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A preliminary estimate of the breeding distribution of Sooty Falcon *(Falco concolor)* in Jordan

Fares Khoury[1]*, Khaled Abu-Tayeh[2], Tarek Qaneer[3] & Ra'ed Saleem‡[4]

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Abstract: This report presents the available data and the results of the first rapid assessment of the Sooty Falcon *(Falco concolor)* population in Jordan, including a preliminary distribution model. The species was recorded at 18 sites, some of which were recently discovered, mainly in the Hizma basin close to the Saudi border, and along the southern and Dead Sea Rift Margins. The model, along with knowledge gained during recent fieldwork, will aid in planning a systematic breeding population survey, which will serve as the baseline for a monitoring program and conservation actions for this threatened species in Jordan. As the breeding population in southern Jordan appears to be continuous with the recently surveyed inland populations of north-western Saudi Arabia, the authors suggest cross-border cooperation, which could improve future actions to protect this species from further decline.

Keywords: threatened species, Species Distribution Model, Middle East, breeding colonies

Összefoglalás A tanulmány bemutatja a Jordániában előforduló hamvas sólyom *(Falco concolor)* állományának első, gyors felmérésének eredményeit és a rendelkezésre álló adatokat, beleértve egy előzetes elterjedési modellt is. A fajt 18 helyszínen észlelték, amelyek közül több újonnan felfedezett; az előfordulások elsősorban a szaúdi határ közelében fekvő Hizma-medencében, valamint a déli térségekben és a Holt-tenger-árok peremvidékén fordultak elő. A modell, valamint a legutóbbi terepi felmérések során szerzett ismeretek segítséget nyújtanak egy a fészkelőállományt célzó, szisztematikus állományfelmérés megtervezéséhez, amely alapjául szolgál majd egy monitorozási programnak és e veszélyeztetett faj megőrzését célzó természetvédelmi intézkedéseknek Jordániában. Mivel a dél-jordániai költőállomány feltehetően összefügg a nemrég felmért északnyugat-szaúd-arábiai szárazföldi populációkkal, a szerzők határon átnyúló együttműködést javasolnak, amely javíthatja a faj további állománycsökkenésének megelőzését célzó jövőbeni intézkedések hatékonyságát.

Kulcsszavak: veszélyeztetett faj, elterjedési modell, Közel-Kelet, fészkelőkolóniák

[1] Department of Biology and Biotechnology, American University of Madaba & Jordan BirdWatch Association, Amman, Jordan
[2,4] Jordan BirdWatch Association, P.O. Box 71, Amman 11953, Jordan
[3] Royal Society for the Conservation of Nature, Amman, Jordan
** corresponding author, e-mail: f.khoury@aum.edu.jo*

Introduction

The Sooty Falcon *(Falco concolor)* breeds in the Middle East and north-eastern Africa during the late summer of the Northern Hemisphere and winters in south-eastern Africa and Madagascar. This small falcon feeds mostly on birds and insects. The breeding season extends from July to October and is timed so that nestling provisioning coincides with the autumn migration of small birds. On the mainland, Sooty Falcons' nesting sites appear to be rather scattered, whereas on some islands, aggregations in the form of loose colonies are more common (BirdLife International 2025).

The Sooty Falcon has been categorized as "Vulnerable" on the IUCN Red List since 2017 (BirdLife International 2025). It is also listed in Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and as a Category 1 species under the CMS Raptors Memorandum of Understanding (MoU), as well as in Appendix II of CITES. The global population size has recently been estimated at 1053–1360 pairs (Leonardi *et al.* 2026). Due to lack of data, population estimates may vary regionally and remain inconsistent. Additionally, information on inland breeding distribution and ecology is largely considered incomplete (CMS 2023 and http://www.cms.int/raptors/en/page/agreement-text). Unlike island populations, where nests and birds can be easily located and monitored, inland areas are often vast and less accessible. Thus, one of the main challenges remains assessing inland population sizes and distributions.

