chose the "10% training presence", following [48] and [55]; to produce binary maps for each of the 10 replicates. We then created a single binary map by allocating 'suitable' to a pixel that had 'suitable' values in more than 50% of the model runs (i.e. >5 replicates) [36]. Potential habitat gains and losses under the different climate-change scenarios could then be measured from the binary maps by subtracting the future from the current map (following [56, 57].

To measure the effectiveness of Iraq's PAs in protecting and conserving *Gazella subgutturosa*, habitat suitability inside and outside each PA was calculated for the current and future climate scenarios. Iraq has 23 PAs including some proposed ones, which cover about 1.5% of the terrestrial land surface of the country [12]. We excluded PAs that are lakes or dams, and also heritage PAs, because these are unsuitable for *Gazella subgutturosa*, leaving 16 out of the 23 PAs. We then compared the mean habitat suitability inside and outside each PA for current and the future scenarios. The paired inside-outside difference of each PA was calculated, and the differences became the response variable of a Gaussian Generalized Linear Model (GLM) using scenario (RCP2.6s or RCP8.5s) and time (current, 2050s and 2080s) as predictors, as well as the interaction between the two (following [58], implemented in R 3.4.3 (R foundation for Statistical Computing, Vienna, Austria, http://www.r-project.org).

2.4. IUCN Red List assessment

IUCN Red List Categories and Criteria [18] were applied for a regional assessment of the *Gazella subgutturosa* distribution under the effect of climate change. We used a grid-cell size of 2 × 2 km (4 km^2) following IUCN guidelines to calculate the Extent Of Occurrence (EOO) and Area Of Occupancy (AOO) (for more details, see Refs. [18,59], using the current occurrence records and the binary presence/absence predicted maps for the future scenarios (see Ref. [24]. We used the Geospatial Conservation Assessment Tool (GeoCAT) developed by the Royal Botanical Gardens at Kew to measure EOO and AOO (see http://geocat.kew.org/editor).

We estimated the number of "locations", defined as "a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present" [18]. We consider illegal hunting to be the main threat to *Gazella subgutturosa*, based on information from local authorities and the EPOG. In this study, the size of a 'location' was calculated based on the area covered by the threat, and may include one or more sub-populations (for more details how to measure locations, see Ref. [18]: 60–61). The same calculation was applied to measure the number of locations from the current and future binary maps produced by MaxEnt.

The use of EOO and AOO for Red Listing is based mainly on Criterion B (small geographic range) or Criterion D (a very small geographic range). In this study Criterion B was used with two main sub-criteria: 1) 'severely fragmented or number of locations', 2) 'continuing decline', an explanation of the continuing threat of illegal over-hunting which leads to decline [24] (see Table S2.) It was enough if one of the geographic-range metrics (EOO or AOO) met one of the appropriate criteria to classify the species, and then the regional adjustment was applied as appropriate.

IUCN criterion A was used for assessments based on future scenarios, appropriate when species are predicted to lose large parts of their ranges (IUCN, 2016), and particularly under category A3 for predicted population decrease. The generation time of *Gazella subgutturosa* is 4.7 years (~5 years) [19], and thus all estimates of decline were scaled to the standard ten years [18]. The predicted

