

Breeding distribution of the Vulnerable Sooty Falcon (*Falco concolor*) in northwestern Saudi Arabia, the NEOM region

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Abstract The Sooty Falcon (*Falco concolor*) is a high conservation priority species in Saudi Arabia. The species is classified as Vulnerable globally but is considered Endangered in the Arabian region. A significant portion of the global Sooty Falcon population is thought to breed within Saudi Arabia, but national population estimates have been inconsistent and disputed, complicating population trend assessments. To address this, standardized methods for consistent temporal analysis are essential, particularly as the country continues to expand its tourism development and conservation initiatives. While most publicly available studies on the life history and distribution of the Sooty Falcon have been conducted in Oman and the United Arab Emirates, extensive research is currently underway across Saudi Arabia. This paper presents the most recent and comprehensive breeding distribution data for the Sooty Falcon population within the NEOM region, in northwestern Saudi Arabia. While this species was thought to prefer coastal habitats in Saudi Arabia, surveys conducted in the landlocked Hisma desert revealed several previously undescribed inland colonies. These findings highlight limitations in our current understanding of Sooty Falcon distribution and population dynamics. This two-year baseline study marks a first step toward standardizing local population monitoring, enabling repeated assessments to evaluate population trends over time. Ultimately, these fine-scale distribution data will inform conservation management at the local and regional levels.

Keywords: distribution, breeding ecology, habitat range, nearest neighbor

Összefoglalás A hamvas sólyom (*Falco concolor*) kiemelt természetvédelmi jelentőségű faj Szaúd-Arábiában. A faj globálisan sebezhetőnek (Vulnerable) minősül, az Arab-félszigeten azonban veszélyeztetettnek (Endangered) számít. A globális populáció jelentős része feltehetően Szaúd-Arábiában költ, ugyanakkor az országos állománybecslések következetlenek és vitatottak, ami megnehezíti a hosszú távú trendek értékelését. Emiatt elengedhetetlenek az egységes módszerek az idősoros adatok konzisztens elemzéséhez, különösen most, amikor az ország jelentősen bővíti turisztikai fejlesztéseit és természetvédelmi programjait. Amíg a hamvas sólyom életmenetével és elterjedésével kapcsolatos, nyilvánosan elérhető kutatások többsége Ománban és az Egyesült Arab Emírségekben készült, addig jelenleg Szaúd-Arábia több térségében folynak kiterjedt kutatások. Ez a tanulmány a legfrissebb és legteljesebb képet mutatja be a hamvas sólyom költési elterjedéséről a NEOM térségében, Szaúd-Arábia északnyugati részén. Noha korábban úgy gondolták, hogy ez a faj Szaúd-Arábiában elsősorban a tengerparti élőhelyeket részesíti előnyben, a szárazföld belsejében, a Hisma-sivatagban végzett felmérések több, korábban nem ismertett szárazföldi költőkolóniát tártak fel. Ezek az eredmények rámutatnak a faj elterjedésével és populációdinamikájával kapcsolatos jelenlegi tudásunk hiányosságaira. Ez a két éves alapfelmérés az első lépést jelenti a helyi populációmonitoring egységesítésére, amely lehetővé teszi a költőállomány ismételt, időbeli össze-

hasonlító értékelését. Hosszabb távon ez a részletes elterjedési adatbázis hozzájárul a faj tudományosan megalapozott természetvédelmi kezeléséhez helyi és regionális szinten egyaránt.

Kulcsszavak: elterjedés, kolonialis költés, költésökológia, élőhely-használat, legközelebbi szomszéd távolság

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Introduction

The Sooty Falcon (*Falco concolor*) is a small, migratory raptor whose known breeding distribution aligns with flyways. It breeds both solitarily and colonially on islands and coasts of the Arabian Peninsula and north-eastern Africa, from Egypt to Djibouti. Inland, the Sooty Falcon nests solitarily in discontinuous populations from Libya and Egypt to the west, north to Israel and Jordan, and east to Iran and Pakistan (Leonardi *et al.* 2024, Birdlife International 2026). It is classified as globally Vulnerable but is considered Endangered in the Arabian region, which hosts the largest population (Jennings 2010, Symes *et al.* 2015, Boland & Burwell 2020). However, global population estimates have been inconsistent and disputed, complicating efforts to assess population trends and develop effective conservation measures (McGrady *et al.* 2023).

