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Research Article

Habitat Suitability Modelling for Feline Species in Jordan: A tool for Climate-Responsive Conservation Planning

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Abstract

Three of the four known feline species in Jordan are categorized as critically endangered, according to the latest Red List assessment of mammals in Jordan, of which caracal: *Caracal caracal,* sand cat *Felis margarita*, and jungle cat *Felis chaus*. The fourth species, discussed within this paper – the wild cat *Felis silvestris,* is a species of least concern. Human activities such as hunting, poisoning, habitat destruction, and fragmentation are among the pressures seriously affecting the small and restricted populations of critically endangered felines. This study is the first to provide predictions on habitat suitability for the four species based on the two Representative Concentration Pathways (RCPs), predictions of how greenhouse gas concentration in the atmosphere, of 2.6 (representing “very stringent” corrections to the number of greenhouse gases accumulating in the atmosphere) and 8.5 (the “business-as-usual” or also known as the “worst-case scenario”). Results showed an alarming decline in suitable habitats for all species. The sand cat is predicted to lose its entire suitable habitats in 2050 and 2070 according to RCP 8.5, while both the caracal and jungle cat are to face the very precarious pressure of declined areas of suitable habitat. Jordan’s network of protected areas was deemed inadequate, according to this study, to protect the feline species and maintain their population. As potential solutions to counter the

combined anticipated impacts occurring from both human activities and anticipated climate forecasts, it is necessary to strengthen the enforcement of environmental policies intended to protect reserves and natural areas, strengthen ex-situ conservation measures, minimize human pressures, to cope with the predicted habitats loss in the future, and to review the current network of protected areas.
Keywords: *Caracal caracal*, *Felis chaus*, *Felis margarita*, *Felis silvestris*, Habitat suitability, Jordan.

Introduction

Biodiversity conservation requires knowledge and understanding of species distribution (Margules and Pressey 2000). However, data on animal species is usually unavailable due to the logistical and human costs involved (Prendergast et al. 1999; Bowker, 2000; Ottaviani et al. 2004). Obtaining the data is one thing, synthesizing it is another in order to elaborate on the importance of the relationship between species and their habitats to consider the ecology of species (Cowles, 1899; Grinnell, 1917). As such, researchers have relied on modeling and predicting species distribution to plan for biodiversity conservation (Pereira and Itami 1991; Akcakaya and Atwood 1997; Peterson and Robins 2003; Ortega-Huerta and Peterson 2003; Araujo et al. 2004; Gibson et al. 2004; Sanchez-Cordero et al. 2005). Moreover, species environmental correlations were used for habitat suitability and to envisage the extent of distribution to species across complex landscapes (Verner et al. 1986; Guisan and Zimmermann 2000; Manly et al. 2002).

To delineate species distribution over a region, presence/absence and presence only can be utilized to understand the extent of suitable habitats in light of increasing climate threats that negatively impact habitat viability, aiding in the development of scenarios for species distribution (Tsoar et al. 2007).

This study used presence-only information to predict habitat suitability for four feline species reported native to Jordan: the caracal - *Caracal caracal*, wild cat - *Felis silvestris*, sand cat - *Felis margarita*, and jungle cat - *Felis chaus* (Amr, 2012; Eid et al. 2020). Three of the four species - the caracal, sand cat, and jungle cat - are critically endangered, according to the latest assessment of mammals in Jordan, while wild cat is specified as a species of “least concern” (LC) (Eid et al. 2020). In addition, both the caracal and jungle cat have a confined range of distribution within Jordan, and they are rarely seen. This article will contribute to conservation efforts, and protected areas management by predicting the changes in the suitable habitats in the future in response to the anticipated changes in climate and human impacts. It proposes recommendations to conserve threatened species in Jordan. The modeling used herein is to inform a future spatial conservation process for the species in Jordan.

Material and methods

Study region

Jordan has situated approximately 80 km to the East of the Mediterranean Sea (29º 11´ to 23º 22´ North, and 34º 19´ to 39º 18´ East). Its climate is characterized by hot, dry summers and wet, cool winters (Al-Qinna, 2018). The country contains three main climatic regions: the Ghor (lowlands), Highlands, and the Desert regions (FAO, 2012; Al-Qinna, 2018). Generally, around 90% of Jordan is arid to semi-arid, characterized by a very low annual precipitation ranging from a minimum of 28 millimeters at the south and eastern Badia region to a maximum of 570 millimeters at the upper northern highlands region (Al Eisawi 1996). The temperature across the country varies between 13°C in the southern Badia region to 28°C at Aqaba (The Ministry of Environment 2014).

The Species Distribution Model (SDM) was established for the Middle East Region and then cropped to the Jordan area due to the relatively small area of Jordan and in order to allow for more variation in the environmental factors and to incorporate a larger number of presences records. This approach ensures capturing the entire environmental range of a species and minimizing the uncertainty that might occur due to the truncated response curve (Sánchez-Fernández et al. 2010).

Presence records

Records of feline species' presence data were sourced from (i) the Global Biodiversity Information Facility (GBIF) available at (www.gbif.org), (ii) Mammals of Arabia compiled by Harrison and Bates, (1991), and (iii) local records obtained from author records as well as records obtained from the available literature especially the Red Data Book of Mammals of Jordan and the mammals of Jordan (Amr, 2012; Eid et al. 2020). These records accounted for populations and species ranging from 1990 to 2020. GBIF records were queried for the Middle East area, for the timeframe 1950 to 2020. Processing and further area calculations were done in accordance with the UTM 36N projection (Fig. 1-4).