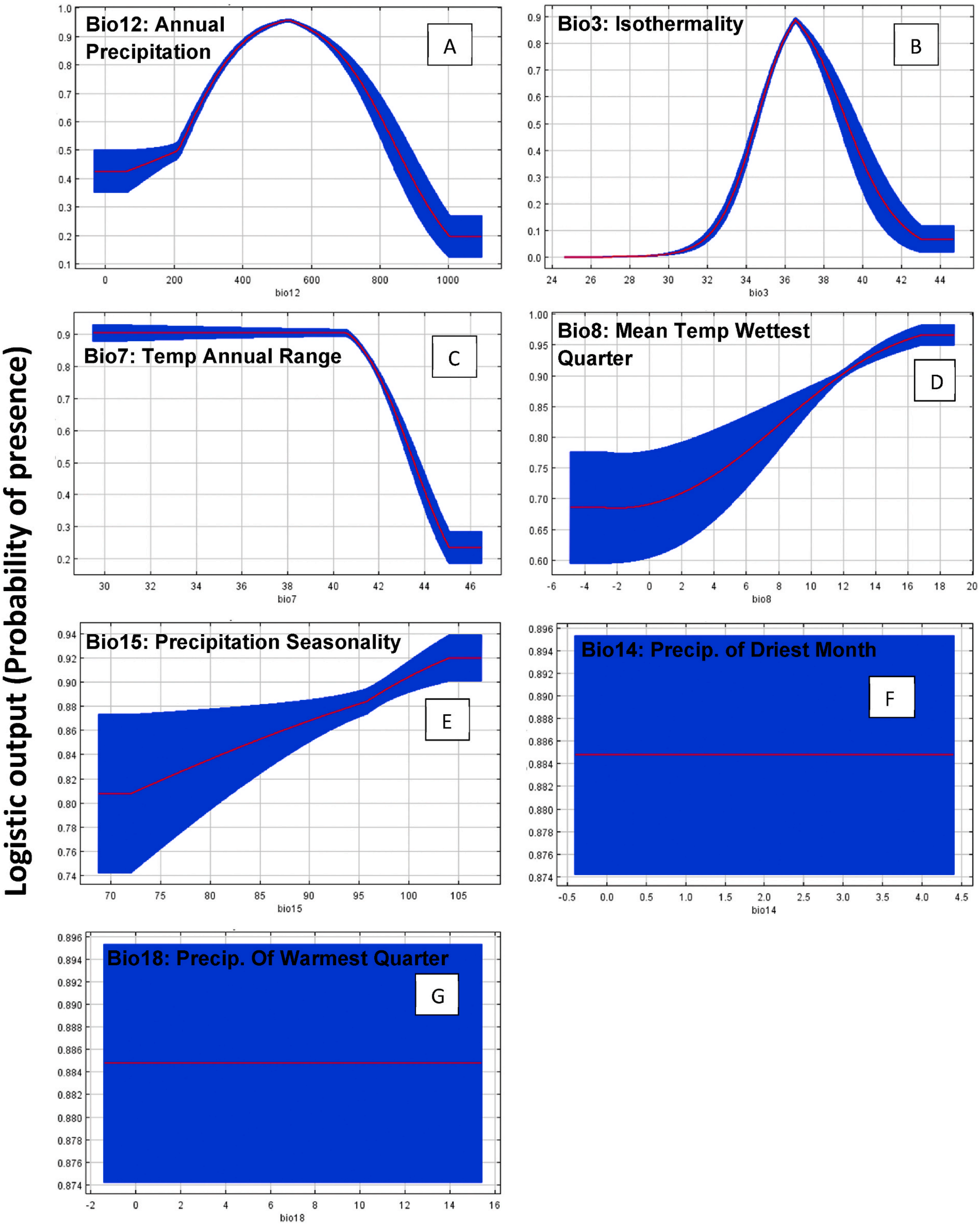

Fig. 2. Response curves of the seven environmental variables (e.g. A Bio 12, B Bio 3, C Bio7, D Bio8, E Bio15, F Bio14, G Bio18) used in MaxEnt to model the distribution of *Gazella subgutturosa*.