The estimated global population of Sooty Falcons is currently between 1,400 and 2,000 breeding pairs, with both global and regional populations reported to be decreasing (Jennings 2010, Gallo-Orsi *et al.* 2014, BirdLife International 2026, Leonardi *et al.* 2026). Local population declines have been documented on islands in Oman, the UAE, and Bahrain, where detailed, long-term monitoring has highlighted downward trends (Kavanagh & King 2008, Shah *et al.* 2008, McGrady *et al.* 2017, 2018, 2023). Recently, inland Sooty Falcon populations have been studied in the White Desert National Park in Egypt (Salama *et al.* 2020), and within 12 regions in Israel, where estimated 8–25% population declines were reported in comparison to the previous surveys undertaken in 1986 (Frumkin *et al.* 1993, Goren *et al.* 2023). However, in the Arabian Peninsula, published records of consistent monitoring in recent years are available only for accessible island colonies in the Arabian Sea and the Arabian Gulf, leaving known and potential inland breeding sites under-researched or unexplored. Consequently, information required for accurate conservation assessments remains scarce throughout much of the species' range (McGrady *et al.* 2016).

The Sooty Falcon's chick-rearing stage occurs through the autumn of the northern hemisphere and is synchronous with the migration of songbirds. In the Red Sea, the known breeding distribution of the Sooty Falcon aligns with the confluence of several migratory flyways (Shobrak 2011). The Red Sea population constitutes both the quantitative core of the global population and the geographic centre of the species' breeding distribution (Leonardi *et al.* 2024). The Sooty Falcon is a high conservation-priority species in Saudi Arabia, where a significant portion of the estimated global population nests (Gallo-Orsi *et al.* 2014,

Boland & Burwell 2020). A national population survey focusing only on the coastal Red Sea estimated the Sooty Falcon population in Saudi Arabia to be between 260 and 381 pairs, representing approximately one-third of the minimum estimated global population (Gaucher *et al.* 1995). The survey, conducted in 1991 and 1992, remains the national population estimate, despite the authors' acknowledgment that the aerial methodology likely led to an underestimation (Gaucher *et al.* 1995).

Before the recent emergence of records of more inland breeding, the Sooty Falcon's breeding distribution in Saudi Arabia was thought to be mainly limited to Red Sea islands (Gaucher *et al.* 1988, Jennings 2018). More extensive and recent investigations into inland and coastal nesting sites have gained attention due to conservation initiatives driven by Saudi Arabia's large-scale development projects. These projects, aligned with the country's "Vision 2030", introduce both challenges and opportunities for conservation efforts (Calabrese *et al.* 2024). NEOM, located in the Tabuk region of northwestern Saudi Arabia, is one of the country's largest development projects (Alam *et al.* 2021). The project has committed to adhering to International Finance Corporation (IFC) standards and includes ambitious initiatives to protect critical habitats for high conservation priority species, including the Sooty Falcon. However, data sharing between private and public research entities has been limited, hindering knowledge exchange and impeding the development of comprehensive conservation strategies (McGrady *et al.* 2023). In addition, in the most recent review of Tabuk's biodiversity, the Sooty Falcon was not listed as occurring in the NEOM area (Ansari *et al.* 2022), highlighting discrepancies in recent publications.

Population density can be reliably estimated only from detailed distribution records, and it is essential for accurately assessing population dynamics and evaluating the effectiveness of conservation efforts (Jacquier *et al.* 2021). For example, studies on colonial behavior in the Lesser Kestrel (*F. naumanni*) have demonstrated correlations with breeding success (Serrano *et al.* 2004). However, this relationship remains unexplored in the Sooty Falcon and requires investigation to inform targeted restoration measures, such as habitat protection, enhancement, or creation (Bragin *et al.* 2017, McGrady *et al.* 2017).

This paper presents the most recent data collected by NEOM to provide guidance for long-term monitoring and eventual population trend analysis. Establishing standardized methodologies for detailed yet practical temporal analysis will be crucial as Saudi Arabia continues to expand its conservation and development initiatives. These efforts will help ensure that NEOM's conservation strategies align with its sustainable development goals and that the critical habitats of the Sooty Falcon are preserved within the changing landscapes of the Arabian Peninsula.

Material and Methods

All Sooty Falcon surveys were conducted during the mid-to-late breeding season, from mid-August to early October, in 2022 and 2024, in the inland Hisma Desert and the islands of NEOM, Saudi Arabia. In both survey years, the objective was to obtain comprehensive data on the island populations of Sooty Falcons and to explore the inland desert in search for breeding pairs.

Study area

The Hisma Desert is a historically and culturally significant region in Saudi Arabia. Its basins contain continuous sandy and rocky habitats, with well-vegetated runnels and wadis extending from Wadi Rum in Jordan. The survey site within the Hisma Desert was initially selected based on a review of incidental sightings, eBird reports, unpublished breeding records (Jennings 2018), and known Sooty Falcon breeding habitat characteristics from other countries (Goren *et al.* 2023).

Surveys were also conducted on accessible islands with potential or confirmed breeding activity (Gaucher *et al.* 1995, Jennings 2010). In 2022, Tiran and Sanafir islands were surveyed opportunistically by boat along accessible coastlines, but access was further restricted in 2024, preventing any data collection. Access to Baraqan Island was only granted in 2024. Islands that contained Sooty Falcon nests and were accessible in both the 2022 and 2024 breeding seasons include Yuba, Silah, Waleh, and Shushah. For context of habitat, a brief description of each site is detailed.

