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Sooty Falcon *(Falco concolor)* in the northern Saudi Arabian Red Sea: population assessment and conservation

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Abstract This study investigates the phenology, abundance, distribution, and breeding success of the Sooty Falcon in the northern Saudi Arabian Red Sea, focusing on the Al Wajh Bank and An Numan Island. Over four years (2021–2024), surveys identified an average of 58 pairs breeding in critical nesting habitats and population trends, revealing that these areas host 3–4% of the global population and 11.6% of the Arabian Peninsula population. Sooty Falcons predominantly nested in rocky outcrops, with Quman Island accounting for nearly half of the breeding pairs in the Al Wajh Bank. Breeding success varied across years and locations, with overall productivity ranging from 1.34 to 1.80 fledglings per nest. Human disturbance, invasive predators, and climate change were identified as potential threats, with localized declines linked to predator presence. Despite stable trends in some islands, overall population numbers dropped by up to 25% in 2024. Conservation recommendations include habitat protection, biosecurity measures, and invasive species eradication. This baseline assessment contributes to global conservation efforts, highlighting the urgent need for additional monitoring and mitigation to protect this vulnerable species in a rapidly changing environment.

Keywords: phenology, abundance, distribution, breeding success, habitat selection

Összefoglalás Ez a tanulmány a hamvas sólyom fenológiáját, állománynagyságát, elterjedését és költési sikerét vizsgálja Szaúd-Arábia északi Vörös-tengerének térségében, különös tekintettel az Al Wajh Bank és az An Numan-sziget területére. A 2021–2024 közötti négy év felmérései átlagosan 58 költő párt azonosítottak a kritikus fészkelőhelyeken, valamint feltárták az állománynagyság és trendek alakulását. Az eredmények szerint ez a térség a világpopuláció 3–4%-át, valamint az Arab-félsziget populációjának 11,6%-át foglalja magában. A hamvas sólymok túlnyomórészt sziklakiemelkedésekben fészkeltek, és az Al Wajh Bank területén a Quman-sziget adta a költőpárok csaknem felét. A költési siker évek és helyszínek között változott: az összesített produktivitás fészkenként 1,34 és 1,80 kirepült fióka között alakult. A lehetséges veszélyeztető tényezők között az emberi zavarás, az inváziós ragadozók és az éghajlatváltozás szerepeltek, míg a lokális állománycsökkenések ragadozók jelenlétéhez kapcsolódtak. Noha egyes szigeteken stabil trendeket figyeltek meg, 2024-re az összpopuláció akár 25%-kal is csökkent. A természetvédelmi ajánlások közé tartozik az élőhelyek védelme, a biológiai biztonság megteremtése, valamint az inváziós fajok eltávolítása. Ez az alapfelmérés hozzájárul a globális természetvédelmi erőfeszítésekhez, és hangsúlyozza a sürgős igényt további monitorozásra és beavatkozásokra annak érdekében, hogy megóvjuk ezt a sebezhető fajt a gyorsan változó környezetben.

Kulcsszavak: fenológia, állománynagyság, elterjedés, költési siker, élőhelyválasztás

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Introduction

Phenology, abundance, and distribution of breeding birds, along with their breeding success, are crucial baseline parameters for evaluating population trends and dynamics, pinpointing biodiversity hotspots, and identifying potential breeding sites. These factors also contribute to understanding habitat preferences and quality (Sarasola *et al.* 2018, Koleček *et al.* 2020, Kamp *et al.* 2021, Vitasse *et al.* 2021, Lees *et al.* 2022). Worldwide, 49% of bird species have declining populations, while 6% have unknown trends (BirdLife International 2022), therefore, increasing knowledge on these species, and assessing threats on their populations can provide invaluable tools to inform much needed decisions for their conservation and enhancement and reverse negative trends.

In the Red Sea region, birds nesting on islands or in the mainland remain poorly studied, with major gaps in knowledge regarding distribution, population size, and long term trends, largely due to historically uneven survey effort and limited access to offshore sites. (Jennings 2010, Porter & Aspinall 2010, Symes *et al.* 2015, BirdLife International 2024, http://datazone.birdlife.org/site). This is often because they breed in very low density in desert areas or on difficult to access islands.