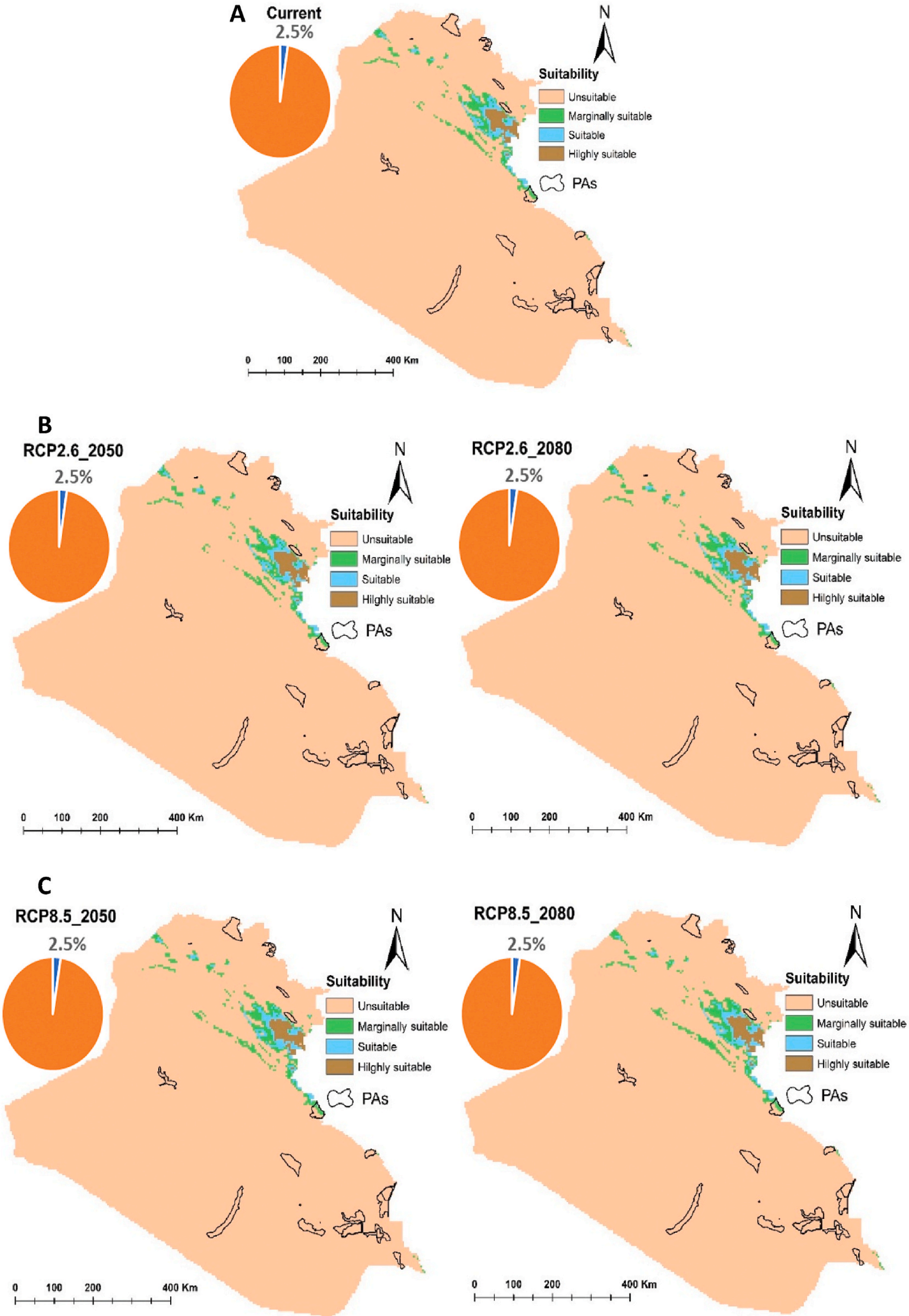

Fig. 3. Predictions of habitat suitability for the current A panel and future scenarios (RCP2.6s B panel and RCP8.5s C panel for 2050s and 2080s) overlapped with Iraqi Protected Areas (PAs) (black polygons), the Pie charts showing the fraction of climate refuges inside the PAs for each time regardless of the suitability categories.

change in habitat suitability was estimated based on the difference in EOO/AOO between the current and each future scenario, expressed as a percentage and scaled to ten years. These percentages were then used to classify the species based on the IUCN Red List Criteria, including the regional assessment (following [24]: LC = loss <30%, VU = loss >30%, EN = loss >50%, CR = loss >80% [18]. Finally, IUCN (2012) recommend comparing the global range of the species with the local range being assessed. For more details about the Iraqi city locations, see Fig S3. All means are quoted with standard errors.

3. Results

3.1. Model performance and important variables

Model performance was good in terms of both mean AUC (0.93 ± 0.07, with the difference between training and test values very small at 0.009) and mean TSS score (0.51 ± 0.08). Out of seven environmental variables, three were found to be important in shaping the predicted habitat suitability of *Gazella subgutturosa*. These include two with high influence, Bio12 (annual precipitation) and Bio3 (isothermality BIO2/BIO7), while Bio7 (temperature annual range) played a minor role (Fig. 2 and Table S1). Based on the percentage contribution and the permutation importance in the final model of MaxEnt, the relative influence of the three variables represented more than 95% of model performance. The response curves show that the species can survive under annual precipitation between 200 and 600 mm, and mean temperatures between 30 and 42 °C (Fig. 2), i.e. semi-arid environments.

3.2. Current and future climate conditions

Based on the current predictions, habitat suitability for *Gazella subgutturosa is highest* between south Sulaymaniyah near to the Zagros Mountains to the south-east of Diyala (Baqubah) towards the Iranian border to the east, and west towards Kirkuk (Fig. 3, Fig S1). There are also some patches of suitability around Mosul in the north and Kut in the south east near the Iranian border (Fig. 3 & S1). There are only slight differences under the future climate scenarios (Fig. 3 & S1), and the proportion of suitable habitat generally (Fig. 4) and just within PAs (2.5%) remains the same for current and future maps. In term of gains or losses of habitat under future climate scenarios, losses exceed gains except under RCP8.5 for 2080 (Table 2, Fig. S2) but the numbers are small.

3.3. Effectiveness of PAs

Most of the suitable habitat predicted by the models is located outside the PAs. This is not surprising because all the occurrence records are located outside the PAs (see Figs. 1 and 3). There is no significant difference in mean habitat suitability inside PAs compared to outside PAs under the current climate (mean [inside-outside] = −0.021, 95% confidence limits −0.069 to 0.023, paired t = −0.91, df = 15, p = 0.38), and none of the future climate scenarios (RCP2.6 and RCP8.5 in 2050 and 2080) is any different ($F_{4,75}$ = 0.0001, n.s.).

