Environmental vulnerability to flooding and habitat suitability mapping of *Gazella marica*

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Abstract

Floods are one of the catastrophic natural disasters that have threatened human society and biodiversity throughout history. This is particularly so in coastal habitats such as the Mond Protected Area of Iran and is one of the principal factors endangering Arabian sand gazelle in this area. The Arabian sand gazelle is considered an independent species in Iran and The Mond Protected Area is its only habitat in Iran. This study aimed to determine the suitability of the habitat and identify the flood-prone areas of Mand protected area. Using the maximum entropy method and MaxEnt software, a habitat suitability map was prepared. To study the impacts of Mond River flooding on gazelle habitats within the Mond Protected Area and provide 25 to 500-year return period flood inundation maps, a two-dimensional HEC-RAS model was developed. After mixing

the flood inundation maps with the suitability map, it was determined that significant parts of the center and west sections of the study area are prone to devastating floods. Generally, in this study, we have determined by using flood zoning techniques in areas that are likely to be affected by floods, which is very effective in managing floodplain areas and controlling floods to reduce flood damage to the only sand gazelle's habitat in Iran.

Keywords: Mond Protected Area, *Gazella marica*, MaxEnt, Flood Inundation Mapping, HEC-RAS

Introduction

Habitat loss and fragmentation can lead to patch isolation, impede individual movements, diminish the suitability of the remaining habitats, and increase genetic drift and inbreeding in isolated populations (Alho et al., 2012; Nayeri et al., 2022; Mohammadi et al., 2023; Rezaei et al., 2023), which can result in local extinction of species (Ara et al., 2022). In a fragmented landscape, the long-term persistence of species is dependent on gene flow and demographic exchange between subpopulations (Ascensão *et al*., 2018; Arash *et al*., 2020). Therefore, maintaining landscape permeability has increasingly become a focus of conservation efforts, particularly for large mammals (Baldwin, 2009, Babu, 2023).

The range of the Arabian sand gazelle (*Gazella marica*) previously spanned from south-eastern Turkey southwards across the Arabian Peninsula to UAE, Oman, and Yemen, but is now limited to the few small remaining populations across the Middle East (Schulz et al., 2013; Mallon & Kingswood, 2019. In Iran, the species occurs only in the Mond Protected Area. Mond's protected area is located in the Bardkhon section of Deir city in Bushehr Province of Iran, 130 km south of Bushehr port. Sand gazelles typically inhabit deserts, including dunes, sandy areas, and coastal plains, but avoid sloping and rocky areas IUCN, 2017. the dunes and desert areas of southwest and west of Iran at the border of Iran and Iraq are probably the historical habitat of sand gazelles (Hemami *et al*., 2020).

The species is classified as "vulnerable" by the IUCN Red List of Threatened Species (IUCN, 2017). The main threats to this species are uncontrolled hunting and trapping, ecosystem conversion, ecosystem degradation, livestock farming and ranching and small-holder grazing(Farhadinia *et al*., 2009; Hosseini-Zavarei *et al*., 2013; IUCN, 2017).

Maximum entropy (MaxEnt) is a widely used and effective method for predicting species distributions concerning multiple environmental variables(Phillips & Dudík, 2008). This algorithm considers the interactions between continuous or categorical predictor variables and produces predicted habitat suitability maps to evaluate the distribution of species(Phillips *et al*., 2006). Thus, modelling by the maximum entropy algorithm is widely considered to be a robust and reliable method to assess and predict the distribution of species using data from various environmental sources(Phillips & Dudík, 2008).

Floods (below bank full levels) can distribute nutrients and sediments critical for plant development, replenish groundwater aquifers and wetlands and assist optimal growth of many species (Kozlowski, 2002). However, larger floods usually cause serious damage to the environment, especially to biodiversity(Gandhi et al., 2007; Lugeri et al., 2010; Maron *et al*., 2015; Zhang et al., 2021). Major floods (above bank full discharge levels) can uproot trees and submerged plants. Mammals respond to flooding regimes as seasonal shrinking and expansion habitats, with the highest species abundance occurring in the dry season when there is a significant increase in terrestrial habitats(Mamede & Alho, 2006). Therefore, major floods are likely to negatively impact mammals subject to such events. Wildlife abundance varies across dry and wet seasons, with seasonally flooded grassland most used by mammals in the dry season(Alho & Silva, 2012).

In 1987, as a result of the flooding of the Mond River, which caused a lot of human and financial damage in Dashti and Deir county, after the water subsided, the carcasses of 200 gazelle were buried by the region's environmentalists on the shores of the Persian Gulf and the islands of the region, especially Khan Island. It was counted, also during the flood of December and January of 2004, about 200 of them were lost and its population decreased drastically(Bayani, 2016). Also, in late 2015 and early 2016, this area was flooded twice in less than a month. Considering that the protected area is the only habitat of the sand gazelle in Iran, sudden decreases in the population of this species may lead to the occurrence of the bottleneck phenomenon in the population of this species. The protected area of Mond is surrounded on all four sides: from the north of the habitat by the Mond River, from the west by the Persian Gulf, from the south by the gas facilities and the Khor-khan road, and the east by the coastal highway of Dayyer-Busher and the city of Bordekhon. The significant adverse impacts of flooding in threatening wildlife, especially the Arabian sand gazelle, are threefold. These include flash floods that can directly injure and kill gazelles,