- Yuba Island consists primarily of steep ancient reefs rising to 100 m above sea level, with sandy bays at lower elevations. The limestone cliffs contain small caves and crevices that Sooty Falcons use for nesting. Vegetation is sparse, limited to scattered salt-tolerant shrubs.
- Silah Island comprises four low-lying rocky islands containing sandy bays and salt-tolerant shrubs. Sooty Falcon breeding activity has been observed on the largest of the four Silah islands.
- Waleh Island is a raised reef island with most areas between 5 and 10 m above sea level and a peak of 30 m on the western end. The island is predominantly rocky, with scattered vegetation and small sandy bays.
- Shushah Island consists of cliffs and flat areas with rocky overhangs, with much of the interior currently undergoing development. During and before both surveys, it was the only island with Sooty Falcon pairs undergoing development.

Survey techniques

For each survey, a minimum of two observers surveyed Sooty Falcon breeding activity between the hours of 07:00 and 17:00, with breaks during the hottest times of the day. In 2022, a total effort of 21 field workdays was allocated for these surveys, between 3 and 23 October. This included 12.5 days of island surveys (with two visits for each island where Sooty Falcon nests were confirmed) together with 8.5 days of surveys in the inland Hisma area. In 2024, initial island surveys were completed over eight fieldwork days between 20 and 27 August and again for a tagging and ringing effort from 16 to 31 October, where accessible nests were checked for contents and Baraqan Island was surveyed for the first time, since access had been restricted prior to October. The inland Hisma survey was completed in a total of 11 days from 24 September to 5 October.

Breeding status was classified as confirmed, probable, or possible, following Jennings (2010) Atlas of Breeding Birds of Arabia (ABBA). For instance:

- Confirmed pair: nest contents observed, (eggs/young) or adult(s) repeatedly entering the same cavity/ledge with prey during ≥ 2 visits, ≥ 3 days apart.
- Probable pair: repeated (≥ 2 visits) territorial behavior (mobbing, alarm calls, perching at the same ledge) during the core breeding period, within a clearly delineated nesting cliff segment, but nest contents not visible.
- Possible pair: observation of interaction without repeated evidence.

Probable nest sites were revisited at the beginning and end of the season to minimize likelihood of inaccurate location assessments. Behavioral observations indicating territoriality or nesting activity, therefore, contributed to the total number of pairs (labelled as probable), even if nests were not visible. For all unconfirmed pairs, the observers discussed their observations of Sooty Falcon behaviors extensively before classifying them to reduce uncertainty and maintain consistency.

Due to the accessibility of most island areas, surveys on each island were conducted by observers on foot, covering all accessible breeding areas to record GPS locations at nests. Inaccessible cliffs of islands were surveyed from boats using binoculars and cameras. When nests were inaccessible, observers recorded waypoints at their current location along with an estimation of the direction and distance to the observed pair. The same approach was used for the inaccessible nests in the Hisma region. Inland surveys in the Hisma region were similar to the methodology of Goren *et al.* (2023) but were opportunistic based on accessibility and time allotment.

Analysis

Probable nest locations are inferred centers of activity, so results should be treated with caution in interpretation. Since this is an estimation, rather than a complete census, confirmed and probable pairs were summed to estimate the minimum number of breeding pairs. In contrast, possible pairs (recorded only in 2022) were excluded from analysis and were shown only in the spatial display. At inaccessible sites, waypoints were collected at the observation location and manually adjusted in ArcGIS Pro based on the recorded direction and distance from the observer.

For each location thoroughly surveyed and that contained more than one pair (e.g. Yuba, Waleh, Baraqan, Shushah, and the Hisma), a Convex Hull in ArcGIS Pro was created by connecting the outermost points of the locations of confirmed and probable breeding pairs in both years to represent the total area of observed nesting (envelope area encompassing observed breeding locations, in km²). For each year, density within this area was estimated by dividing the number of breeding pairs by the area of the associated Convex Hull. Additionally, for 2022, separate Convex Hulls were created for the two distinct patches (north and south) of observed breeding in the Hisma, based on the spatial separation of observed breeding sites. These Convex Hulls represent envelope areas which encompass the observed breeding locations, rather than breeding habitat area. Therefore, the area used for density is a geometric extent, not mapped habitat, which was not determined in this study. The Average Nearest Neighbor was analyzed in ArcGIS Pro to determine the spatial distribution (reported in mean observed nearest neighbour distance, Nearest Neighbor Index

(NNI), and z-score) between breeding pairs in the total area of each island (Yuba, Waleh, Shushah, and Baraqan) and the Hisma in each survey year. In the Hisma, clusters were delineated when two or more breeding pairs were less than 1.2 km apart, the shortest known distance between inland nesting pairs reported in the published literature (Goren *et al.* 2023). The mean observed distance was calculated for each cluster and averaged to represent the distance between pairs in potential inland “colonies”.