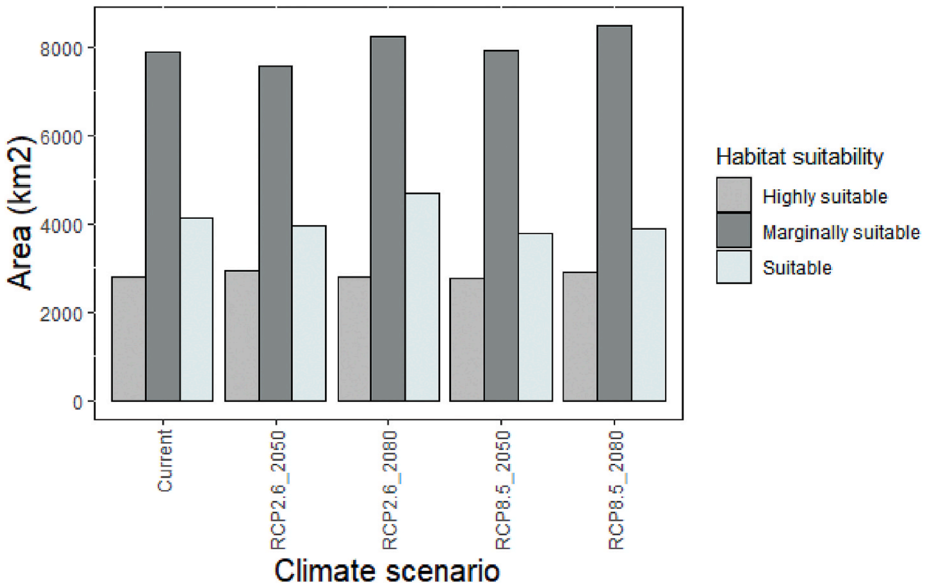

Fig. 4. Comparing the change in habitat suitability (km^2) between current and future scenarios. The areas calculated were based on the pixel cells located under each categories of suitability for each raster separately for current and RCP2.6 and RCP8.5 for 2050s and 2080s.

Table 2
Gain and loss of habitat suitability of *Gazella subgutturosa* under future climate scenarios.

Time	Gain km^2	Loss km^2	Unchanged km^2	Unsuitable km^2
RCP2.6_2050	2196	2718	80802	361818
RCP2.6_2080	2556	3222	80298	361458
RCP8.5_2050	3204	3960	79560	360810
RCP8.5_2080	4662	2106	81414	359352

3.4. IUCN Red List assessments

Based on an AOO of 168 km^2 (Table 3), the assessment indicates that this species is locally Endangered (EN) in Iraq, but based on the EOO it is classified as Least Concern (LC) at 91,070 km^2 in Iraq. As there is no decline in habitat suitability into the future, the MaxEnt models suggest that the species is also of Least Concern (LC) under all assumptions (Table 3). Nevertheless, the IUCN guidelines recommend the worst case scenario be adopted when classifying a species, and therefore we classify the Goitered gazelle as Endangered (EN).

4. Discussion

The Goitered gazelle (*Gazella subgutturosa*) is a globally declining species, with population decreases over the past couple of decades estimated to be between 30 and 50% [42,60,61]. Conservation of the gazelle is important not only to protect this species, but also because the species has a large influence in arid and semi-arid ecosystems on the development and maintenance of other plants and animals (Svizzero, 2019). Understanding the true distribution and range of this species is crucial in order to mitigate its decline and plan effective strategies to promote its survival into the future.

The distribution of *Gazella subgutturosa* in this study was highly influenced by two predictors; annual precipitation and isothermality, with habitat suitability highest between 200 and 600 mm and 30–42 °C respectively. These ranges reflect a semi-arid environment, and although the species mostly prefers plains, populations can survive at higher altitudes and under more continental climates [42]. According to the current and future predictions of habitat suitability under different climate-change scenarios, *Gazella subgutturosa* could inhabit the entire north-east between Sulaymaniyah city and Baqubah city towards the Iranian border. This result matches that of the last field survey and the IUCN Red List range map distribution [42]. The suitable habitat based on climate consists of sites rich in shrubland, grasslands and semi-desert, which provide the ideal ecological characteristics for this species to survive. These results are the first step for including Iraq in the IUCN range map for this species, as well as providing a vital expansion to the IUCN SSC Antelope Specialist group data and range maps. This study also presents an opportunity to inform future field work targeted at highly suitable areas with no occurrence records.

Although there was little difference in habitat suitability between the current and all four future climate change scenarios, some losses and gains in suitability were seen across Iraq. The biggest change was seen under the RCP8.5 scenario in 2080, where there are increases in both 'suitable' and 'marginally suitable' habitat compared to all other scenarios. Under this scenario the highest gains were predicted in terms of absolute area (km^2), and also the lowest losses. This suggests that even under the worst climate-change scenarios, habitat suitability for the gazelle is relatively stable or will become even more suitable than current scenarios. Although many taxa are predicted to be heavily impacted by climate change (Thomas et al., 2004; Ihlow et al., 2011), other studies have found high stability in habitat suitability (Riordan et al., 2018) and increases in species richness [55] under severe climate change predictions. This offers a potential glimmer of hope for the conservation of the gazelle, as climate change is unlikely to cause severe population reductions: *Gazella subgutturosa* is able to survive in extreme heat and drought conditions because it has a number of physiological adaptations that will allow it to cope with climate change [62]; Svizzero, 2019).