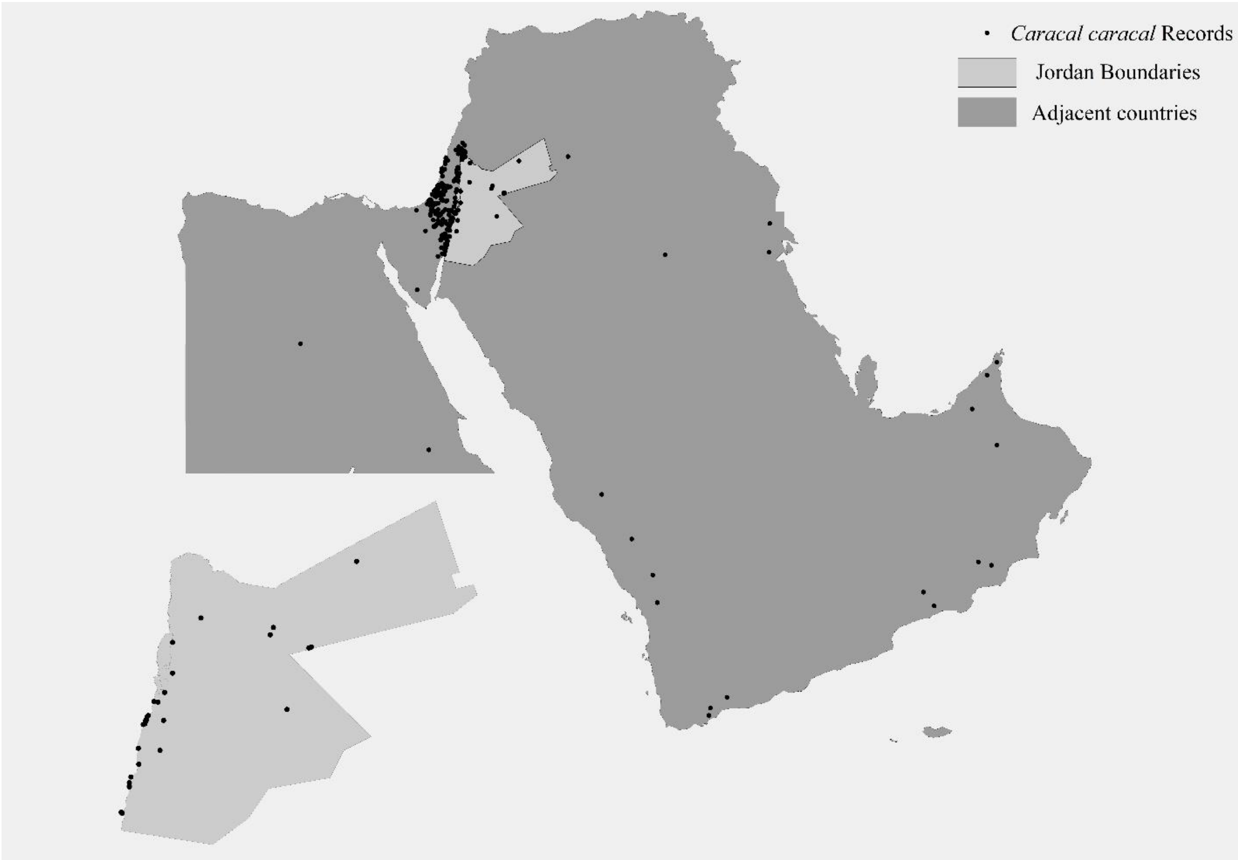

Figure 1. The density of records for Caracal (*Caracal caracal*) (514 records) for the Middle East Region obtained from GBIF, Eid et al. 2020, and Mammals of Arabia covering the period (1950 – 2010).

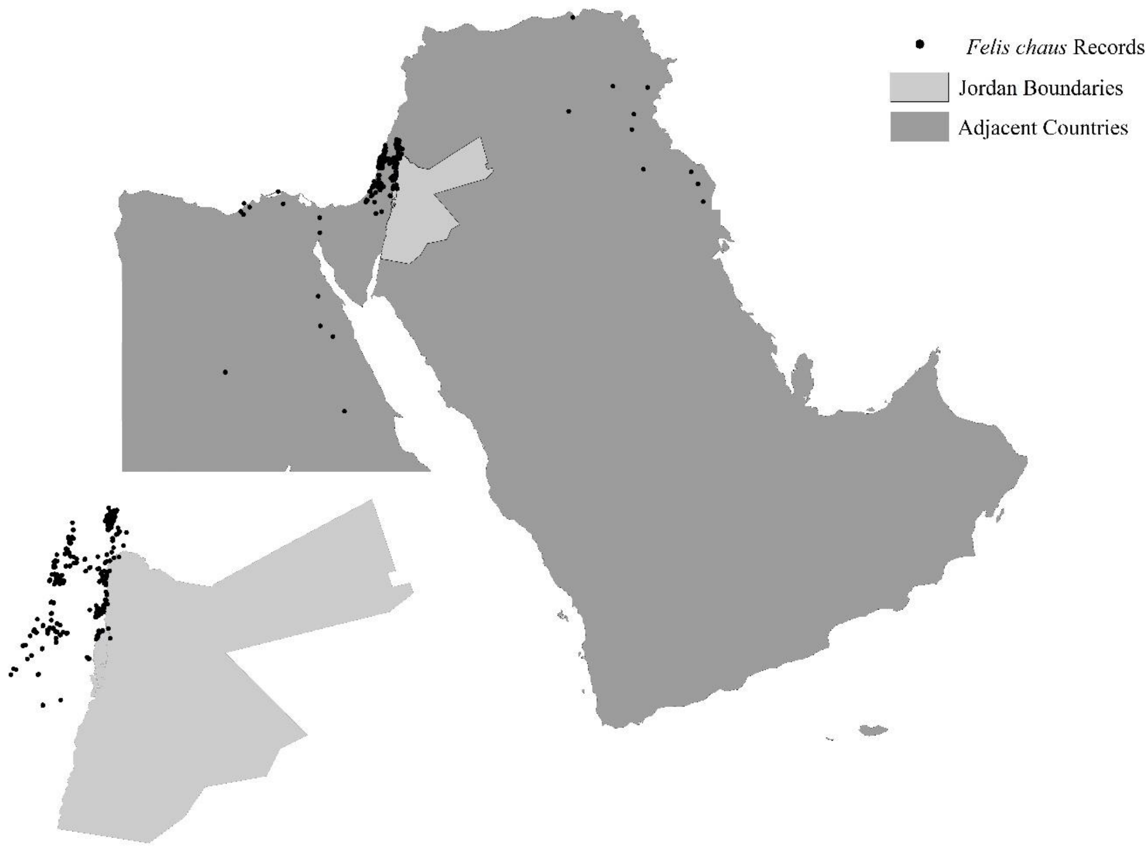

Figure 2. The density of records for Wild Cat (*Felis chaus*) (680 records) for the Middle East Region obtained from GBIF, Eid et al. 2020, and Mammals of Arabia covering the period (1950 – 2010).

Figure 3. The density of records for Sand Cat (*Felis margarita*) (37 records) for the Middle East Region obtained from GBIF, Eid et al. 2020 and Mammals of Arabia covering the period (1950 – 2010).