destruction of enclosures surrounding the protected area, which results in predation by wolves(Shalmon *et al*., 2020) or animals escape to high altitude areas and the possible exposure to disease by drinking polluted floodwater(Waris, 2020). It has been found that large floods were considerably reducing the gazelle population on Farur Island, Iran due to these factors(Fadakar *et al*., 2021). A practical solution to minimize future flood damage is identifying flood-prone areas(Klemas, 2015; Arash *et al*., 2020). Flood inundation maps provide experts with valuable information on flood-prone areas, which may minimize damage and losses caused by floods. For flood modelling and flood inundation maps, the two-dimensional mathematical software HEC-RAS was used, having proven its capabilities in flood modelling in previous studies(Mihu-Pintilie *et al*., 2019; Quirogaa *et al*., 2016).

Mond Protected Area is highly susceptible to severe floods because it is located south of the Mond River which leads into the Persian Gulf. This region has experienced three major floods in the years 1986, 2003 and 2016 according to the Iran Water Resources Management Company(IWRMC, 2021). According to available reports, the 2016 major flood killed more than half of the gazelle population in the area (Environmental Protection Organization, 2019). Yet, no plans have been made to manage the floods in this area. This study presents the first predictive mapping of habitat suitability of the Arabian sand gazelle habitat. Additionall, we model the flood potential of the area to determine the extent to which areas that are suitable for the species areas are affected by floods. The objectives of this study are as follows: 1- Assessing the suitability of gazelle habitat 2- Determining the flood potential of the region and 3- Determining the suitable habitat areas that are affected by floods.

Material and methods

Study Area

The Mond Protected Area with its aquatic and terrestrial ecosystems is located downstream of the Mond River, which is the major cause of the flooding in the area. It has been described as a developing area economically, with an endangered and fragile ecosystem (Bryant, 1981). The area is located in the Sahara-Sindian phytochorion with predominant vegetation comprising mainly Poaceae, Asteraceae, and Chenopodiaceae. The average annual precipitation is 155 mm, while the annual average temperature is 24 °C. The site extended between 27° 15′ to 28° 45′ northern latitude and 51° 15′ to 51° 35′ eastern longitude (Fig. 1). The region's soil is of saline and alkaline whose salinity is primarily due to bedrock, sea sediments and Mond river water. This area is included in

the De Martonne classification system is having a dry climate(Mehrabian *et al*., 2009). The Mond River flows north of the protected area and discharges into the Persian Gulf (Fig. 1). The river has several branches, the main one being the Qara Aghaj River, and is sourced from Fars Province. This river is permanent and is the fifth largest river in Iran.
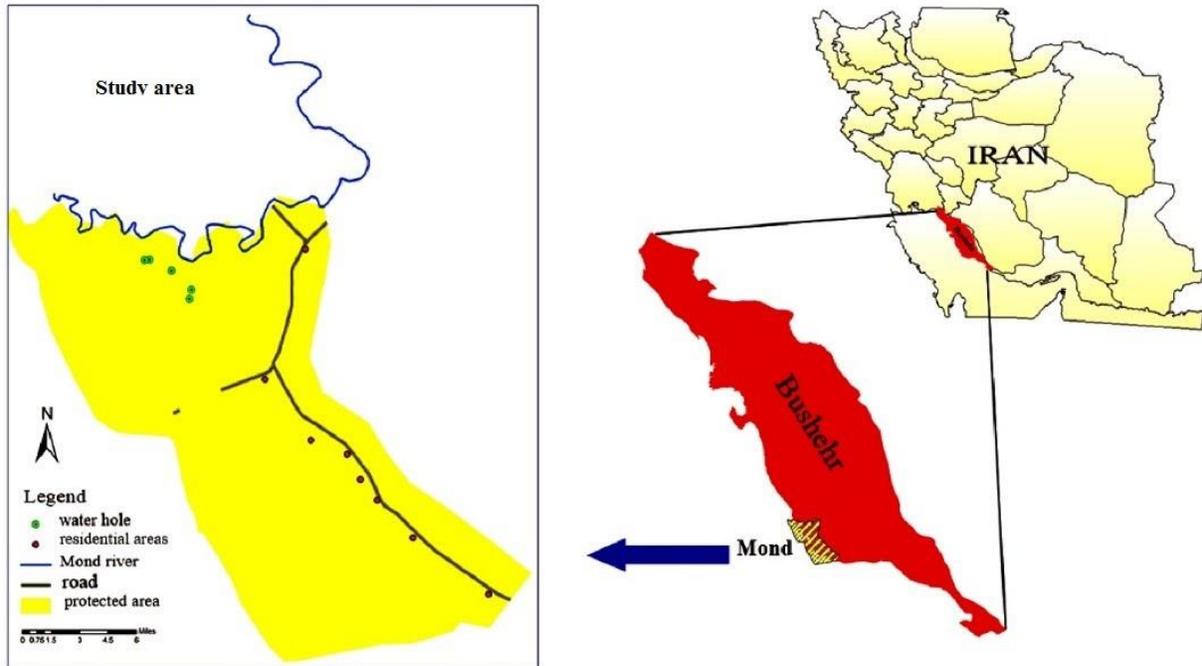
Figure 1. Location and Bing image of the protected area.