In Saudi Arabia, out of the 219 bird species breeding in the Kingdom, 26 are regionally and nine globally threatened with extinction (Boland *et al.* 2020). For these species, abundance estimates (if any) date back more than a decade (Jennings 2010) and many should be regarded as broad estimates with high uncertainty (Boland *et al.* 2020).

The Sooty Falcon *(Falco concolor)* is classified as globally vulnerable and regionally endangered on the IUCN red lists, and is a high priority species in Saudi Arabia (Abuzinada 2005, Symes *et al.* 2015, Boland & Burwell 2022). However, these classifications utilise data that are not always comprehensive or accurate and are often lacking across its breeding range (Leonardi *et al*. 2024). In Saudi Arabia, comprehensive data on abundance, distribution and breeding success are still lacking, with the most recent national assessment done in 2010 (Jennings 2010). The difficulty in gathering sufficient data for the species often lies on its breeding ecology, such as the tendency to nest in inaccessible and/or remote locations, which requires high quantities of resources to be monitored.

Across its breeding range, encompassing the Middle East, north-east Africa and southern Pakistan, the Sooty Falcon nests solitarily or in loose colonies. It favours rugged, mountainous desert regions characterized by canyons, cliffs, or small crags. These areas are extremely hot and arid, with minimal vegetation, ranging from sea level to around 800 meters in elevation. Additionally, it breeds on small coral islands where crevices or shaded areas are available

(Orta *et al.* 2020). Uniquely among Arabian falcons, it feeds its offspring on migrant birds traveling southward in the northern hemisphere autumn. For this reason, its breeding season is delayed compared with other bird species, starting in July/August (Jennings 2010).

In the Red Sea region, the Sooty Falcon nests primarily on predator-free islands, from Tiran Island (Saudi Arabia) in the north to the Bab al-Mandab Strait in the south, with hot spots found in the Al Wajh Bank and Al Lith Islands (Gaucher *et al.* 1994, 1995, Jennings 2010). Recent assessments of Sooty Falcon abundance in Red Sea islands have been only carried out for Egyptian islands (Habib 2019), leaving most of the other areas unassessed. The total number of breeding pairs for the Arabian side of the Red Sea was assessed in 2010 by compiling all existing estimates, and resulted in 350 pairs, of which 300 were found in the Saudi Arabian Red Sea (Jennings 2010). The total Arabian population was estimated at no more than 500 pairs (Jennings 2010). These estimates are now 15 years old and should be updated not only in the Arabian Peninsula but across the whole Sooty Falcon breeding range to identify threats and inform conservation actions.

An urgent update of abundance and distribution of the Sooty Falcon (and other birds) is particularly needed across the Saudi Red Sea, which is believed to host between 15 and 21% of the global population (IUCN 2024). This is especially pressing because, within the new Saudi Vision 2030 (a series of goals to be achieved by Saudi Arabia by 2030, https://www.vision2030.gov.sa/v2030/overview/), Saudi Arabia is developing major luxury tourism hubs at different projects along the Red Sea coastline which include plans to develop previously undeveloped islands (Chalastani *et al.* 2020). An accurate baseline assessment is therefore indispensable to identify protection areas and to provide recent estimates to update global bird databases. This updated baseline will also be important to inform the Saudi Green Initiative targets to protect 30% of Saudi Arabia land and sea and to implement important wildlife conservation goals (Protecting Land & Sea | Saudi Green Initiative Target).

The objectives of this study were to i) assess phenology distribution, abundance, breeding success, preliminary trend and habitat selection of the Sooty Falcon in the northern Saudi Red Sea and assess the importance of this area for the species; ii) identify threats and give recommendations for the conservation of this species in the Red Sea.