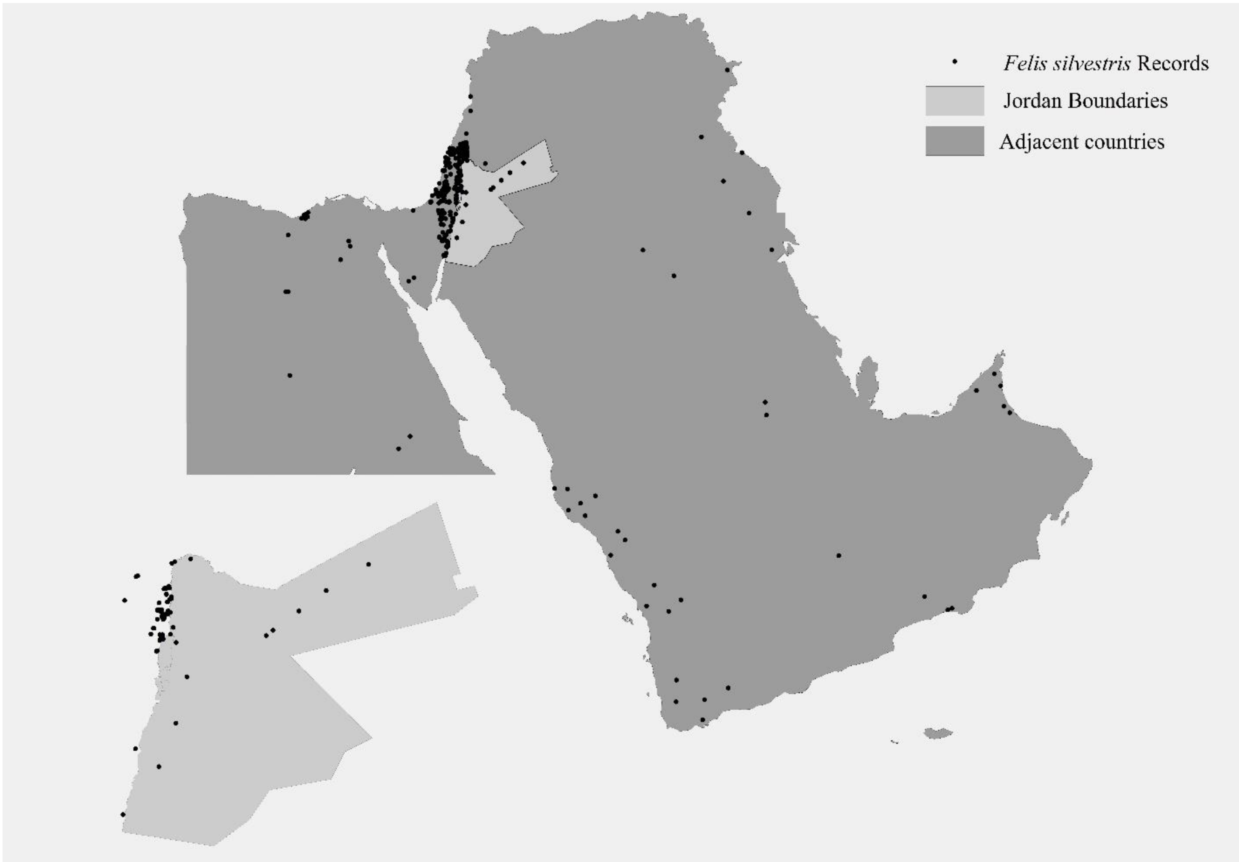

Figure 4. The density of records for Sand Cat (*Felis silvestris*) (1238 records) for the Middle East Region obtained from GBIF, Eid et al. 2020, and Mammals of Arabia covering the period (1950 – 2010).

Data showed variable distributional densities over the study region as shown in Maps 1 to 4. The method entailed performing a spatial thinning of the species' occurrence records by maximizing the linear distance between species occurrences and the number of retained occurrences (Kramer-Schadt et al. 2013; Aiello-Lammens et al. 2015). As such, the possibility of introducing sampling bias in species' presence data was minimized, while retaining the highest achievable distributional information. Thinning the data to a minimum distance of 5.0 Km between species occurrences for the four feline species of concern was performed to optimize the model fit.

Environmental Data

Climatic data were obtained from (www.worldclim.org), where 19 bioclimatic datasets at a spatial resolution of 30 arc-seconds (~1 km) were used. Altitude was downloaded from (www.earthexplorer.usgs.edu) as Shuttle Radar Terrain Mission (SRTM) altitude tiles, which were also used to produce ruggedness and slope variables. The WorldClim data were generated through interpolation of monthly temperature and precipitation records over the period 1970–2000 (Fick and Hijmans, 2017). The global data set was downloaded and clipped to encompass the Middle East and scaled for that of Jordan for model calibration and projection, respectively. The future condition was informed by the application of the Representative Concentration Pathways (RCP) 2.6 and RCP 8.5 datasets. RCP 2.6 is the optimistic scenario, which assumes increasing in GHG emissions and temperatures to reach their peak by mid of 21st century, before decreasing in the second half of 21st century (IPCC, 2014). While, RCP 8.5 is a pessimistic scenario, which assumes a continued increase in GHG emissions and temperatures over the 21st century (Riahi et al. 2011). The clipping and extraction of data and results in this step were completed on ESRI ArcMap 10.4. Multicollinearity presence among the predictors leads to an overfitted model, which is considered a reason for model instability (Dormann et al. 2013; Elith et al. 2017). Therefore, the correlations between all variables using a variance inflation factor (VIF) and excluding the highly correlated variables using the "VIF" function from the "usdm" package in R was applied. A VIF greater than 10 is a signal that the model has a collinearity problem (Naimi et al. 2014).

As a result, nine bioclimatic variables (Table 1) were retained as inputs for modeling the potential distribution of the feline species. The future climate projections for 2050 and 2070, were downloaded from the WorldClim future climate data source (http://www.worldclim.org/CMIP5v1). For each RCP, there are several general circulation models (GCMs), which have been developed by different institutes with slightly different parameters (Fordham et al. 2011). Therefore, to minimize inter-model variability we followed Sanderson et al. (2015) recommendations by obtaining the average prediction of a minimum of five GCMs (X1, x2, x3, x4, and x5). In the absence of guidelines on the selection of the optimum number of GCMs, the quantity of GCMs used per study varies considerably from one study to another (Ahmed et al. 2019).

Table 1: Environmental Variables used in SDM modeling for feline species after eliminating highly correlated variables with VIF>10.

Variables	**VIF**	**Description**
Altitude	2.21	Altitude obtained from Shuttle Radar Terrain Mission, earthexplorer.usgs.gov
Aspect	1.03	Calculated from Altitude surface using ASPECT function in ESRI ArcMap 10.6.
bio 01	7.78	Annual Mean Temperature
Bio 02	1.69	Mean Diurnal Range (Mean of monthly (max temp - min temp))
Bio 03	3.12	Isothermally (BIO2/BIO7) (* 100)

Bio 08	6.42	Mean Temperature of Wettest Quarter
Bio 09	3.81	Mean Temperature of Driest Quarter
Bio 14	2.69	Precipitation of Driest Month
Bio 15	2.39	Precipitation Seasonality (Coefficient of Variation)
Bio 18	3.04	Precipitation of Warmest Quarter
Bio 19	1.76	Precipitation of Coldest Quarter
Ruggedness	1.61	Terrain Ruggedness calculated from Altitude surface using GDAL library in QGIS 3.14.
Slope	1.03	Calculated from Altitude surface using SLOPE function in ESRI ArcMap 10.6.

Modeling Framework

The ensemble SDMs framework, using the weighted average consensus approach to minimize model uncertainty, was applied to identify the current and future distribution ranges (Araújo and New 2007; Marmion et al. 2009). The ensembles included two different SDM algorithms, MaxEnt (Phillips et al. 2006) and Random Forest (RF) (Breiman, 2001), implemented in the “biomod2” R package (Thuiller et al. 2016). Calibrating SDMs with a truncated training dataset (i.e., at a restricted geographical scale such as country political boundary) are weak in their ability to capture the environmental conditions that species experienced throughout its full range (Titeux et al. 2017; El-Gabbas and Dormann 2018). Such models may produce errors in prediction and uncertainty as a result (Hannemann et al. 2016). Therefore, for each species, a model using the filtered species occurrences and the uncorrelated current environmental predictors that cover a broad spatial scale were calibrated and projected to the scale of Jordan. This allowed the broad special scale to be overlapped with the environmental domains of the species presence more precisely at the national level (Phillips, 2008; Phillips and Dudík 2008; Bagchi et al. 2018). When applied in the analysis, 10’000 background points were randomly sampled from the calibrated range to identify the environmental ranges (Bagchi et al. 2018).