Collection of Presence Data

The presence points in the region during three periods of August 2016 to April 2017 was recorded by direct observation, footprints, and fecal samples. Coordinates were collected using a Garmin 62s GPS device. Considering that the transect method has been used for sampling mammals in various studies to collect presence data(Enari & Sakamaki, 2012; Nowzari *et al*., 2007), we use transect for sampling.

The method of spatial dilution of presence points in the SDM toolbox(Brown, 2014) in ArcGIS was employed to reduce the autocorrelation of the presence points. 96 presence points of the species were recorded, which were used to evaluate the suitability of the habitat.

Selection of Environmental Variables for the Habitat Suitability Model

The habitat suitability model was predicted by the MaxEnt algorithm using variables related to species behavior and ecology when selecting habitats and points of presence for the Arabian sand

gazelle. Variables that affect the distribution were selected with field observations and literature review, including vegetation (Iranian Organization of Forests and Rangelands) (Table 1), land use (Table 2), distance from the sea, distance from rivers and distance from water holes (Produced by authors), distance from urban, rural areas, and climatic variables (annual mean temperature (BIO1), annual precipitation (BIO12) and precipitation seasonality coefficient *100 (BIO15)) (Hijmans *et al*., 2005; Hu & Jiang, 2010; Hosseini-Zavarei et al., 2013; Mondal *et al*, 2013; Khosravi *et al*., 2016; Shams-Esfandabad *et al*., 2019). However, we excluded topography because of low landscape heterogeneity and topographic features. The land use and vegetation map are shown in Figure 2.
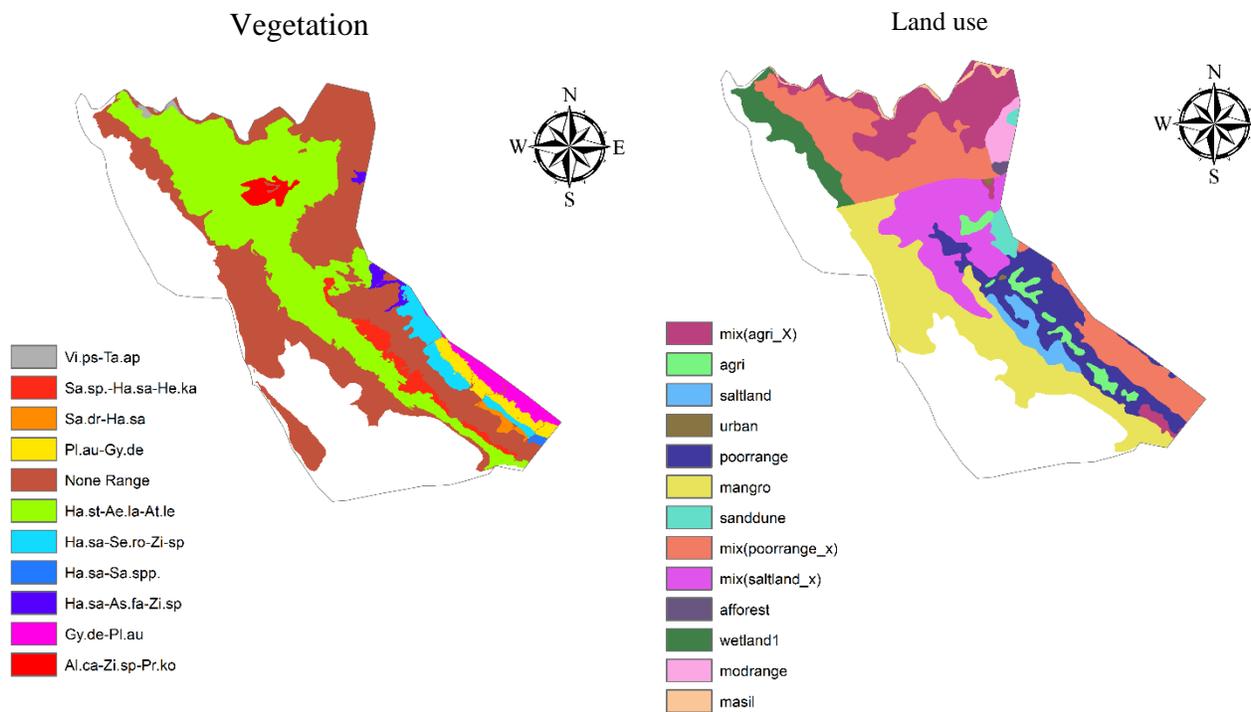
Figure 2. Land use and vegetation map

Table 1. Vegetation-type floor table.