Materials and Methods

The study was conducted across the three islands south of Duba (27° 6'N, 35° 45'E, from now on called Duba Islands) and the 92 islands comprised in the Al Wajh Bank (25° 35'N, 36° 45'E) in Saudi Arabia *(Figure 1)*. The Duba islands include two low-lying and sparsely vegetated sandy islands less than 3 hectares (ha) and one bigger island of about 558 ha (An Numan). An Numan is a rocky outcrop surrounded by lowland and low beach dunes with sparse salt-tolerant vegetation. The Al Wajh Bank stretches from Al-Dahara Island in the north to the southernmost island of Qardala. The size of the Al Wajh Islands spans from less than 1 ha to more than 1600 ha. All the islands have sparsely vegetated sandy substrate, 52 of them have mangroves, and 12 include rocky outcrops. The two study sites were chosen due to their historical importance as breeding sites for Sooty Falcons and the presence of suitable nesting

habitats, as well as their inclusion in a planned development area. On islands, Sooty Falcons typically nest in exposed coastal environments, selecting natural cavities, shallow crevices, or ledges within rocky outcrops, low to high cliffs, or consolidated coral formations, often with minimal vegetation cover and clear access to open airspace. Climatically, the breeding period (August to October) in the study area is characterized by very high temperatures and virtually no rainfall: mean daily highs typically exceed ~35 °C in August and remain above ~32 °C through October, with average minimum temperatures above ~26 °C, and negligible precipitation throughout this period (WeatherSpark 2024). Surveys for this study took place annually from 2021 to 2024. In 2021, all islands of the Al Wajh Bank were visited to assess suitable Sooty Falcon habitat and the presence of breeding pairs. The main criteria for suitable habitat was the presence of rocky outcrops or cavities that could provide shelter. From 2022 to 2024, only the islands with suitable habitat were visited during the identified season. However, all islands were visited every summer (July and August) for the annual seabird census (see Calabrese *et al.* 2024) and Sooty Falcons were also searched for, to ensure that potential use of alternative habitat types was not overlooked. The Duba Islands were visited from 2022 to 2024. Visits started in August and were timed to assess the start and the peak of egg laying. The census was carried out late August/beginning of September, coinciding with the hatching of the first eggs laid, and including late breeders in the count. The count was conducted by direct nest identification during ground surveys, with two to five field workers systematically searching the whole surface of each island (Bibby *et al.* 2012). When found, occupied nests were marked with unique numbers, GPS coordinates, and tracked year-on-year, with new nests assigned new numbers. If the nests were accessible, their content was noted and the number of eggs and/or nestlings (and age) recorded. On An Numan Island, most nests were not accessible, but they were detected by the constant mobbing of the breeding adults at the nesting site.

For each breeding attempt found, the general nesting habitat was recorded and classified into the following categories: rocky outcrops derived from ancient or fossil coral reefs, vegetation and shrubs, and mangroves. Because Sooty Falcons do not build nests and rely exclusively on pre-existing substrates, the spatial distribution of breeding pairs is inherently constrained by the availability and spatial arrangement of suitable nesting habitat.

Nearest neighbour analysis (Boots & Getis 1988, Dale & Fortin 2014) was conducted for each island with more than one nest and for each breeding season to describe spatial patterns of occupied nest sites. For each island-year combination, mean nearest neighbour distance (NND) was calculated as an indicator of average spacing among breeding pairs. To assess whether NND differed significantly within the same island across years, we performed one-way ANOVA. To evaluate whether occupied nests were more clustered or dispersed than expected under a random spatial distribution, the Nearest Neighbour Index (NNI) and associated Z-score were calculated.

Because NNI and NND assume spatial homogeneity and do not explicitly account for the distribution of available nesting substrates, results should be interpreted as descriptive indicators of the spatial pattern of occupied sites rather than direct evidence of behavioural spacing preferences. Temporal comparisons may also be influenced by interannual variation in breeding pair numbers. Given the limited number of breeding seasons analysed (four years), this approach provides an exploratory assessment of spatial consistency rather than

a statistically robust test of long-term trends. All analyses were conducted using the open-source software R (R Development Core Team 2024).

Breeding success was monitored by counting the number of eggs in each nest during the initial visits and carrying out follow-up visits around every two weeks until the end of the season. Follow-up visits allowed for the counting and aging of nestlings, which provided data on clutch and brood sizes, hatching success and fledging success. These visits also included nestling colour ringing to aid in individual tracking. Productivity was determined as the mean number of fledglings per recorded breeding attempts. ANOVA and Tukey's HSD test were used to assess differences in productivity between islands and years. Analysis were performed using R (R Development Core Team 2024).