Results

A total of 83 and 108 Sooty Falcon breeding pairs were discovered in the NEOM area in 2022 and 2024, respectively (*Figures 1–6*). In 2022, 19 Sooty Falcon pairs were found in the Hisma, as well as 64 distributed across the NEOM islands (*Table 1*). In 2024, 69 pairs were found within the islands and 39 in the Hisma (*Table 2*). The density of breeding pairs on islands in 2022 was the highest on Waleh Island (33.33 pairs/km²) and lowest on Yuba (18.99 pairs/km²) (*Table 1*). North Hisma contained a lower density of breeding pairs (0.58 pairs/km²) than in the south (0.86 pairs/km²) (*Table 1*). In 2024, the density of breeding pairs in the Hisma was 0.03 pairs/km² overall; the highest density was found in Baraqan Island (135.95 pairs/km²), and the lowest on Shushah Island (19.07 pairs/km²) for the islands (*Table 2*).

The observed mean nearest neighbor distance between pairs in the Hisma was 2.24 km with a Nearest Neighbor Index of 0.62 (z-score=-2.70) in 2022, and 2.60 km (with NNI=0.59, z-score=-4.54) within the whole area in 2024. Three clusters were delineated in 2022, with an average observed distance of 0.28 km. In 2024, the average distance between pairs within

Table 1. Count of Sooty Falcon breeding pairs observed on each island and the Hisma in the 2022 breeding season within NEOM, Tabuk, Saudi Arabia

1. táblázat A 2022-es költési időszakban megfigyelt hamvas sólyom költőpárok száma szigetekre és a Hisma térségére bontva, a NEOM (Tabuk, Szaúd-Arábia) területén

Site name	Confirmed pairs	Probable pairs	Total pairs	Convex Hull area (km ²)	Density (pairs/km ²)
Baraqan Island	Not surveyed	Not surveyed	Not surveyed		
Shushah Island	5	9	14	0.47	29.79
Sila Island		1	1		
Sinafir Island		3	3	0.08	
Tiran Island		2	2	0.01	
Yuba Island	30	3	34	1.79	18.99
Waleh Island	9	1	10	0.30	33.33
The Hisma (cluster 1: North)		7	7	12	0.58
The Hisma (cluster 2: South)		12	12	14	0.86
Grand Total	44	44	88		

Table 2. Count of Sooty Falcon breeding pairs observed on each island and the Hisma in the 2024 breeding season within NEOM, Tabuk, Saudi Arabia

2. táblázat A 2024-es költési időszakban megfigyelt hamvas sólyom költőpárok száma szigetekre és a Hisma térségére bontva, a NEOM (Tabuk, Szaúd-Arábia) területén

Site Name	Probable pairs	Convex Hull area (km ²)	Density (pairs/km ²)
Baraqan Island	12	0.09	135.95
Shushah Island	8	0.42	19.07
Sila Island	1	–	–
Sinafir Island	Not surveyed	Not surveyed	
Tiran Island	Not surveyed	Not surveyed	
Yuba Island	43	1.09	39.63
Waleh Island	5	0.11	44.83
The Hisma (total area)	42	1.58	0.03
Grand Total	108		

the 10 delineated clusters was 0.40 km. In 2022, Yuba Island had the shortest average distance between pairs, with an observed mean distance of 0.07 km (with NNI=0.48, z-score=-5.86), followed by Shushah Island with 0.14 km (with NNI=1.17, z-score=1.224) and Waleh Island with 0.22 km (with NNI=1.98, z-score=5.92). The island with the shortest observed distance in 2024 was Baraqan: 0.08 km (with NNI=1.24, z-score=1.61), followed by Yuba: 0.09 km (with NNI=0.86, z-score=-1.79), Waleh: 0.24 km (with NNI=V, z-score=6.75), and Shushah: 0.25 km (with NNI=1.65, z-score=3.51).

Discussion

Although this study represents the most recent and comprehensive survey of the Sooty Falcon population in NEOM, inconsistencies in the 2023 survey methodology preclude establishing a continuous baseline for future population trend assessments. Additionally, these counts represent minimum estimates rather than a true census, and detectability varied between survey years and locations. While the surveys herein constitute the most substantial information available for the NEOM region to date, future surveys should address methodological inconsistencies if the data described herein are to contribute toward a baseline for assessing local population trends.