Number	Scientific Name	Code
1	*Platychaete Aucheri-Gymnocarpus Decander*	Pl.au-Gy.de
2	*Gymnocarpus Decander-Platychaete Aucheri*	Gy.de-Pl.au
3	*None Range*	None Range
4	*Hammada Salicornica-Astragalus Fasciculifolius-Ziziphus Spina-Christi*	Ha.sa-As.fa-Zi.sp

5	*Halocnemum Strobilaceum-Aeluropus Lagopoides-Atriplex Leucoclada*	Ha.st-Ae.la-At.le
6	*Salsola Sp.-Hammada Salicornica-Heliantemum Kahiricum*	Sa.sp.-Ha.sa-He.ka
7	*Hammada Salicornica-Salsola Spp.*	Ha.sa-Sa.spp.
8	*Hammada Salicornica-Sedletzia Rosmarinus-Ziziphus Spina-Christi*	Ha.sa-Se.ro-Zi-sp
9	*Salsola Drummondii-Hammada Salicornica*	Sa.dr-Ha.sa
10	*Vitex Pseudo-Negundo-Tamarix Aphylla*	Vi.ps-Ta.ap
11	*Alhagi Camelorum-Ziziphus Spina-Christi-Prosopis Koelziana*	Al.ca-Zi.sp-Pr.ko

Table 2. land use table

Number	Land use
0	Mix(agri)
1	Agri
2	Saltland
3	Urban
4	Poor rang
5	Mangro
6	Sanddune
7	Mix (poor)
8	Mix (saltland)
9	afforest
10	Wheatland
11	Mod range
12	Torrent

Maximum Entropy Implementation

To remove the highly correlated variables from the analysis, we produced a Pearson Correlation Matrix (Booth, Niccolucci, & Schuster, 1994) in ArcMap (version 10.8.1) and the case of a correlation of over 0.7, one variable was removed(Sachser et al., 2017). The correlation test showed a correlation of 0.84 between two layers of seasonal temperature (BIO4) and annual precipitation (BIO12), therefore the seasonal temperature was removed because of the more

critical yearly rainfall due to the more significant impact on the desired species. There was also a calculated positive correlation of 0.98 between the distance from the villages and the roads, resulting in the layers of the towns being set aside. The roads are the priority due to passing vehicles and sound production, road mortality, fragmentation, and access by hunters and poachers. There is a 0.86 correlation between the distance from agricultural land and seasonal precipitation, and the layer of distance from agricultural land was removed. After this analysis, 11 variables were retained (r < 0.7)(Hameed et al., 2020; Kabir et al., 2017), including tree bioclimatic variables (WorldClim version 2.1 climate data) (BIO1, BIO12, BIO15), Distance to the sea, distance to the water-hole, distance to road, vegetation, landuse.

We used a spatial downscaling method to transfer the original 1-km resolution of WorldClim data (BIO1, BIO12, BIO15) to the target resolution of 30 m (Flint and Flint, 2012). All maps were projected to Lambert conformal conic (WGS84 Datum) with a grid cell size of 30*30 meters. Maps needed to be in ASCII format to import data into MaxEnt 3.3.3K software. To do this, a conversion tool was used in ArcGIS 10.3 software. Excel 2013 software was used to prepare the presentation of species data for import into the MaxEnt software.

MaxEnt Model Simulation and Evaluation

We used the MaxEnt software platform to create species distribution models of gazelles (Ara, Ashrafi, Zarrintab, & Esfandeh, 2022; Byeon, Jung, & Lee, 2018). While creating the MaxEnt model, 25% of the sample data was used as testing data, and 75% as training (Matyukhina et al., 2014; Pearson, Raxworthy, Nakamura, & Townsend Peterson, 2007). The following settings were used for the model: regularization multiplier =1, maximum iterations = 1000, convergence threshold = 0.0001 and maximum number of background points =10000(Phillips et al., 2006) and tenfold cross-validation (10 replicates). The success and performance of the MaxEnt model were assessed by the area under receiver operating characteristic (ROC) curve (AUC). Model performance is often judged based on AUC values with models considered to be: rejected with an AUC value of 0.5–0.6; poor with 0.6–0.7; average with 0.7–0.8; good with 0.8–0.9; and excellent with 0.9–1.0 (Baldwin, 2009; Monterroso, Brito, Ferreras, & Alves, 2009). In addition, to facilitate the interpretation of the habitat models produced we created response curves for each environmental variable included in the model (Hassanvand et al., 2018). A jackknife test in MaxEnt was used to determine each variable's importance and contribution(Khattak et al., 2022;

Phillips et al., 2006). The MaxEnt model assigns each cell values from zero to one, which indicates the suitability of that cell as a habitat for the species of interest.

Flooding Potential of the Protected Area

A HEC-RAS (Hydrological Engineering Centre – River Analysis System) mathematical model was used for 2-D modelling of the meandering reach of Mond River extreme floods. The United States Army Corps of Engineers (USACE) developed HEC-RAS, one of the most accurate and user-friendly mathematical models for flood modelling(Brunner, 2016). The model's primary input data includes river geometry, land use and upstream and downstream boundary conditions. An ALOS DEM dataset with a coarse vertical resolution (30 m) was downloaded from the Jaxa website and was used as the river geometry input file. The constructed mesh for flood modelling contains 3000 cells with uneven areas ranging from 0.2 to 0.25 Km^2.

The surface water data at the Qantareh hydrometric station has been measured annually since 1969 by the Iran Water Resources Management Company. The minimum, average, and maximum flow discharges of the Mond River are 307 m^3/s (in 2007), 37 m^3/s, and 4855 m^3/s (in 1971), respectively. Areas on the river floodplains are prone to devastating floods, occasionally causing major damage and casualties. In 2016, for instance, the river experienced a flood of 4,800 m^3/s (recorded at the Qantareh hydrometric station upstream of the basin). Therefore, the peak discharge of the observed hydrograph is with a return period of 25 to 200 years at the Qantareh hydrometric station (Table 3).