Most of the decline of *Gazella subgutturosa* is probably the result of direct human activity (Svizzero, 2019). Illegal hunting and poaching is common in these areas, and gazelles are often killed for meat or as trophies. In addition, *Gazella subgutturosa* shares a very similar niche to other domestic grazers, such as sheep, so are often hunted by herders to reduce competition for scarce food resources (Xu et al., 2012; Svizzero, 2019). Herders are also keen to reduce the potential spread of disease and infection into their flocks. Agricultural farmers are also likely to want to hunt the gazelle to protect their crops from grazing damage (Svizzero, 2019). The establishment of new PAs is therefore a crucial step in protecting *Gazella subgutturosa.* All 43 occurrence records in Iraq were found outside PAs, and the mean habitat suitability for the gazelle was no higher inside compared to outside PAs. PAs have proven successful for the conservation of this species in other countries including Azerbaijan and Turkenistan, both of which have successfully increased their populations of *Gazella subgutturosa* (Svizzero, 2019). Nevertheless, other studies suggest that PAs were not located in areas suitable to conserve high gazelle densities (Durmus, 2010; [63]. Our study also suggests that new PAs should be established across Iraq in other areas with higher numbers of gazelles, and our predicted distribution maps suggest suitable locations for them. In addition, as the future habitat suitability is generally similar to the current suitability, the boundaries of PAs that are established now will need relatively little adjustment over time in order to continue to conserve *Gazella subgutturosa* effectively in the future, regardless of the climate-change pathway.

The IUCN Red List Categories and Criteria are recognized as the foremost system to categorise risks and threats to plant and animal species globally [64,65]. Software such as GeoCAT [66] now offer open source, accessible tools to enable Red List assessments, and have been used effectively to categorise multiple taxa [67,68]. IUCN Red List assessments based on the occurrence records and the

Table 3
IUCN Red List assessments for *Gazella subgutturosa* based on occurrence records and under climate change scenarios. Based on the gap between the scenarios, 10 years, and ~5 years.

Time	EOO km^2	AOO km^2	IUCN Category and Criteria	Assessment status
Current based on records	91,070.159	168	B2a, b(v)	EN
Current based on model	205,113	92,800	A3c	LC
RCP2.6_2050	201,569	92,220	A3c	LC
RCP2.6_2080	191,903	92,060	A3c	LC
RCP8.5_2050	196,393	91,960	A3c	LC
RCP8.5_2080	191,240	95,640	A3c	LC

current climate categorise *Gazella subgutturosa* as Endangered (EN). These results are the first to provide an IUCN estimate for *Gazella subgutturosa* in Iraq, and help to fill in the information lacking from the last assessment. Our results suggest that the gazelle in Iraq is significantly more threatened than the global population, which was only classed as vulnerable (VU). This further highlights the need to add Iraqi *Gazella subgutturosa* population data to the IUCN range maps in order to improve their conservation and status.

The main limitation of this study was the shortage of records, a result of the conflicts of the past 40 years which have prevented systematic surveys for biodiversity in Iraq. There is a lack of data on the gazelle inside Iraqi PAs, which if remedied would help future studies. Lack of funds limited the amount of surveying we could do, and many areas were not safe to be visited by our team. The more factors that can be included in SDMs (e.g. evolution, species interactions, dispersal, land use, and demography), the more accurate their predictions can be, but this requires much more detailed studies of gazelle ecology and behaviour. Some of those factors mentioned above not recommended when IUCN Red List assessment in process for more details see Refs. [29,30,69].

5. Conclusion

This study provides new information about the habitat suitability and distribution of *Gazella subgutturosa* in Iraq, lacking from previous IUCN assessments. Although habitat suitability for the gazelle is predicted to remain relatively constant across time and different climate-change scenarios, losses and gains in suitability were reported in various areas across Iraq. We highlight the importance of establishing and maintaining new PAs in Iraq in areas with high densities of *Gazella subgutturosa,* because occurrences of the gazelle were found mostly outside the current PA network, and habitat suitability for the gazelle was no higher inside PAs compared to outside. Based on these new occurrence locations, an IUCN Red List assessment allowed the first classification of *Gazella subgutturosa* in Iraq, found to be Endangered (EN). As well as providing new information and data for the IUCN SSC Antelope Specialist group, these findings can help with the surveying, conservation and protection of *Gazella subgutturosa* in Iraq.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.heliyon.2022.e12501.