The model predictions were projected into the scale of Jordan to delineate the current potential distribution for each species. The spatial cross-validation was applied to ensure independent model evaluation (i.e., calibrating data not used for model evaluation) (Tisseuil et al. 2012, Radosavljevic and Anderson 2014). To this end, species’ presences points were divided spatially into four blocks, of which three blocks were used for SDMs training and the left fourth block used for evaluation iteratively until each block was used for evaluation (Bagchi et al. 2013; Baker et al. 2015). This ensured that 1) spatial independence between calibrating and evaluating data, 2) avoiding inflated evaluation metric that raises from spatial auto-correlation between calibrating and evaluating data and, 3) an estimation of model uncertainty (Bagchi et al. 2013, Baker et al. 2015). The model's predictive performance was evaluated using a threshold-independent metric, the area under the curve (AUC) of the receiver operating characteristic (ROC) (Fielding and Bell 1997), and threshold-dependent metric, the True Skill Statistic (TSS) (Allouche et al. 2006). To assess the species' response to the projected impacts of climate change, the current distribution range of each species was projected into the future for the years 2050 and 2070. Due to the large variability among general circulation models (GCMs) that add uncertainties to models' projections (Buisson et al. 2010; Goberville et al. 2015; Baker et al. 2015; Baker et al. 2016), the median of the models' predictions from the GCMs (Barbet-Massin et al. 2010; Beale et al. 2012; Goberville et al. 2015; Cianfrani et al. 2018) was calculated in order to strengthen the accuracy of the forecast model and minimize bias in model predictions (Beale et al. 2012; Goberville et al. 2015; Jiang et al. 2016).

Results

The models were successful in identifying the potentially suitable habitats for the feline species. The highest performance was for *Felis margarita* (AUC= 0.999 and TSS =1), followed by *Felis Chaus* (AUC= 0.998 and TSS =0.994). The model of the *Felis silvestris* species had the lowest performance compared to the other species (AUC= 0.993 and TSS =0.957). The most influential variable was the precipitation of the coldest quarter of the year, while aspect was the least consequence for all of the four species analyzed (Table 2).

Table 2. Variable significance in modeling the habitat suitability of each felid species in the study, showing BIO-19 Precipitation in coldest quarter being most influential and Aspect being the least.

F. silvestris		*F. margarita*		*F. chaus*		*Caracal caracal*	
bio_19	30.5	bio_12	72.0	bio_19	49.0	bio_19	27.2
bio_02	20.3	bio_02	8.6	bio_12	18.5	bio_08	22.9
bio_08	19.9	slope	6.9	Altitude	15.6	bio_02	18.3
bio_01	7.2	bio_03	5.4	bio_10	3.4	bio_12	6.7
bio_12	7.0	Altitude	1.3	bio_04	3.2	bio_03	6.2
bio_04	4.1	bio_08	1.3	bio_08	3.0	bio_10	6.2
bio_03	4.0	bio_01	0.9	bio_09	2.1	bio_04	4.5

bio_10	3.7	bio_09	0.9	bio_01	1.8	bio_01	2.6
Altitude	1.8	bio_19	0.9	bio_02	1.8	slope	2.4
slope	0.9	bio_04	0.7	bio_03	0.8	Altitude	1.7
bio_09	0.5	bio_10	0.7	slope	0.6	bio_09	1.1
aspect	0.1	aspect	0.3	aspect	0.1	aspect	0.1

Our models showed that the response to the expected changes in climate conditions varies among the species and between the scenarios.

Caracal (*Caracal caracal*)

The predicted suitable habitats for caracal, *Caracal caracal* as Pre-Climate Change Conditions in Jordan is estimated as 20,200 km² situated in the western part of the country (Fig. 1 – current). According to RCP 2.6, it is expected to shrink to around 2,400 Km² by 2050 with the remainder occupying its current northwestern position. It is expected to decrease to 2,358 Km² in 2070. This is an approximate 88% decline in area by 2050 and 89% by 2070 loss of caracal habitat compared to its current estimated habitat, respectively. On the other hand, if RCP 8.5 is applied, the caracal habitat is expected to shrink to 4,589 Km² (77%) by 2050 and further to 2,358 Km² (88%) by 2070. For changes predicted for the *in-situ* protection level of the species in Jordan, the pre-climate change habitat conserved in the protected area is about 1,240 m² representing only 6.14% of its total range. According to RCP 2.6, this is expected to drop to 90 Km² in 2050 and again to 85 km² in 2070. On the other hand, when RCP 8.5 is applied, protected areas are to drop to 3.5% of the established protected habitat by 2050 and maintain this level in 2070. A summary of these numbers could be seen in tables 3 and table 4 below. The predicted current range of caracal and the expected impact according to RCP 2.6 and RCP 8.5 on habitat suitability of caracal in Jordan are illustrated in figure 5.