The northern border of the Sooty Falcon's breeding range appears to be in Jordan and Palestine, reaching the margins of the Dead Sea (Andrews 1995, Shirihai *et al.* 1996). In southwestern Jordan, it breeds inland and has been observed nesting mainly in hot, arid areas with sandstone cliffs such as Petra, Wadi Dana, and Wadi Rum (Andrews 1995). Since 1995, it has also been observed sporadically during the breeding season along the southern Rift (Wadi Araba) margins at various altitudes, and along the Dead Sea margins (F. K., T. Q. unpubl. data).

The breeding Sooty Falcon population in Jordan had not received significant attention until the current initiative began in 2024. Our recent fieldwork aimed to collect occurrence data for this species, facilitating the modelling of an initial distribution map that will guide future efforts to study the species more accurately. Moreover, gaining insight into various aspects of the landscapes and birds' behaviour will help us plan a systematic and more comprehensive survey.

Methods

We collected and georeferenced records from the literature, including reports of previous surveys conducted in a few areas of southwestern Jordan (Andrews 1995, Khoury *et al.* 2010, and unpublished records of the authors). This included records that were up to 20–30 years old. We also acquired some information from the staff of the Dana and Mujib Nature Reserves, and the Wadi Rum Protected Area. We did not use records published in public biodiversity databases and citizen science records only because they were recorded mainly

along highways, close to areas where the species is suspected or already known to occur, or because the records were not verified by photos or subsequent field visits of the authors. Moreover, the observers were not known to us (visitors/tourists), and misidentification could not be ruled out.

Most of the recent records were collected during a rapid survey by the authors during the 2024 breeding season (August – October). The survey consisted of extended reconnaissance visits and was designed to explore potentially suitable breeding areas within a short timeframe, given limited resources and field researchers/volunteers. During this rapid survey, we visited several areas along the Dead Sea margins and the southern Rift margins, extending south to the Aqaba Mountains and the Qa Hizma area, which includes the Rum Desert and part of the Mudawwara Desert in southern Jordan.

The survey involved travelling on dirt and asphalt roads with limited traffic, following wadis and areas with potentially suitable habitats. In some cases, we covered up to 100 km per day, stopping at sites with cliffs for 15–30 minutes. We did not apply a fixed distance between stops. Due to time constraints, some observations were conducted at different times of the day, including noon, when birds are less active. Additionally, we camped in less accessible areas, allowing for extended observations in the evening and early morning when falcons may be more active. We used binoculars and cameras with 100–400mm zoom lenses to observe and document the birds. A Garmin eTrex device was used to record locations. The survey started in late August 2024 with three days and two observers (one author and one volunteer) observing birds along the Dead Sea Margins, followed by 7 days in September, including four researchers (three of the authors and one volunteer) in the southern Rift Margins, and 7 days in the Hizma Basin during October (three of the authors and two volunteers).

We used Maxent software to model the probabilities of environmental suitability. 17 old and recent presence-only occurrence points were used to construct different models with various combinations of environmental variables. Climatic variables were derived from the WorldClim dataset (http://www.worldclim.org/bioclim.htm), while other environmental variables, such as "slope" (terrain ruggedness) were derived from the DEM layer. The human activity index is a cumulative measure of recent human modification of terrestrial landscapes, based on modelling the physical extents of anthropogenic stressors – including human settlement, agriculture, transportation, mining and energy production, and electrical infrastructure – and their estimated impacts, with a median year of 2016 (Kennedy *et al.* 2020). We excluded bioclimatic variables that correlate strongly with other variables ($r \geq 0.8$). Only climatic variables relevant to the breeding season were included (e.g., BIO5: maximum temperature of warmest month), as well as those potentially affecting vegetation cover and habitat quality (e.g. BIO12: average annual rainfall). All variables had a resolution of approximately 1 km.