Table 3. Maximum observational flood discharges with a return period of 25 to 200 years at the Qantareh hydrometric station. Raw data based on IWRMC (2021).

T (years)	25	50	100	200
Q_{max} (m^3/s)	5017	5483	5843	6122

Results

Analysis of maximum entropy for Arabian sand gazelle

The area under the curve (AUC) is between 0 and 1 (the number 1 shows the complete separation of the points of presence from the quasi-presence issues). Models for *G.marica* performed much

better than random, with a mean AUC 0.867 over 10 replicate tests run (Fig. 3) which indicates the high accuracy of the model.
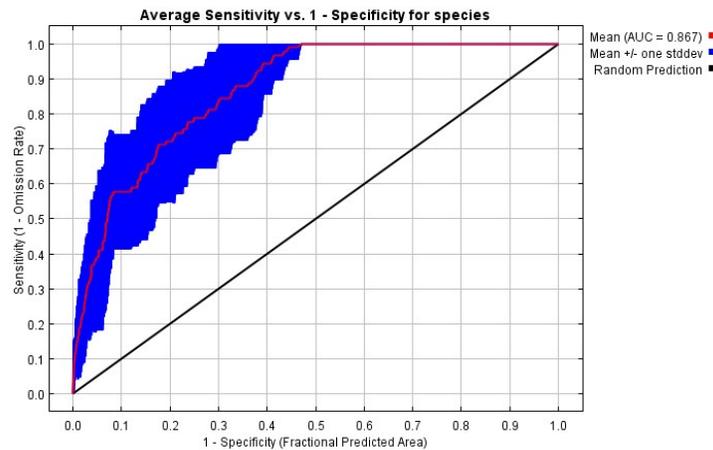
Figure 3. The ability to predict the presence or absence of a model for Arabian sand gazelle in the study area

Phillips et al. (2006) method of Jackknife analysis shows the importance of variables in predicting species presence(Matawa, Murwira, & Schmidt, 2012). The results of a jackknife test of gazelle habitat in the Mond Protected Area indicated that the distance from the ocean has the most significant impact on the distribution of the gazelle. The results obtained from the Jack Knife diagram showed that the variables of distance from the water source, distance from the road, distance from the sea and vegetation have the greatest effect on the distribution of the species (Figure. 4). Also, BIO1 and BIO15 have the least impact on species distribution. Figure 5 shows the response curve of different variables used in the MaxEnt model. According to the percent contribution table of each variable in Table 3, each of the influential variables in the model has a specific percentage that has the highest percentage of participation among the variables distance from the water-hole, and distance from the sea. Table 3 shows the contribution of the variables used to model development.
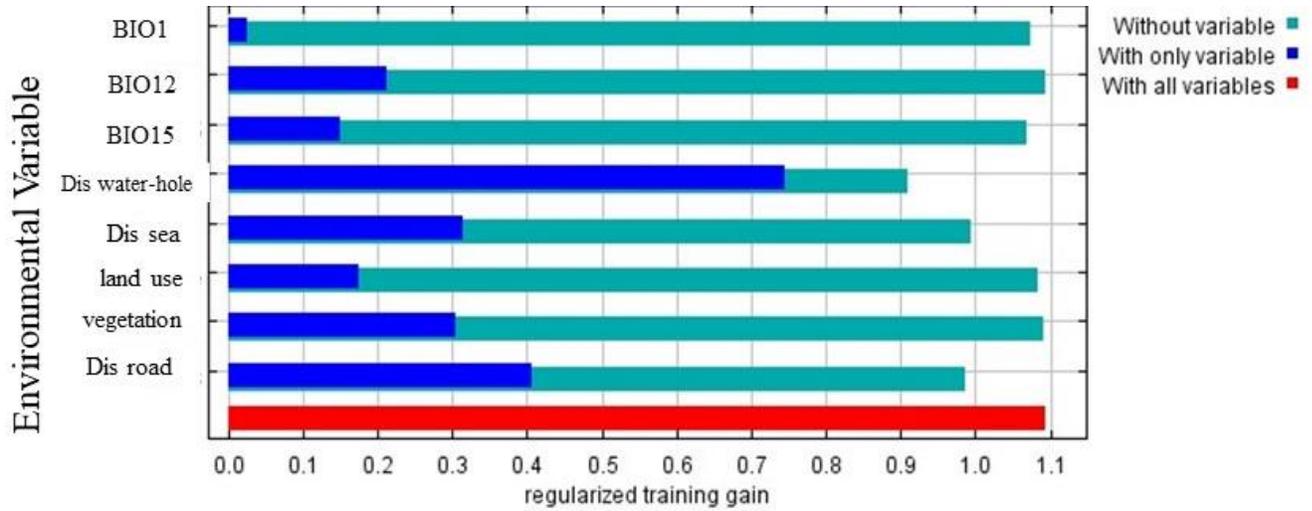
Figure 4. Importance of variables based on Jack-knife training results.
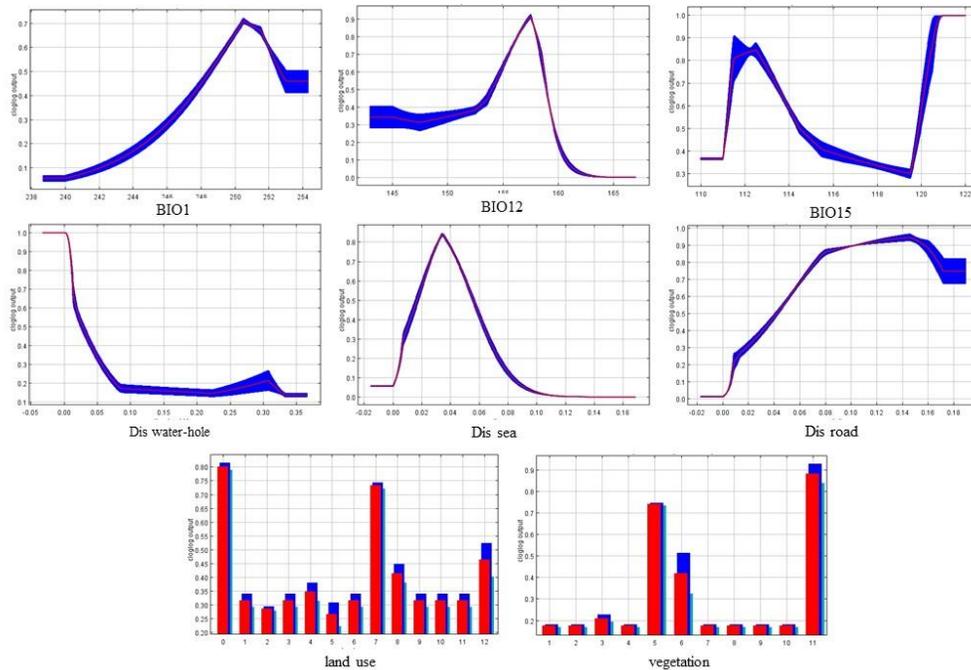
Figure 5. The response curve of different variables used in the MaxEnt model