Even without several islands included in the surveys, the NEOM area accounts for a significant share of the global breeding population (4.1–7.7%) (Leonardi *et al.* 2026). Yuba Island is identified as the most important known breeding colony for Sooty Falcons within the NEOM islands, due to its location as a migratory stopover island, as well as its extensive cliff habitats and network of wadis, which together support a high abundance and relative density of nests. Similarly, the discovery of numerous breeding pairs in the Hisma Desert highlights the relative importance of inland breeding habitat for the species. Because we did not map all potential nest sites, we cannot determine whether clustering

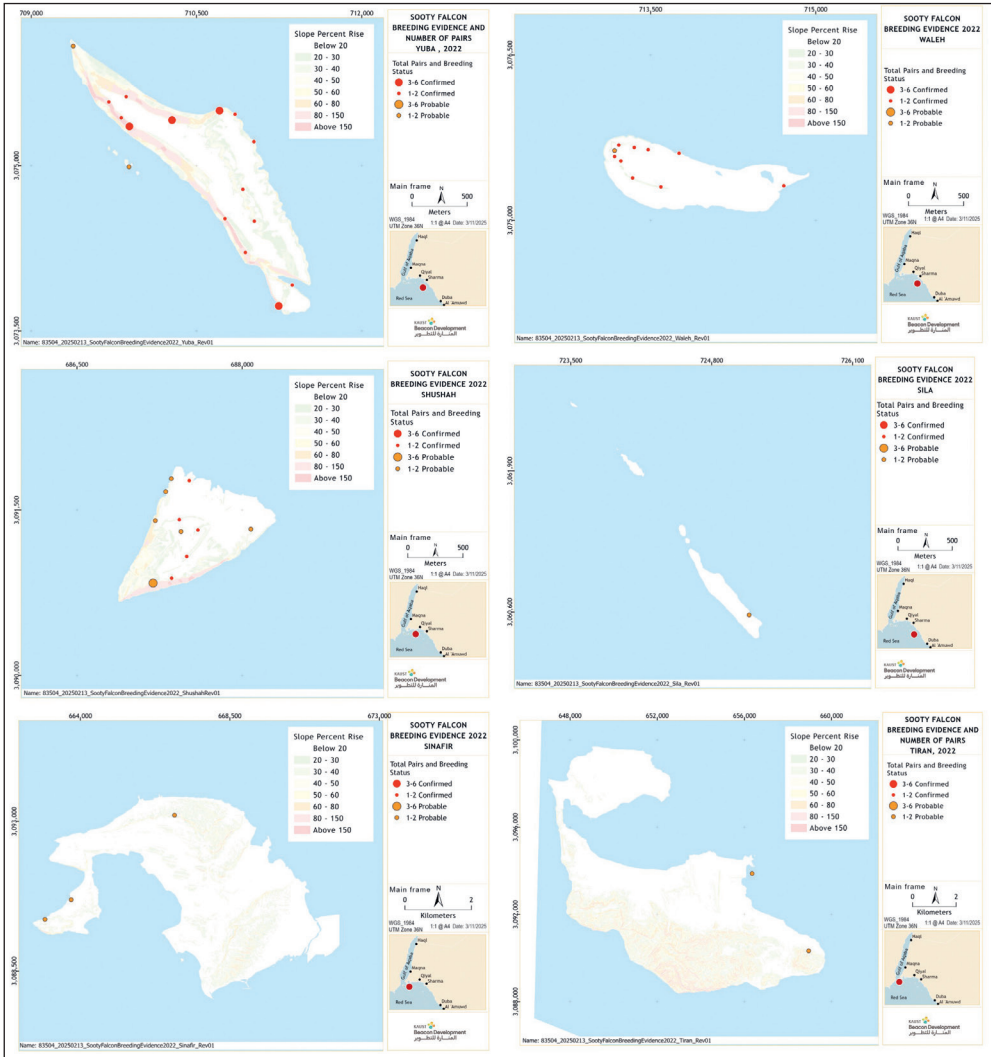


Figure 1. Sooty Falcon breeding distribution on islands in NEOM, Tabuk, Saudi Arabia, in the 2022 breeding season

1. ábra A hamvas sólyom fészkelőhelyei a NEOM szigetein (Tabuk, Szaúd-Arábia), a 2022-es költési időszakban

reflects active coloniality or the spatial configuration of suitable ledges; our NND and NNI values should therefore be interpreted descriptively. Despite this, the observed distance between pairs observed in this inland habitat is relatively close compared to other inland areas, where the minimum distance between nests was 1.2 km (Goren *et al.* 2023). Additionally, the observed pairs were significantly clustered relative to random points within the Convex Hulls; this clustered pattern of breeding pairs in the Hisma may be indicative of coloniality, which contrasts prior assumptions that inland nesting is singular in the Arabian Peninsula (Jennings 2010).