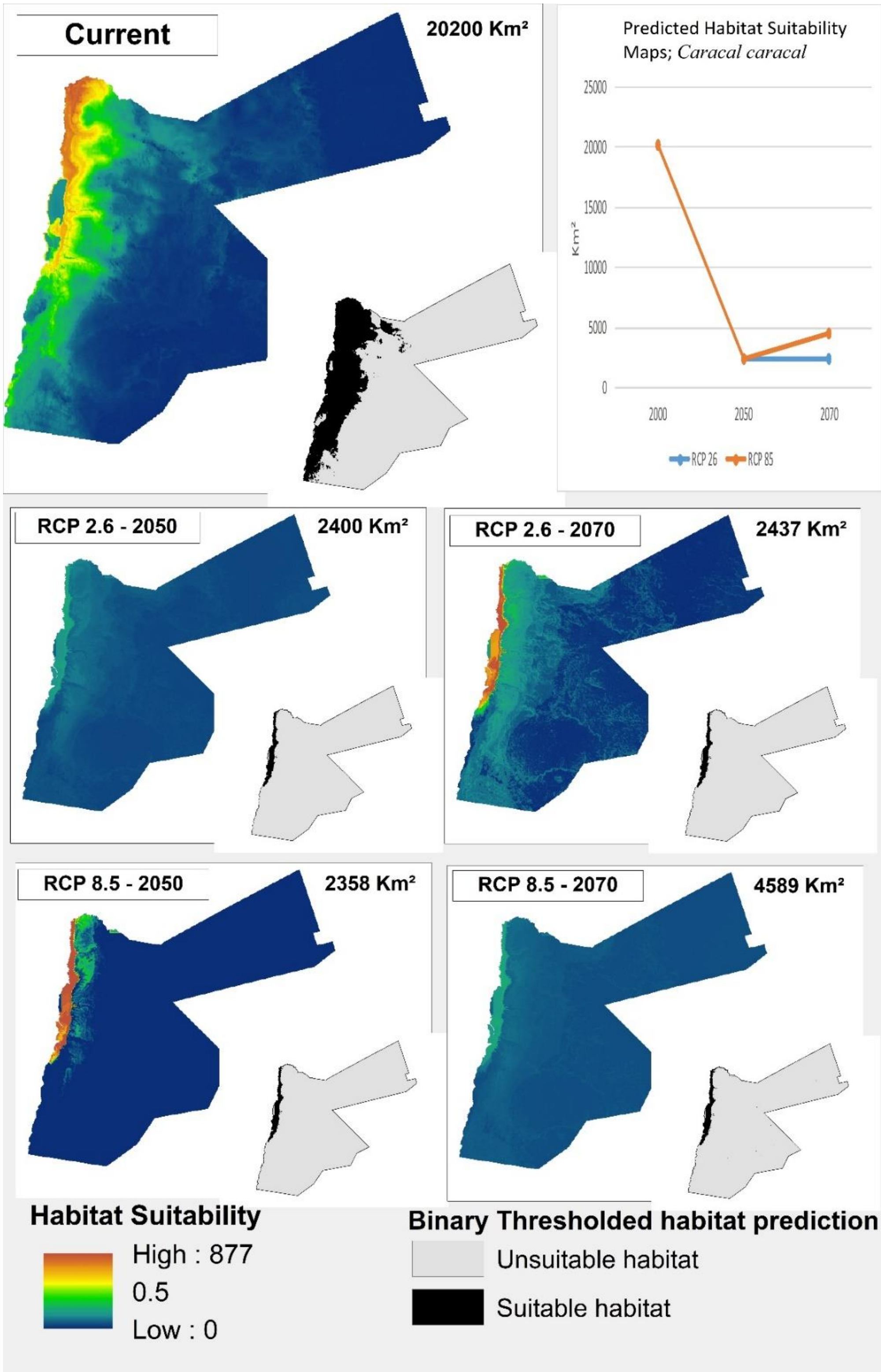

Figure 5. predicted range (suitable habitat) of caracal (*Caracal caracal*) in Jordan according to current climatic conditions (1950 – 2000) and under predicted future climatic conditions RCP 2.6 for the periods

2050 and 2070. Ensemble models (MaxEnt, Random forest). Grey-black maps are binary threshold at (specificity – sensitivity) value of ensemble model.

Jungle cat *(Felis chaus)*

For the Jungle cat, *Felis chaus*, the predicted suitable habitat as Pre-Climate Change Conditions in Jordan is estimated as 3,588 km², which is expected to shrink to around 2,406 km² by 2050 and to 549Km² in 2070 under RCP 2.6 scenario. This is approximately a 33% decline in habitat by 2050 and 90% loss by 2070. Under RCP 8.5, the area of habitat of the Jungle cat is predicted to decrease to 549Km² by 2050 and stay at the same level for 2070. The eventual habitat loss for the Jungle cat in Jordan is estimated at 84% due to climate change as expected under RCP 8.5 by 2070. The predicted current range of jungle cat and the expected impact of RCP 2.6 and RCP 8.5 extremes on habitat suitability in Jordan is illustrated in figure 6.

The Pre-Climate Change habitat conserved in protected areas is about only 177 km² representing only 5% of the pre-climate change range. This is expected to drop to 89.6 Km² in 2050 and completely disappear by 2070. This is equal to a corresponding protection level of 3.6% and 0% of protection for the habitat of Jungle cat in 2050 and 2070, respectively under RCP 2.6. Applying the RCP 8.5 scenario gives even more dire Figures, where the area of the predicted suitable habitat contained in protected areas is expected to disappear. This is an eventual result of 0.0% protection to Jungle cat in the National Protected Area network if counter measures to protect this species are not enacted by 2050 under RCP 8.5 in Jordan. A summary of Jungle cat range and protection levels numbers could be seen in tables 3 and 4.

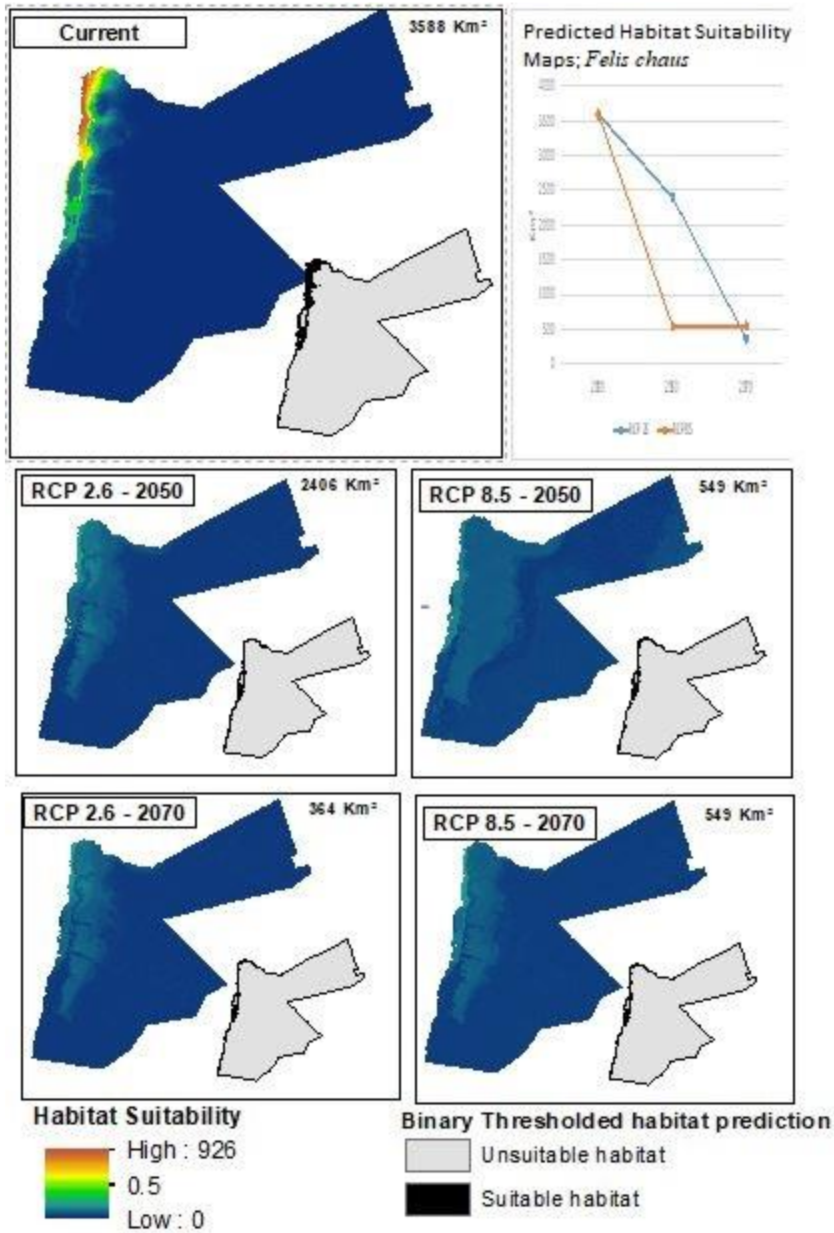

Figure 6. predicted range (suitable habitat) of wild cat (*Felis chaus*) in Jordan according to current climatic conditions (1950 – 2000) and under predicted future climatic conditions RCP 2.6 and RCP 8.5 for the time periods 2050 and 2070. Ensemble models (MaxEnt, Random forest). Grey-black maps are binary threshold at (specificity – sensitivity) value of ensemble model

Sand Cat (*Felis margarita)*

For the sand cat, *Felis margarita*, the predicted Suitable Habitat as Pre-Climate Change Conditions in Jordan is estimated as 1,445 km², which is expected to drastically shrink to under 10 Km² by 2050 and disappear by 2070 under RCP 2.6 assumptions. Whereas the picture is dryer under the RCP 8.5 conditions, the species is predicted to go locally extinct by 2050 as it loses its entire suitable habitat in 2070. The Pre-Climate Change habitat conserved in Protected Area is about only 112 km² representing only 7.7% protection. This is predicted to shrink to 2.1 Km² in 2050 and shrink again to 0 km² in 2070 under RCP 2.6 conditions. On the other hand, modeling under RCP 8.5 conditions predicts that the protected range for the species is to decline to 0.0 Km² (0.0%) at both 2050 and 2070. A summary of these numbers could be seen in tables 3 and 4.