The results of the response curve of the land use variable showed that mixed agriculture and poor lands have the highest probability of the presence of gazelle. Also, the results of the response curve of the species in relation to the vegetation cover showed that the *Palhagi camelorum-Ziziphus spina-christi-Prosopis koelziana* and *Halocnemum strobilaceum-Aeluropus lagopoides-Atriplex leucoclada* have the highest probability of gazelle presence (Figure5).

Table 4. Table of the percent contribution of every covariate.

Variable	Percent contribution
Dis to sea	11.6
Dis to water-hole	65.7
Dis to road	10.4
Vegetation	5.7
Land use	2.4
BIO15	2
BIO1	1.5
BIO12	0.7

Figure 6 shows the habitat suitability map. This map shows that the most suitable part of the habitat is located in the northwest of the area.
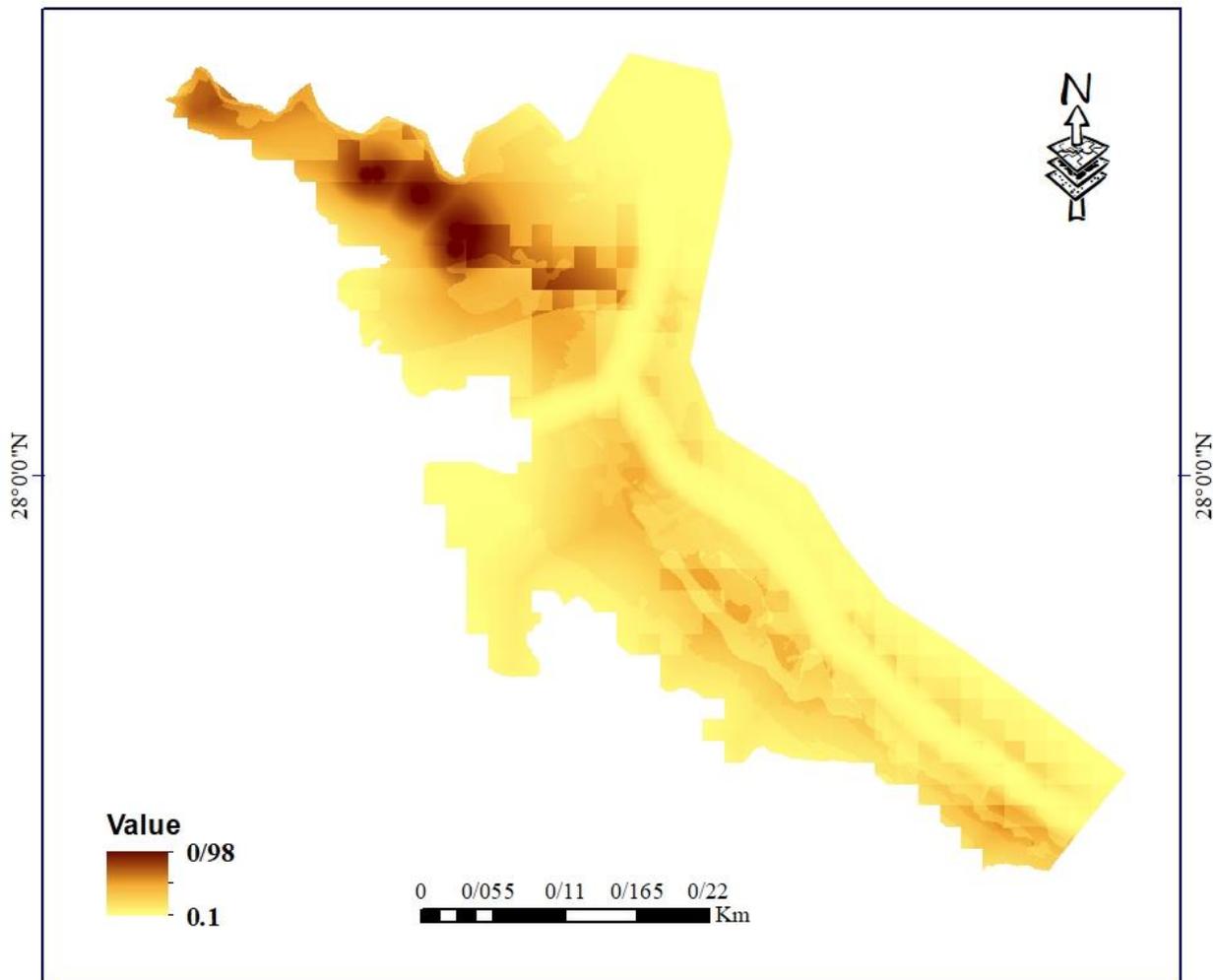
Figure 6. Habitat suitability map