In Maxent, we used the "cloglog" output, which provides estimates of occurrence probabilities ranging from 0 to 1 (Phillips *et al.* 2017). Ten replicate models were generated for each variable combination using cross-validation. A regularization factor (beta multiplier) of 1 was selected. The models with different variable combinations were visually compared and found to be highly similar. Some included only bioclimatic

Table 1. Environmental variables used for modelling environmental suitability for breeding Sooty Falcons in Jordan

1. táblázat A hamvas sólyom jordániai elterjedési modelljének elkészítéséhez használt környezeti változók

Environmental Variable	Description
BIO1	annual mean temperature
BIO2	mean diurnal range
BIO4	temperature seasonality
BIO5	maximum temperature of the warmest month
BIO12	annual precipitation
Slope	Index of ruggedness of the terrain
Human activity index	See text and Kennedy *et al.* 2020.

variables, while others incorporated a mix of bioclimatic, topographic, and human development activity variables. We present one of the average distribution models and the AUC of the ten replicates, which included the variables shown in *Table 1*. We used the area under the Receiving Operator Curve (ROC) curve (AUC) to assess model accuracy and performance (Phillips *et al.* 2006).

Results and Discussion

The model we present here indicates where the Sooty Falcon is likely to occur: along the Dead Sea and southern rift margins, in the Rum Desert, and in the western and northern parts of the Mudawwara Desert, as well as the eastern part of the Aqaba Mountains in southwestern Jordan *(Figure 1)*.

The avifauna of the northern part of the Dead Sea margins is frequently surveyed by the authors, and Sooty Falcons have not been recorded there during the breeding season. There is an old record in the Mujib Nature Reserve, located in the central part of the Dead Sea margins, and its breeding occurrence as far north as Wadi Mujib has been recently confirmed by observations and photos of a Mujib Reserve ranger (Maher Al-Lawanseh *pers. obs.*).

Sooty Falcons have recently been recorded along the southern Rift margins, including the Dana and Um al-Amad areas, the Petra Mountains, the Rahma area near Wadi Araba, the Rum Desert, and the western parts of Al-Muduwwara Desert. Our recent fieldwork revealed new breeding areas that were not previously known to host Sooty Falcons, and an apparent concentration in the south near the borders to Saudi Arabia. The habitats consist mainly of hilly or mountainous rocky deserts with sandstone and/or granite outcrops and cliffs. The Falcon species appear to prefer arid habitats with cliffs and rocky outcrops that also contain some flat or open, often sandy areas with sparse vegetation, such as dwarf shrubs *(Figure 2)*. These areas likely provide suitable conditions for hunting small migratory birds. The recorded breeding sites primarily consist of sandstone and/or granite formations.