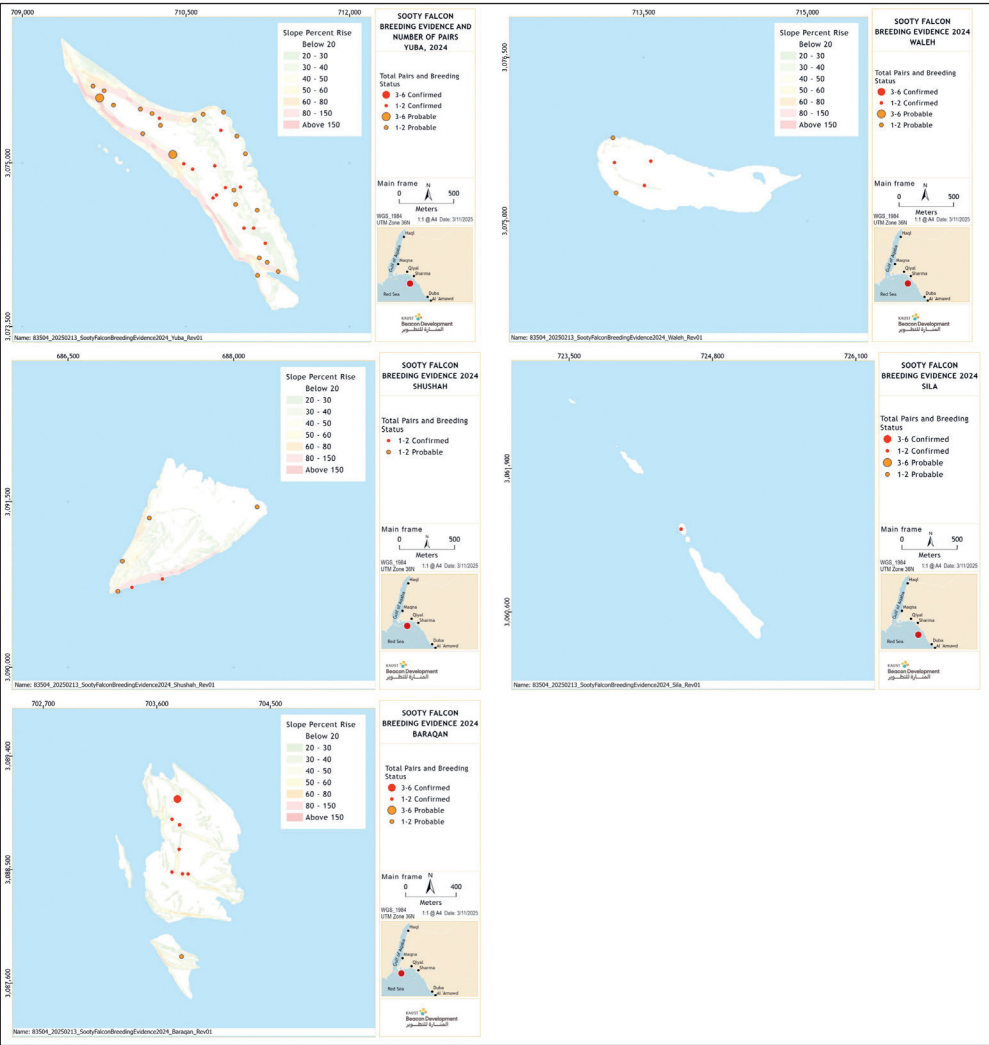


Figure 2. Sooty Falcon breeding distribution on islands in NEOM, Tabuk, Saudi Arabia, in the 2024 breeding season

2. ábra A hamvas sólyom fészkelőhelyei a NEOM szigetein (Tabuk, Szaúd-Arábia), a 2024-es költési időszakban

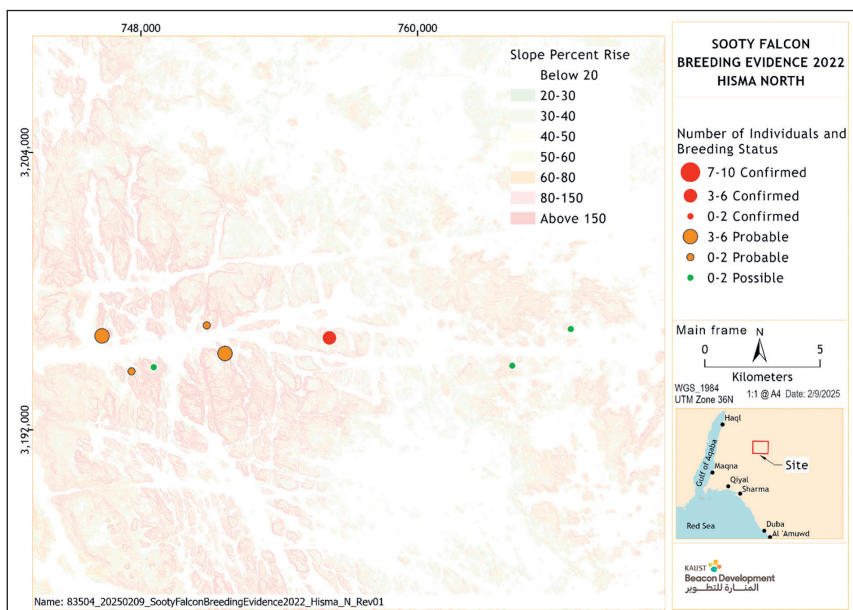


Figure 3. Sooty Falcon breeding distribution in the northern Hisma Desert, NEOM, Tabuk, Saudi Arabia, in the 2022 breeding season