Results

The Sooty Falcon breeding season in the Al Wajh Bank began in August each year, with the first eggs typically laid during the second week of the month. In 2024 the breeding season started at least 10 days earlier than 2021–2023, with the first eggs present already at the end of July/beginning of August. For the Duba Islands, information on phenology is missing due to the inaccessibility of most nests.

Breeding Sooty Falcons were found only on one of the Duba Islands (An Numan) and on 10 islands of the Al Wajh Bank *(Figure 1, Table 1)*. Only those islands were found to provide suitable nesting habitat for the species one of which, was an artificial nesting site, (Calabrese

Table 1. Abundance of the Sooty Falcon, in terms of number of breeding pairs, per each island and each year of survey in the Al Wajh Bank and An Numan island (Saudi Arabia)

1. táblázat A hamvas sólyom párokban kifejezett állománya az Al Wajh Bank és An Numan szigeteken (Szaúd-Arábia), évenkénti és szigetenkénti bontásban

Coordinates	Island	Number of breeding pairs				
		2021	2022	2023	2024	average
25°33′33″N , 036°50′52″E	Quman	20	21	20	18	19.75
25°45′22″N , 036°32′37″E	Ghawar	7	9	10	3	7.25
25°37′52″N , 036°30′26″E	Breem	5	5	5	4	4.75
25°22′06″N , 036°53′48″E	Sheybarah South	3	6	6	2	4.25
25°27′07″N , 036°59′21″E	Suwayhill	2	4	3	3	3
26°03′57″N , 036°28′55″E	Mardunah	1	1	1	2	1.25
25°27′29″N , 037°00′07″E	No Name	1	1	1	1	1
25°27′51″N , 037°01′07″E	Al Numiniat 2	1	1	0	0	0.5
25°27′51″N , 037°01′07″E	Al Numiniat 1	0	0	0	1	0.25
25°27′13″N , 037°01′30″E	Al Numiniat 3	1	0	0	0	0.25
TOTAL	10	41	48	46	34	42.25
27°06′36.1″N , 35°46′05.4″E	An Numan	N/A	18	15	13	15.33
GRAND TOTAL	11	N/A	66	61	47	58

et al. 2026). On An Numan, the number of breeding pairs across the three monitored years varied between 13 and 18 with an average (±SD) of 15.33 (±2.52) *(Table 1)*. At the Al Wajh Bank the average breeding pairs across the four years of study was 42.25 (±6.24) with the minimum number recorded in 2024 and the maximum in 2022 *(Table 1)*. The average number of Sooty Falcon breeding pairs across the two sites (excluding 2021, when the Duba Islands were not monitored) was 58 (±9.85).

Across the study area, the nesting sites consisted solely of rocky outcrops, notably carbonate rocks from ancient coral reefs *(Supplementary material 1)*; and no nests were observed under vegetation or mangroves. On An Numan Island most of the nests were not accessible, being under unstable ledges about 10–20 m high. Most of those nests were distributed along the eastern side of the island with only few nests located in the south-west and south-central cliffs *(Figure 1)*. At the Al Wajh Bank almost all the nests were on the ground, shaded by low rocky outcrops ledges about 50 cm to 1 m high *(Supplementary material 1)* includes some pictures of Sooty Falcon nests on Quman Island. The only exception was Mardunah Island, where the nests were in an inaccessible high cliff. Considering the whole study area, the highest number of nests were recorded on Quman and An Numan Island, hosting 34% and 26% of all breeding pairs respectively. Within the Al Wajh Bank, the island with the