Flood Analysis Results

Due to the higher elevation of the land in the river's right-side floodplain, floodwater enters the river's left floodplain (upstream of the study area). The 25 to 200-year return period floods do not differ significantly in terms of flood extents, but dangerous floods with more extended return periods (and magnitude) cause a larger area to be submerged in the southern part of the protected area (Figure 7).

To the east of the Mond Protected Area's highlands are substantially protected from the potential risk of flooding. However, the central and western areas near the coast are among the areas vulnerable to destructive floods. This matter threatens the safety of animal species, especially the habitat of the Arabian Sand Gazelle.
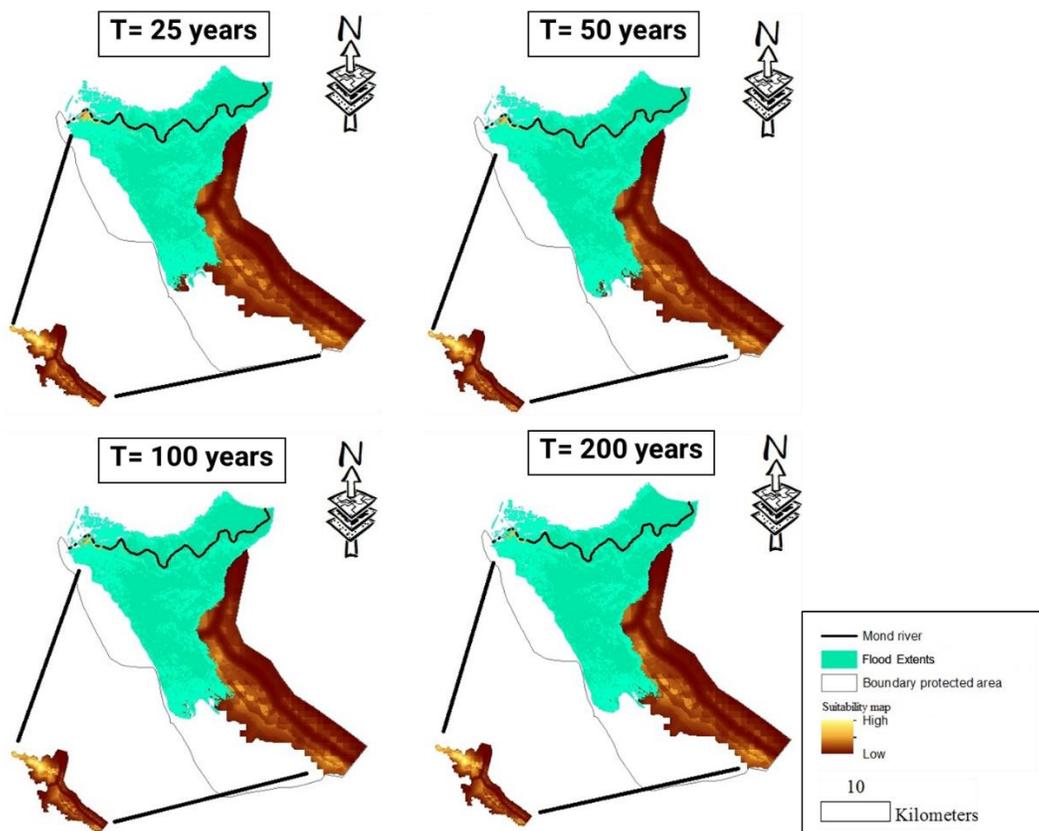
Figure 7. Mond River flood inundation maps with a return period of 25 to 200 years.

Table 4 displays the characteristics of modelled floods with return periods of 25 to 200 years. As indicated, with the increasing intensity of the flood volume, the river's maximum water level and the simulated flood extents increase (Table 5). For example, the flow intensities with a return period of 25 and 200 years are 5017 and 6121 m^3/s, which flood 289 and 313 km^2, respectively of the study area. This means that as the current flood increases by 22 percent, the flooded land area

increases by 8.3 percent. The difference between the maximum levels of the upstream water level with the return period of 25 years with 200 years is 30 cm, but the volume difference is about 50,000 m^3, which indicates high risk of floods.