References

[1] J. Silvertown, Plant coexistence and the niche, Trends Ecol. Evol. 19 (2004) 605–611.
[2] J. Soberón, A.T. Peterson, Interpretation of models of fundamental ecological niches and species' distributional areas, Biodivers. Inf. 2 (2005) 1–10.
[3] G.E. Hutchinson, Homage to Santa Rosalia or why are there so many kinds of animals? Am. Nat. 93 (1959) 145–159.
[4] M.B. Araújo, R.G. Pearson, Equilibrium of species' distributions with climate, Ecography 28 (2005) 693–695.
[5] P.B. Singh, K. Mainali, Z. Jiang, A. Thapa, et al., Projected distribution and climate refugia of endangered Kashmir musk deer Moschus cupreus in greater Himalaya, South Asia, Sci. Rep. 10 (2020) 1511.
[6] C. Parmesan, Ecological and evolutionary responses to recent climate change, Annu. Rev. Ecol. Evol. Syst. 37 (2006) 637–669.
[7] A. Cuena-Lombraña, M. Fois, G. Fenu, D. Cogoni, G. Bacchetta, The impact of climatic variations on the reproductive success of *Gentiana lutea* L. in a Mediterranean mountain area, Int. J. Biometeorol. 62 (2018) 1283–1295.
[8] E. Kaky, Potential habitat suitability of Iraqi amphibians under climate change, Biodiversitas 21 (2020) 731–742.