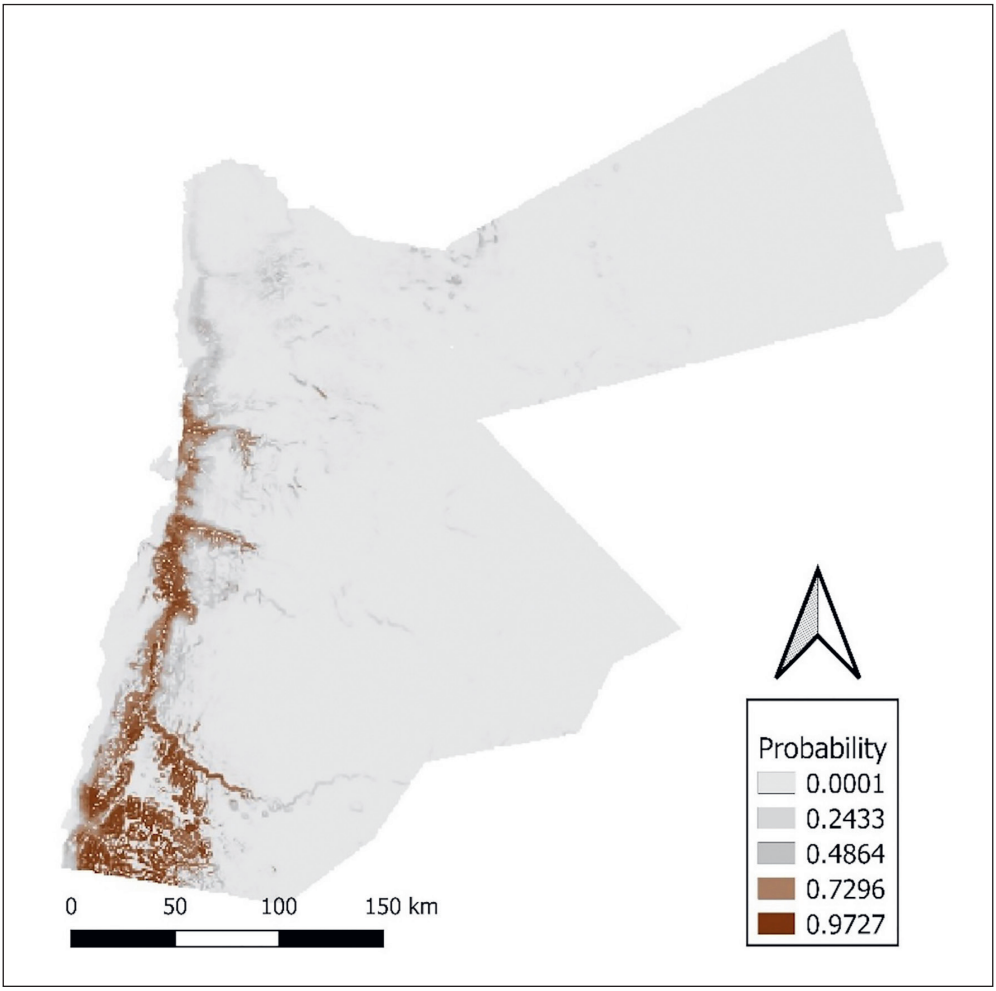

Figure 1. Maxent model showing with probabilities of environmental suitability for breeding Sooty Falcon in Jordan, based on 17 presence-only occurrences

1. ábra Maxent-modell, amely a hamvas sólyom költésére alkalmas környezeti feltételek valószínűségét mutatja Jordániában, 17 előfordulási adat alapján

The main threats to the species include disturbances from human activities, particularly tourism and off-road driving. Overgrazing is also degrading vegetation cover, which could impact the density of migratory passerines – the falcons' primary prey. Additionally, there are plans to mine copper and other metals within its breeding range.

Our fieldwork provided valuable insight into the behaviour and preferred landscapes of breeding Sooty Falcons in Jordan, which will help plan the next population census. The Maxent model is based on only 17 occurrence records, including a few that are over 20 years old, e.g. in the Mujib Nature Reserve near the Dead Sea. Environmental variables used for model construction were clipped to Jordan's borders. Incorporating more data from a broader geographic area, including neighbouring countries, would likely improve

Figure 2. Habitat of Sooty Falcon in Wadi Rum, southern Jordan (Photo: Fares Khoury)
2. ábra A hamvas sólyom élőhelye Dél-Jordániában (Wadi Rum) (Fotó: Fares Khoury)

the accuracy of the model for inland breeding populations. Although the model performed well (AUC=0.986), it is considered preliminary and may not accurately reflect the full breeding distribution of the Sooty Falcon. Nevertheless, this initial distribution map will serve as a guide for planning a systematic survey focused on the species. A more comprehensive and systematic survey will be essential as a baseline for monitoring and conservation efforts.

The most extensive breeding area for Sooty Falcons lies in the extreme south *(Figure 1)*, where the species appears to have a relatively high density, as indicated by the proportion of records from this region (approximately 50% of all occurrences). This suggests that the population is continuous with inland breeding areas further south in Saudi Arabia (e.g. Foster *et al.* 2026). A recent survey in the Neom project area, and AlUla Protected Area estimated that over 50 pairs are breeding there (Foster *et al.* 2026). This finding indicates that inland populations in the region may be larger than previously assumed, highlighting the need for cross-border coordination and collaborative conservation efforts in the future. Moreover, the most recent record of two adults and two juveniles in October 2025 at the Mujib Nature Reserve near the central part of the Dead Sea Margins, which also had a high probability of environmental suitability in the model, could indicate the approximate northern border of its distribution in Jordan and the Middle East.

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