Table 5. Comparison of simulated flood characteristics with different return periods.

Return Period of Flood (years)	Max Flow (m^3/s)	Volume ($m^3 \times 10^5$)	Max Upstream Stage (m)	Flood Extents Area (km^2)
25	5017	2.3	13.8	289
50	5483	2.5	13.9	299
100	5843	2.6	14	307
200	6121	2.8	14.1	313

Discussion

The present study examined species distribution modelling using an SDM of a threatened species overlaid with flood risks (Figure 7). An AUC value of between 0.7–0.9 is reasonable/moderate performance and shows the good validity of the MaxEnt method(Peterson *et al*., 2011). The results show that the northwestern parts of the study area are the most suitable part of the area for the species (Figure 6). Because of the high salinity in the water of the Mond River, water holes are of high importance to the gazelle habitat. The results indicate that distance to sea, distance to road, distance to water-hole and vegetation were the most critical factors affecting the distribution of species (Figure 5). Karmi et al. (2016) found that the water hole is one of the main variables affecting the suitability of the gazelle's habitat, which is consistent with the results of this study. However, Khosravi et al. (2016) indicated that the bioclimatic variables were the most critical predictors in gazelle distribution. In another research conducted by Hemami et al., (2020) their results showed that annual mean temperature, unconsolidated land, temperature seasonality, and consolidated land were the most important variables contributing to the species habitat suitability model.

Due to the proximity of the protected area to urban and anthropogenic center's as well as gardens, gazelles preferentially select sections of habitat with the least stress. roads entail many negative impacts on wildlife, including both direct ones such as roadkill, the barrier to movement, habitat loss and fragmentation or pollution and indirect impacts such as overexploitation of resources or

habitat degradation derived from the increased accessibility to natural areas(Ascensão *et al*., 2018; Barrientos *et al*., 2021; Laurance *et al*., 2014; Van Der Ree *et al*., 2015). Also, the presence of roads and vehicle traffic during the day produces noise, and at night it produces light and noise, which endangers the safety, cycle and nature of wildlife (Rezaei et al., 2022ab, Almasieh et al., 2022; Ashrafzadeh et al., 2023). Additionally, with increasing distance from the sea, the threats caused by the hooves species sinking into the soil are reduced. Hence, the risk of natural and human predators is reduced.

The results of the response curve of the land-use variable for total suitability showed that mixed agriculture and mixed poor land have the highest probability of being suitable Arabian sand gazelle habitat (see figure 5). Moreover, results from the response curve of species relative to vegetation identified habitat containing Alhagi *Camelorum, Ziziphus Spina-Christi, Prosopis Koelziana,* and *Halocnemum strobilaceum-Aeluropus lagopoides-Atriplex leucoclada* being most likely to contain the gazelle.

According to the analysis of the study area's flooding potential based on flood inundation maps with a return period of 25 to 200 years, the study area is significantly vulnerable to this natural phenomenon (Figure 7). As the most crucial threat, the devastating floods in this area jeopardize gazelle's lives directly and reduce the available habitat. According to the findings of the Iran Environmental Protection Agency, some species cannot adapt to post-flood conditions; Therefore, their life is endangered by new conditions. The decrease in reproduction is due to these animals lose their habitats(Boudaghpour et al., 2015).

Based on the habitat suitability analysis, the northern section of the area is the most suitable habitat for gazelles, even though this area is at high risk of flooding. The devastating floods of the Mond protected Area cause the destruction of this species' habitat and their extermination. Among the conservation programs for minimizing flood impacts on the Arabian sand gazelle species, the erection of upstream diversion dams for controlling flash flooding would be ideal, which may also provide drinkable water and electricity for the residents. Another structural flood mitigation measure would be constructing levees on the river's left bank to divert the flood flow (Molinari *et al*., 2013). However, flood risks can be reduced by protecting and rehabilitating vital ecosystems such as coastal wetlands and shoreline vegetation, which absorb floodwater and reduce water runoff (Bayani, 2016). Ecosystem-based measures for reducing risk are called "no-regret" strategies (Bayani, 2016; "Ecosystem-Based Adaptation," IUCN).

By identifying, measuring and interpreting the magnitude and importance of flood environmental effects, its negative effects can be avoided or minimized(Boudaghpour et al., 2015). Mapping flood zones can be used as a new technique to assess environmental damage caused by floods in the region. In this study, we have determined by using flood zoning techniques in areas that are likely to be affected by floods, which is very effective in managing floodplain areas and controlling floods to reduce flood damage to the only sand gazelle habitat in Iran. The results of flood zone mapping showed that in the return period of 200 years, more than 300 square kilometres of the area will be submerged, which means that almost the entire favourable area of the study area will be sunk. Sinking of land affects the life of animals in the area and threatens their habitats when a flood occurs (Boudaghpour et al., 2015. The most important mammal in this area is the sand gazelle. Based on our findings, the only habitat of this species is seriously threatened by flooding.

Coclusion

In general, the protected area is isolated on all four sides and it is not possible for gazelles to easily move and increase genetic diversity by interacting with other populations. Also, because no management plan has been implemented to maintain this species so far, this study may act as valuable background information for conservation and management programs in this area to preserve this threatened species.

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