[9] V. Nolan, E.D. Kaky, A.S. Alatawi, F. Gilbert, Mapping the Indian crested porcupine across Iraq: the benefits of species distribution modelling when species data are scarce, Mamm. Biol. (2022), https://doi.org/10.1007/s42991-022-00290-y.
[10] NECBD (5th National Reports to the Convention on Biological Diversity), Ministry of Environment, Republic of Iraq, 2014.
[11] NRBI (4th National Report on Biodiversity in Iraq), Iraqi Fourth National Reports to the Convention on Biological Diversity, Ministry of Environment, Republic of Iraq, 2010.
[12] UNEP-WCMC, Protected Area Profile for Iraq from the World Database of Protected Areas, January 2020, 2020. Available at: www.protectedplanet.net.
[13] CBD, Decision Adopted by the Conference of the Parties to the Convention of Biological Diversity at its Tenth Meeting, Convention on Biological Diversity, 2010 available: http://www.cbd.int/sp/.
[14] K. Al-Robaae, S.C. Kingswood, Iraq, in: D.P. Mallon, S.C. Kingswood (Eds.), Antelopes, Part 4: Northern Africa, the Middle East, and Asia, IUCN Global Survey and Regional Action Plan, Gland (Switzerland), 2001.
[15] K. Al-Robaae, The Antelops [sic] (Gazelles and oryx) in Iraq, Natural History Museum, University of Basrah, 1996. Unpublished report.
[16] D.L. Harrison, P.J.J. Bates, The Mammals of Arabia, second ed., Harrison Zoological Museum, Sevenoaks, England, 1991.
[17] R.T. Hatt, The Mammals of Iraq, vol. 106, Miscellaneous Publications, Museum of Zoology, University of Michigan, 1959, pp. 1–113.
[18] IUCN Standards, Petitions Committee, Guidelines for Using the IUCN Red List Categories and Criteria. Version 14. Prepared by the Standards and Petitions Committee, 2019.
[19] IUCN, The IUCN Red List of Threatened Species, 2020. Version 2020-1. Accessed online by 05/07/2020, https://www.iucnredlist.org.
[20] J. Elith, C.H. Graham, R.P. Anderson, M. Dudı 'k, S. Ferrier, et al., Novel methods improve prediction of species' distributions from occurrence data, Ecography 29 (2006) 129–151.
[21] M. Fois, G. Fenu, G. Bacchetta, Estimating land market values from real estate offers: a replicable method in support of biodiversity conservation strategies, Ambio 48 (2019) 313–323.
[22] J. Elith, J.R. Leathwick, Species distribution models: ecological explanation and prediction across space and time, Annu. Rev. Ecol. Evol. Syst. 40 (2009) 677–697.
[23] A. Guisan, W. Thuiller, Predicting species distribution: offering more than simple habitat models, Ecol. Lett. 8 (2005) 993–1009.
[24] E. Kaky, F. Gilbert, Assessment of the extinction risks of medicinal plants in Egypt under climate change by integrating species distribution models and IUCN Red List criteria, J. Arid Environ. 179 (2019) 1–9, https://doi.org/10.1016/j.jaridenv.2019.05.016.
[25] B.A. Hawkins, et al., What do range maps and surveys tell us about diversity patterns? Folia Geobot. 43 (2008) 345–355.
[26] T.S. Vasconcelos, M.Á. Rodríguez, B.A. Hawkins, Species distribution modelling as a macroecological tool: a case study using New World amphibians, Ecography 35 (2012) 539–548.
[27] J. Elith, S.J. Phillips, T. Hastie, M. Dudík, Y.E. Chee, C.J. Yates, A statistical explanation of MaxEnt for ecologists, Divers. Distrib. 17 (2011) 43–57.
[28] M.M. Syfert, L. Jopp a, M.J. Smith, D.A. Coomes, etal, Using species distribution models to inform IUCN Red List assessments, Biol. Conserv. 177 (2014) 174–184.
[29] D.A. Keith, M. Mahony, H. Hines, J. Elith, etal, Detecting extinction risk from climate change by IUCN Red List criteria, Conserv. Biol. 28 (2014) 810–819.
[30] J.C. Stanton, K.T. Shoemaker, R.G. Pearson, H.R. Akcakaya, Warning times for species extinctions due to climate change, Global Change Biol. 21 (2015) 1066–1077.
[31] M. Fois, A. Cuena-Lombrana, G. Fenu, D. Cogoni, G. Bacchetta, The reliability of conservation status assessments at regional level: past, present and future perspectives on Gentianalutea L. ssp. luteain Sardinia, J. Nat. Conserv. 33 (2016) 1–9.
[32] T. Newbold, F. Gilbert, S. Zalat, A. El-Gabbas, T. Reader, Climate-based models of spatial patterns of species richness in Egypt's butterfly and mammal fauna, J. Biogeogr. 36 (2009) 2085–2095.
[33] T. Newbold, L.N. Hudson, S.L.L. Hill, S. Contu, et al., Global effects of land use on local terrestrial biodiversity, Nature 520 (2015) 45.
[34] O. Venter, E.W. Sanderson, A. Magrach, J.R. Allan, et al., Global terrestrial human footprint maps for 1993 and 2009, Sci. Data 3 (2016), 160067.
[35] S.L. Pimm, C.N. Jenkins, R. Abell, T.M. Brooks, et al., The biodiversity of species and their rates of extinction, distribution, and protection, Science 344 (2014).
[36] E. Kaky, F. Gilbert, Using species distribution models to assess the importance of Egypt's protected areas for the conservation of medicinal plants, Jornal of Arid Environments 135 (2016) 140–146.
[37] S. D'agata, D. Mouillot, L. Wantiez, A.M. Friedlander, et al., Marine reserves lag behind wilderness in the conservation of key functional roles, Nat. Commun. 7 (2016), 12000.
[38] J.E.M. Watson, D.F. Shanahan, M. Di Marco, J.R. Allan, et al., Catastrophic declines in wilderness areas undermine global environmental targets, Curr. Biol. 26 (2016) 2929–2934.
[39] R.A. Houghton, B. Byers, A.K. Nassikas, A role for tropical forests in stabilizing atmospheric CO2, Nat. Clim. Change 5 (2015) 1022–1023.
[40] R.A. Houghton, B. Byers, A.K. Nassikas, A role for tropicalforests in stabilizing atmospheric CO2, Nat. Clim. Change 5 (2015) 1022–1023.
[41] FAO, Towards Sustainable Agricultural Development in Iraq: the Transition from Relief, Rehabilitation and Reconstruction to Development, 2003, p. 222.
[42] IUCN SSC Antelope Specialist Group, Gazella subgutturosa. The IUCN Red List of Threatened Species 2017: e.T8976A50187422, 2017, https://doi.org/10.2305/IUCN.UK.2017-2.RLTS.T8976A50187422.en.
[43] R.J. Hijmans, S.E. Cameron, J.L. Parra, P.G. Jones, A. Jarvis, Very high-resolution interpolated climate surfaces for global land areas, Int. J. Climatol. 25 (2005) 1965–1978.
[44] B. Naimi, M.B. Araújo, sdm: a reproducible and extensible R platform for species distribution modelling, Ecography 39 (2016) 368–375.
[45] K. Riahi, D.P. van Vuuren, E. Kriegler, J. Edmonds, B.C. O'Neill, et al., The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview, Global Environ. Change 42 (2017) 153–168.
[46] D.P. van Vuuren, J.A. Edmonds, M. Kainuma, K. Riahi, J. Weyant, A special issue on the RCPs, Climatic Change 109 (2011) 1–4.
[47] G. Wayne, The beginners's guide to representative concentration pathways, Skeptical Science (2013).
[48] R.G. Pearson, C.J. Raxworthy, M. Nakamura, A. Townsend Peterson, Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar, J. Biogeogr. 34 (2007) 102–117.
[49] J. Franklin, Mapping Species Distributions: Spatial Inference and Prediction, Cambridge University Press, Cambridge, UK, 2009.
[50] M. Abdelaala, M. Foisa, G. Fenua, G. Bacchettaa, Using MaxEnt modeling to predict the potential distribution of the endemic plant Rosa arabica Crép. in Egypt, Ecololgical Informmatics 50 (2019) 68–75.
[51] E. Kaky, V. Nolan, A. Alatawi, F. Gilbert, A comparison between ensemble and MaxEnt species distribution modelling approaches for conservation: a case study with Egyptian medicinal plants, Ecol. Inf. 60 (2020), 101150.
[52] J. Pearce, S. Ferrier, Evaluating the predictive performance of habitat models developed using logistic regression, Ecol. Model. 133 (2000) 225–245.
[53] O. Allouche, A. Tsoar, R. Kadmon, Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS), J. Appl. Ecol. 43 (2006) 1223–1232.
[54] Y. Guo, et al., Prediction of the potential geographic distribution of the ectomycorrhizal mushroom Tricholoma matsutake under multiple climate change scenarios, Sci. Rep. 7 (2017), 46221.
[55] E. Kaky, F. Gilbert, Predicting the distributions of Egypt's medicinal plants and their potential shifts under future climate change, PLoS One 12 (2017), e0187714.
[56] O. Broennimann, W. Thuiller, G. Hughes, G.F. Midgley, J.M.R. Alkemade, A. Guisan, Do geographic distribution, niche property and life form explain plants' vulnerability to global change? Global Change Biol. 12 (2006) 1079–1093.
[57] W. Thuiller, S. Lavorel, M.B. Araujo, M.T. Sykes, I.C. Prentice, Climate change threats to plant diversity in Europe, Proc. Natl. Acad. Sci. U. S. A. 102 (2005) 8245–8250.
[58] E. Kaky, F. Gilbert, Allowing for human socioeconomic impacts in the conservation of plants under climate change, Plant Biosyst. (2019), https://doi.org/10.1080/11263504.2019.1610109.