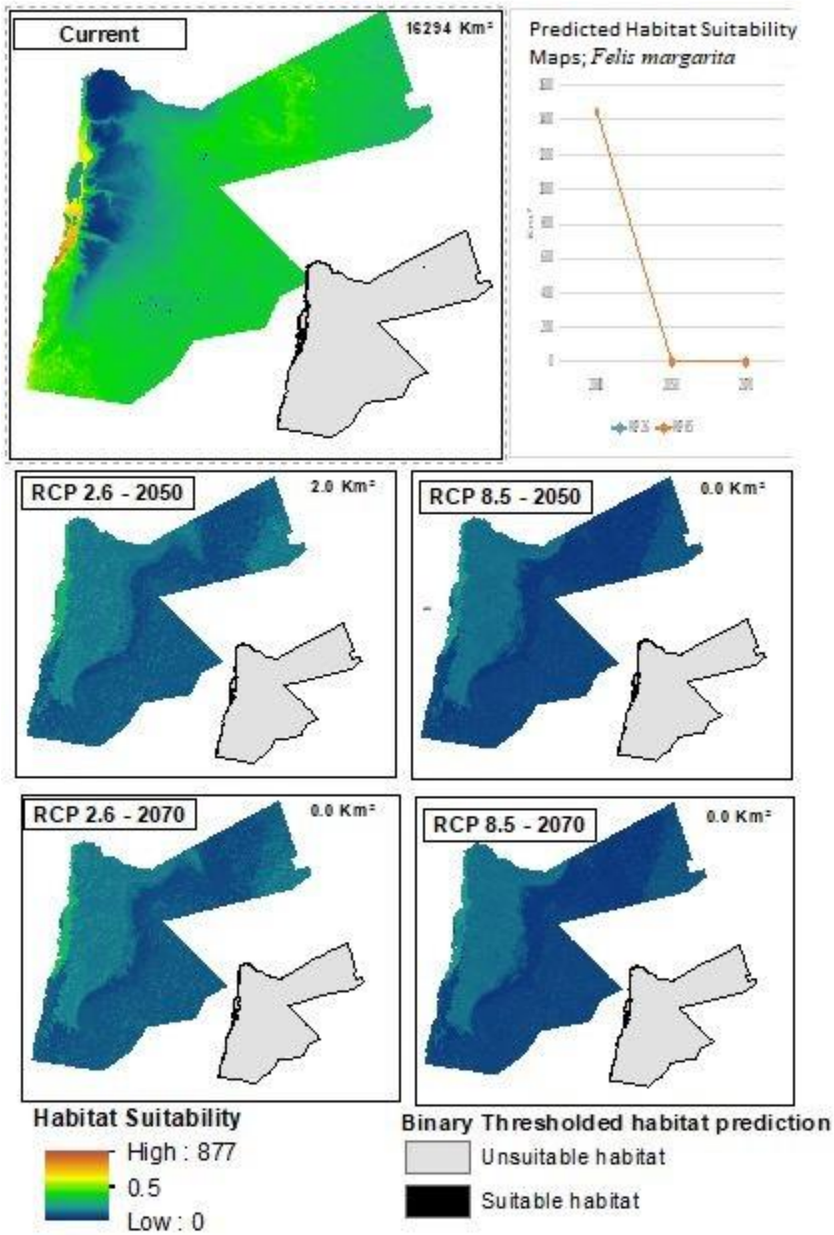

Figure 7. predicted range (suitable habitat) of Sand Cat (*Felis margarita*) in Jordan according to current climatic conditions (1950 – 2000) and under predicted future climatic conditions RCP 2.6 for the time periods 2050 and 2070. Ensemble models (MaxEnt, Random forest). Grey-black maps are binary threshold at (specificity – sensitivity) value of ensemble model.

Wild Cat (*Felis silvestris*)

Results of the Wild cat, *Felis silvestris* showed that the predicted suitable habitat as Pre-Climate Change Conditions in Jordan is estimated as 16,249 km² which is predicted to shrink to approximately 4825 Km² by 2050 and to 4,703 Km² in 2070 under RCP 2.6. The loss of available habitat for *F. silvestris* is expected to be more drastic under RCP 8.5. Modeling under RCP 8.5 showed that wild cat's suitable habitat would shrink to 3,436 km² by 2050 and to 3,861 km² by 2070. The overall impact of climate change is expected to decrease the suitable habitat of the species in Jordan to about 71% and 76% of its pre-climate change conditions under RCP 2.6 and RCP 8.5, respectively.

Pre-Climate Change habitat conserved in Protected Area is about 1,055 km² representing only 6.4% of the species habitat. This is predicted to remain as 10,557 Km² in 2050 and shrink to 182 Km² in 2070. This corresponds to an increase of protected area compared to the baseline of pre-climate change levels - an increase of 22% in 2050 and 3.8% in 2070. On the other hand, if RCP 8.5 showed that the predicted range of wild cat in Jordan is predicted as 3,436 km² in 2050 and 3,861 in 2070. The corresponding protection levels for the species are 4.1% in 2050 and 3.9 in 2070 (Fig. 8). A summary of these numbers could be seen in tables 2 and 3.