3. ábra A hamvas sólyom fészkelőhelyei a Hisma-sivatag északi részén (Tabuk, Szaúd-Arábia) a 2022-es költési időszakban

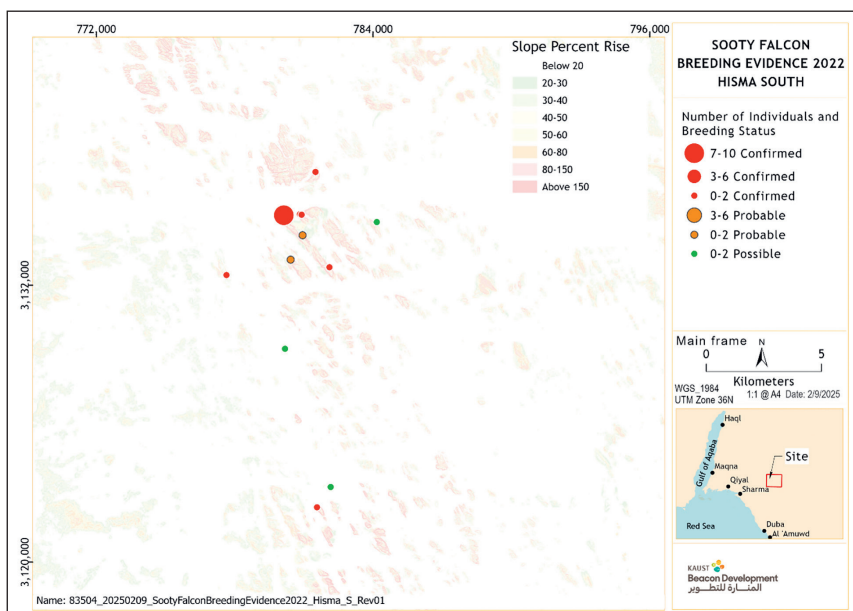


Figure 4. Sooty Falcon breeding distribution in the southern Hisma Desert, NEOM, Tabuk, Saudi Arabia, in the 2022 breeding season

4. ábra A hamvas sólyom fészkelőhelyei a Hisma-sivatag déli részén (Tabuk, Szaúd-Arábia), a 2022-es költési időszakban

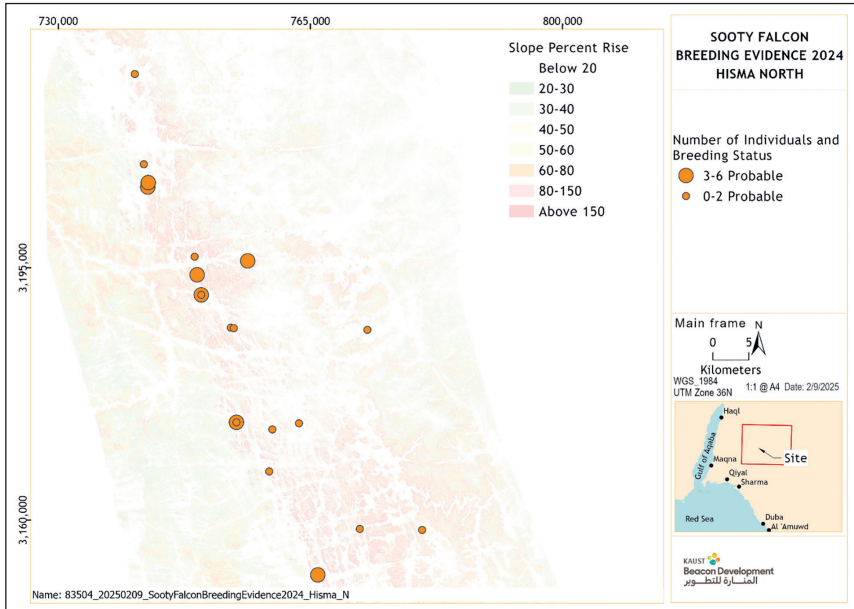


Figure 5. Sooty Falcon breeding distribution in the northern Hisma Desert, NEOM, Tabuk, Saudi Arabia, in the 2024 breeding season

5. ábra A hamvas sólyom fészkelőhelyei a Hisma-sivatag északi részén (Tabuk, Szaúd-Arábia) a 2024-es költési időszakban