[59] IUCN, IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission, IUCN, Gland, Switzerland and Cambridge, U.K, 2001.
[60] D.P. Mallon, S.C. Kingswood, Antelopes. Global Survey and Regional Action Plans. Part 4: North Africa, the Middle East and Asia, IUCN, 2001.
[61] B. Buuveibaatar, et al., Mongolian Gobi supports the world's largest populations of khulan Equus hemionus and goitered gazelles Gazella subgutturosa, Oryx 51 (2016) 639–647. IUCN 2017.
[62] R.S. Hetem, W.M. Strauss, L.G. Fick, S.K. Maloney, L.C.R. Meyer, M. Shobrak, A. Fuller, D. Mitchell, Does size matter? Comparison of body temperature and activity of free-living Arabian oryx (Oryx leucoryx) and the smaller Arabian sand gazelle (Gazella subgutturosa marica) in the Saudi desert, J. Comp. Physiol. B 182 (2012) 437–449, https://doi.org/10.1007/s00360-011-0620-0.
[63] E. Bagherirad, N. Ahmad, M. Amirkhani, M. Abdullah, M. Mesdaghi, A. Kabudi, Seasonal habitat use of Persian gazelles (Gazella subgutturosa subgutturosa) based on vegetation parameters at golestan national park, Iran, Arid Land Res. Manag. 28 (2014), https://doi.org/10.1080/15324982.2013.868379.
[64] A.S.L. Rodrigues, J.D. Pilgrim, J.F. Lamoreux, M. Hoffmann, T.M. Brooks, The value of the IUCN Red List for conservation, Trends Ecol. Evol. 21 (2006) 71–76, https://doi.org/10.1016/j.tree.2005.10.010.
[65] J.-C. Vie, C. Hilton-Taylor, S.N. Stuart, Wildlife in a Changing World—An Analysis of the 2008 IUCN Red List of Threatened Species, IUCN, Gland, 2009.
[66] S. Bachman, J. Moat, A.W. Hill, J. de la Torre, B. Scott, Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool, ZooKeys (2011) 117–126, https://doi.org/10.3897/zookeys.150.2109.
[67] M.L. Niemiller, G.O. Graening, D.B. Fenolio, J.C. Godwin, J.R. Cooley, W.D. Pearson, B.M. Fitzpatrick, T.J. Near, Doomed before they are described? The need for conservation assessments of cryptic species complexes using an amblyopsid cavefish (Amblyopsidae: typhlichthys) as a case study, Biodivers. Conserv. 22 (2013) 1799–1820, https://doi.org/10.1007/s10531-013-0514-4.
[68] M.M. Romeiras, S. Catarino, I. Gomes, C. Fernandes, J.C. Costa, J. Caujapé-Castells, M.C. Duarte, IUCN Red List assessment of the Cape Verde endemic flora: towards a global strategy for plant conservation in Macaronesia, Bot. J. Linn. Soc. 180 (2016) 413–425, https://doi.org/10.1111/boj.12370.
[69] R.G. Pearson, J.C. Stanton, K.T. Shoemaker, M. Aiello-Lammens, et al., Life history and spatial traits predict extinction risk due to climate change, Nat. Clim. Change 4 (2014) 2017–2221.