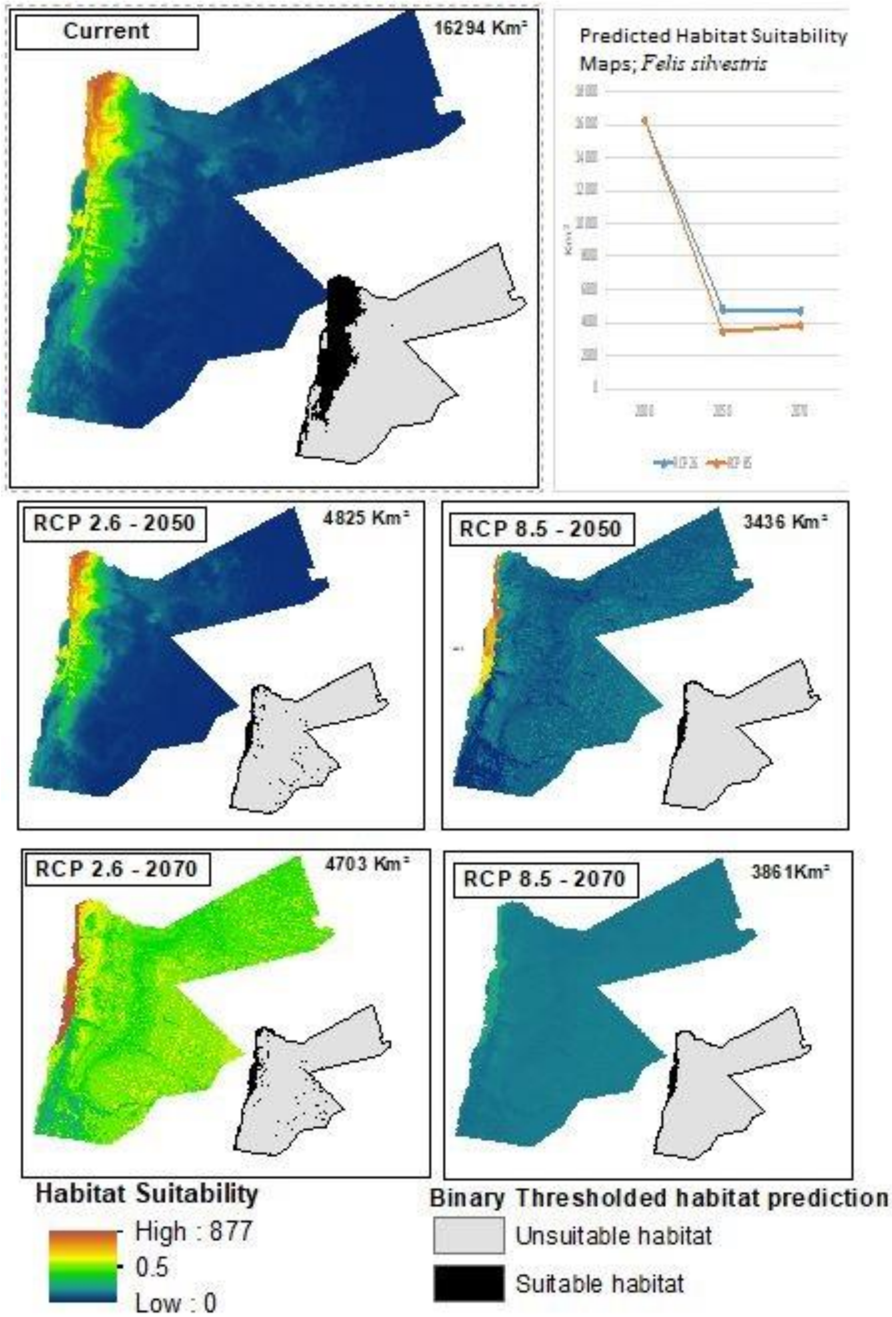

Figure 8. Predicted range (suitable habitat) of wild cat (*Felis silvestris*) in Jordan according to current climatic conditions (1950 – 2000) and under predicted future climatic conditions RCP 2.6 for the time periods 2050 and 2070. Ensemble models (MaxEnt, Random forest). Grey-black maps are binary threshold at (specificity – sensitivity) value of ensemble model.

In terms of feline species richness, our model shows that the current hotspot for the feline is concentrated on the narrow western strip that lies to the east of the Dead Sea. According to RCP2.6 and RCP8.5 scenarios, the model predicts a significant decrease of this hotspot and a shift towards the North West corner of the Jordanian Kingdom (Fig. 9). This remaining feline-rich strip is located outside the current protected areas network and deemed outside the current conservation measures of the kingdom.

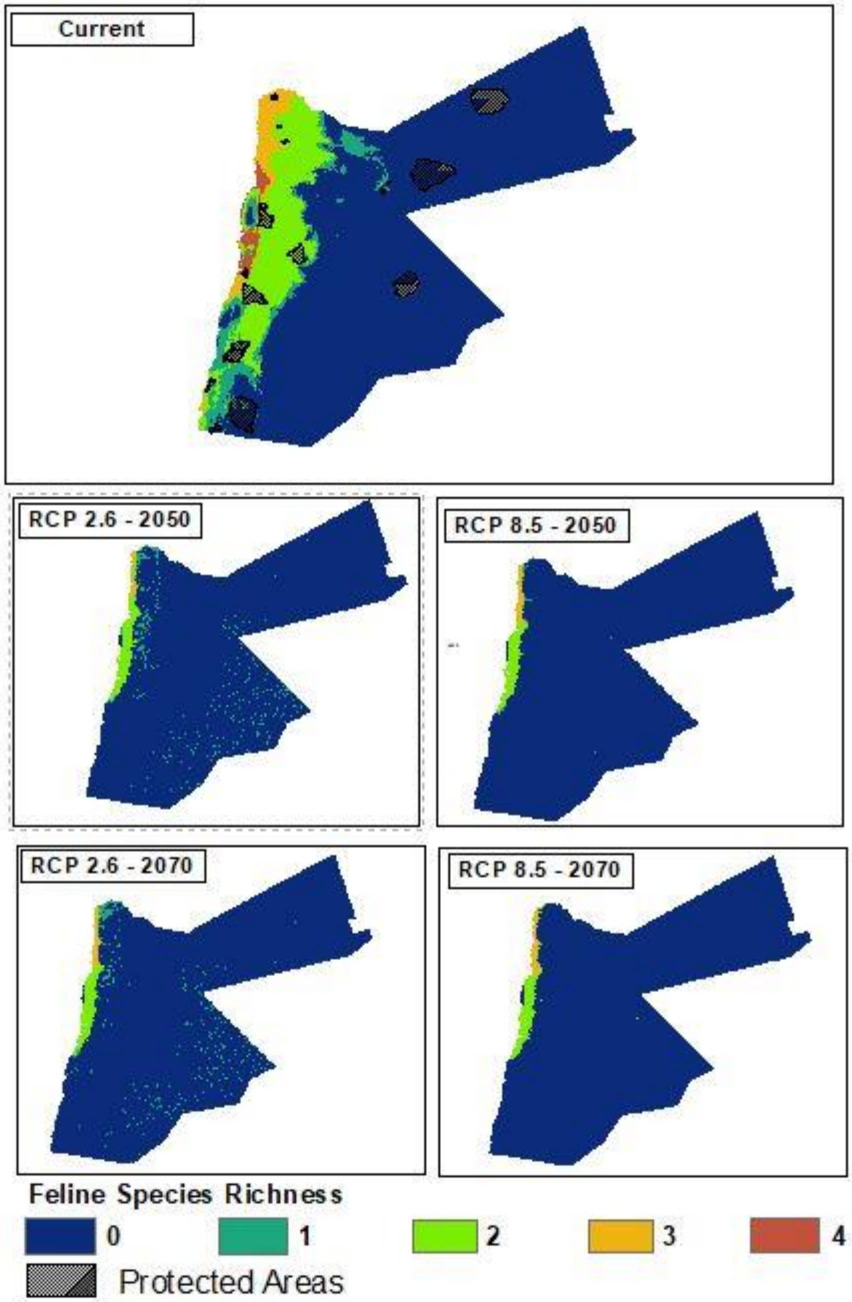

Figure 9. Predicted Feline species richness in Jordan according to current climatic conditions (1950 – 2000) and under predicted future climatic conditions RCP 2.6 & RCP8.5 for the time periods 2050 and 2070. Ensemble models (MaxEnt, Random forest). It shows the drastic decline of feline rich range in Jordan.