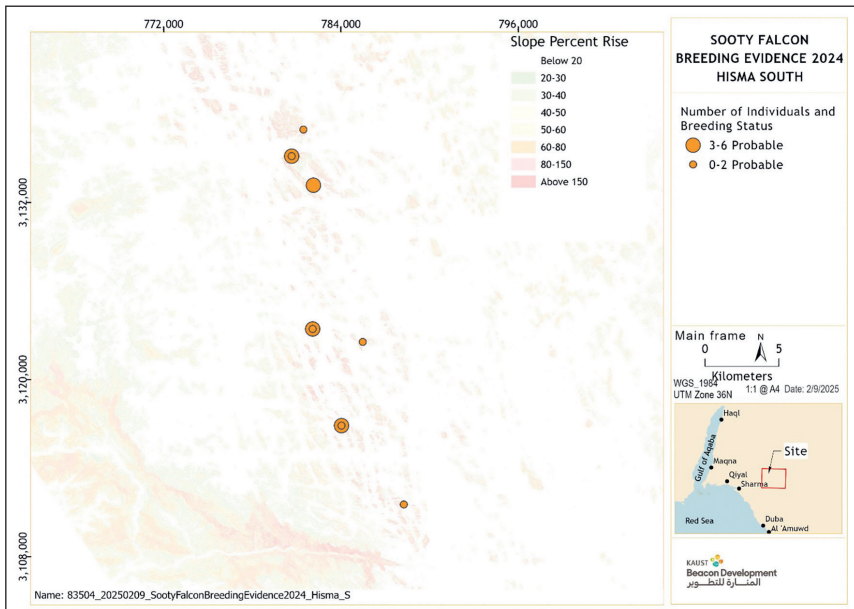


Figure 6. Sooty Falcon breeding distribution in the southern Hisma Desert, NEOM, Tabuk, Saudi Arabia, in the 2024 breeding season

6. ábra A hamvas sólyom fészkelőhelyei a Hisma-sivatag déli részén (Tabuk, Szaúd-Arábia) a 2024-es költési szezonban

This discovery supports the speculation that Sooty Falcon's inland nesting range could extend beyond what was confirmed in the literature prior to this study (Jennings 2010). Consequently, the species' distribution may not be as fragmented or discontinuous as previously thought. While the Red Sea islands remain the known center of Sooty Falcon distribution globally, additional investigations into inland nesting sites, particularly throughout the Arabian Peninsula, are essential for a more complete understanding of the species' range and ecology. Ongoing studies of Sooty Falcon breeding in northwestern Saudi Arabia are likely to add significantly to the known national breeding population (Jennings *pers comm*).

The relatively high nest density and abundance within Yuba Island and the Hisma Desert underscore their importance as key breeding habitats. Other NEOM islands, such as Tiran and Sanafir, may harbor even larger colonies and should be prioritized in future surveys, once access is permitted. As highlighted in regional studies, such as those conducted in Oman, local-scale distribution of the Sooty Falcon is strongly influenced by proximity to foraging areas and prey abundance, as well as by human disturbance (McGrady *et al.* 2019). Although this two-year dataset is not suitable for assessing population trends, it is essential to acknowledge the apparent decline in the abundance and density of breeding pairs on Shushah Island, the only island hosting Sooty Falcons in the NEOM area undergoing development during the survey years. Consistent human presence on Shushah Island may be driving the decline in breeding, as reported in other island colonies with repeated human visitation (McGrady *et al.* 2019). Alternatively, or additionally, breeding could be influenced by potential reductions in nesting or foraging habitat (e.g. cliff overhangs, rocky outcrops, or native vegetation cover) on the island due to development. Further research is needed to evaluate the potential impacts of habitat disturbances on breeding success and distribution. Maintaining healthy prey populations is critical, as low breeding success is correlated with food shortages (McGrady *et al.* 2017).

Consistent monitoring is crucial for exploring population dynamics and trade-offs in nest density, such as heightened intraspecific competition in exchange for enhanced predator deterrence. This study emphasizes the importance of applying standardized survey methods outlined in international guidelines to assess regional and global population trends, which are imperative for conservation planning (McGrady *et al.* 2017). The NEOM dataset serves as a first step toward long-term conservation efforts in this area. However, fine-scale monitoring within accessible colonies should also capture trends in dispersal, nest fidelity, and breeding success to ensure a comprehensive understanding of population dynamics in future research.

The simultaneous development and conservation monitoring efforts within NEOM provide unique opportunities for Sooty Falcon conservation within a changing landscape. For example, protected habitats are being determined, and habitat restoration is being planned at a local level. However, the success of these localized efforts depends on continuous monitoring and adaptive management strategies at national and international levels. Collaboration among stakeholders therefore remains critical to addressing the remaining data gaps and ensuring knowledge exchange is not impeded. The Raptors Memoranda of Understanding and the International Species Action Plan for the Sooty Falcon in 2024 are invaluable efforts to bridge these gaps and ensure cohesive conservation strategies (Leonardi *et al.* 2024).

This baseline for the distribution of Sooty Falcon breeding in NEOM highlights the importance of both inland and island habitats in Saudi Arabia. These new insights into the behavior and distribution of inland populations underscore the urgent need for consistent monitoring and habitat preservation to safeguard this iconic species.

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