Table 3. Fate of feline suitable habitat in the Kingdom of Jordan as predicted by ensemble model (MaxEnt & Random Forest) showing the initial low level of protection of feline species in protected area network and deterioration of conservation levels through Climate change as per RCP 26 during the 21st century.

Species	**Pre-climate change range (**Km²)	**Pre-climate change protection level (**Km²)	**RCP2.6 2050 range (**km²)	**RCP2.6 2050 protection level* (**Km²)	**RCP2.6 2070 range (**Km²)	**RCP2.6 2070 protection level (**Km²)
Caracal	20,200	1239 (6.1%)	2400	89.5	2358	85 (3.6%↓)
Sand cat	1444.8	112 (7.7%)	2.1	0	0	0.0 ✖
Wild cat	16294	1055 (6.4%)	4825	1055 (22%)	4703	182 (3.8%↓)
Jungle cat	3588	177 (5.0%)	2406	89.6 (3 .6%)	549	0.0✖

Table 4. Fate of feline suitable habitat in the Kingdom of Jordan as predicted by ensemble model (MaxEnt & Random Forest) showing the initial low level of protection of feline species in protected area network and deterioration of conservation levels through Climate change as per RCP 85 during the 21st century.

Species	**Pre-climate change range (**Km²)	**Pre-climate change protection level (**Km²)	**RCP 8.5 2050 range (**Km²)	**RCP 8.5 2050 protection level*(** Km²)	**RCP 8.5 2070 range** (Km²)	**RCP 8.5 2070 protection level** (Km²)
Caracal	20,200	1239 (6.1%)	4589	161(3.5%)	4589	161(3.5%↓)
Sand cat	1,444.8	112 (7.7%)	0.0	0.0	0.0	0.0 ✖
Wild cat	16,294	1055(6.4%)	3436	142 (4.1%)	3861	153(3.9%↓)
Jungle cat	3,588	177(5.0%)	549	0.0	549	0.0 ✖

↓= protection level decline from pre climate change levels

✖ = Species is no longer protected in the national protected Areas network

Discussion

Felines of Jordan have experienced various negative impacts resulting from human activities since the beginning of the nineteenth century including hunting, habitat destruction, poisoning, and the cause of the local extinction of some apex species, such as the Arabian leopard *Panthera pardus* and Cheetah *Acinonyx jubatus* (Eid et al. 2020). Despite the continuous efforts to conserve these animals, either by the establishment of protected areas network or through issuing laws and bylaws, felids in Jordan are still facing an accelerating number and degree of threats (Eid et al. 2020). The current results are alarming, in light of the continuing threats and the impacts of climate change as this research illustrates.

The caracal is under serious threat in Jordan due to the limited area it occupies and the extent of its occurrence, which caused it to be placed as a CR species (Eid et al. 2020). Threats are mainly represented by habitat destruction, hunting (Eid and Handal 2018), and reduced prey, which is in accordance with Digeronimo et al. (2010). In Jordan, caracal prefers semi-deserts and mountainous areas with thick vegetation (Amr, 2012). The results of our study showed a significant reduction in suitable habitats of due regardless RCPs. This significant reduction is risky in light of its current Red List status, suggesting that it will become locally extinct in Jordan in the next few years. The modeling also provides frightening results for the capacity of the existing protected areas to conserve suitable habitats for the caracal in the future, noting the decline expected according to the two RCPs. Currently, Dana and Mujib Biosphere Reserves contain small populations of caracal, but with the predictions obtained from our analysis, these reserves will not harbor any suitable habitats to support the existence of those populations anymore in the future and may push these individuals at risk of extinction.

The jungle cat is a very secretive animal, with very limited sightings; however, two specimens were found poisoned near Al-Baqurah in 1988 (Kock et al. 1993; Amr, 2012). This species is under several pressures including hunting, poisoning by farmers for allegedly attacking poultry, and the expansion of agricultural areas around the riverbeds of Yarmouk and Jordan rivers (Abu Baker et al. 2003; Amr et al. 2004; Amr, 2012). Although, military presence currently protects this species in the border area as it prefers riparian habitats with dense vegetation (Amr, 2012). The results of this study showed a 33% loss by 2050 and 90% loss by 2070 according to RCP 2.6, and 84% in 2050 and 2070 according to RCP 8.5. This is a huge loss in suitable habitats, which might bring this CR species to the edge of local extinction. The existing human activities represented by the expanded agricultural practices and heavy use of pesticides and the ongoing climate change as a new threat will add more pressures on this species. The only protected area for the jungle cat is Yarmouk Forest Reserve. However, this study predicts that the suitable habitat for this species will disappear, potentially driving this CR species to extinction. Accordingly, urgent conservation measures are required to protect this species.

The sand cat is another CR species, according to the latest assessment of mammals in Jordan (Eid et al. 2020). Amr (2012) stated that it prefers sandy deserts and depressions without Acacia and it is an extremely sensitive animal to human disturbance and habitat encroachment. According to RCP 2.6, SDMs predicted a significant decrease in suitable habitats from 10 Km^2 in 2050 to zero in 2070, and the results of RCP 8.5 were more serious as it predicts local extinction of this species in 2050 and the loss of the entire suitable habitat in 2070. The results indicated that the current network of protected areas would not support the conservation of the sand cat in the future.

The wild cat is the only species that are predicted to survive, according to the results of this study and based on climate change anticipated impacts, the current network of protected areas is expected to be adequate to conserve about 50% of its current habitats and those predicted for 2050 and 2070. Generally, the wild cat is anticipated to be the most resilient to changes in habitat and is considered a common species (Amr, 2012). Locals consider this cat as a domestic cat and it is not under direct threat. It is known that the wild cat survives in a wide range of habitats from densely forested areas to dry regions with access to permanent water bodies (Amr, 2012)

Conclusion

In conclusion, the felids of Jordan are under serious and continued threats, especially those listed as CR species based on the Red List assessment of mammals in Jordan, with the exception of the wild cat (Eid et al. 2020). The continued human pressures of habitat destruction, hunting, and habitat disturbance affect the remaining populations. As their numbers decrease, it's also expected that smaller population sizes will contribute to greater vulnerability.

The study showed that climate change poses a real threat to these species and might contributes to local extinction to some by 2050. With the exception of Caracal, the predicted habitat prior to climate change shows a relatively low habitat suitability index over Jordon. This shows the fact that the Jordanian range of these species is somewhat a marginal part of their global or regional range and thus is predicted for local extinction under climate change. The area of reserves and conservation areas in Jordan are considered low, and the survival of the felids in Jordan up to 2050 and beyond depends on enhanced protective actions that aim to safeguard the species from habitat loss due to climate impacts and human activities. The current network of protected areas in Jordan, according to this research, will be inadequate to maintain the feline species up to 2050 and 2070.

It would be very important to start thinking about community-based conservation, special conservation areas and establishing corridors to protect these animals in the future. Re-introduction programs and strengthening *ex-situ* conservation measures should be a priority to ensure sustaining a viable population in Jordan, and avoid further extinction of feline species.

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