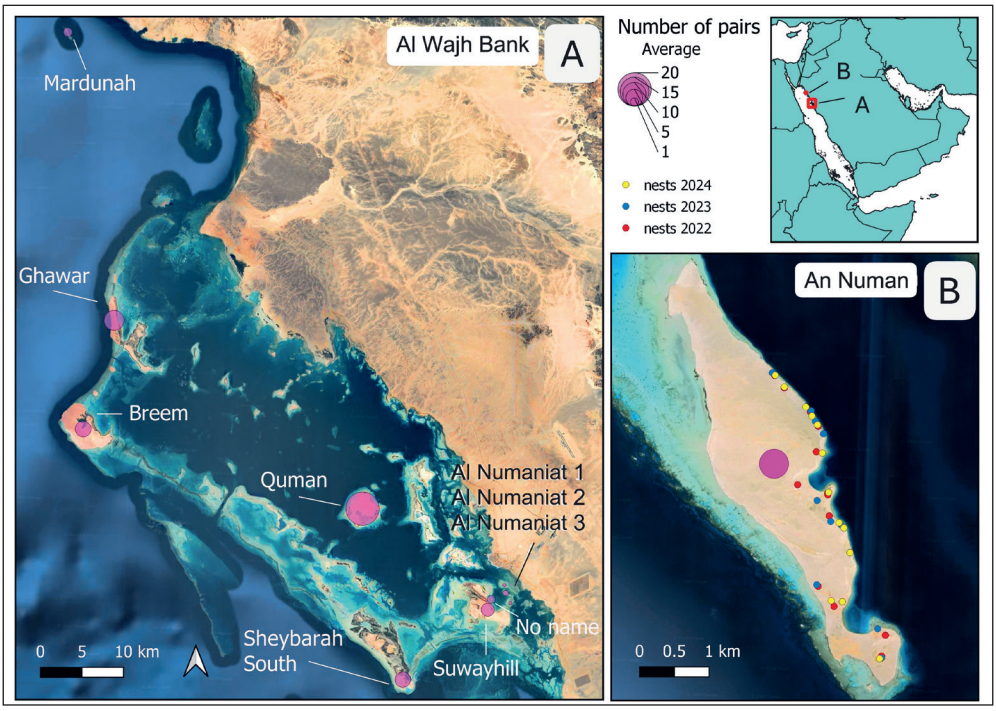

Figure 1. Maps of the study sites representing: A= Average number of Sooty Falcon breeding pairs over the period 2022–2024 on An Numan Island and location of the nests, B= Average number of Sooty Falcon breeding pairs over the period 2021–2024 per each island of the Al Wajh Bank

1. ábra A vizsgált helyszínek térképei: A= A hamvas sólyom-költőpárok átlagos száma a 2022–2024 közötti időszakban An Numan szigetén és a fészkek elhelyezkedése, B= A hamvas sólyom költőpárok átlagos száma a 2021–2024 közötti időszakban az Al Wajh-part egyes szigetein

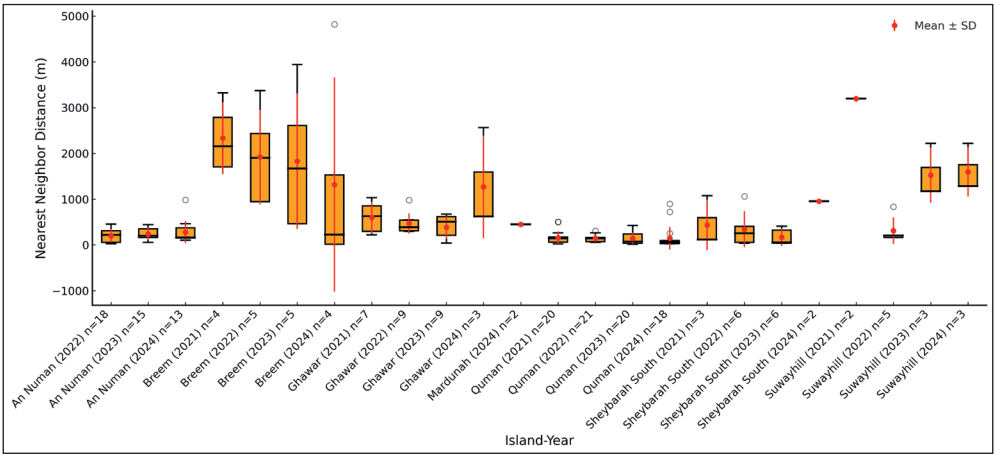

Figure 2. Nearest Neighbour Distance of Sooty Falcon nests per each year of survey and island
2. ábra A hamvas sólyom fészkek legközelebbi szomszéd távolsága évenként és szigetenként

highest proportion of nests across the four years of surveys was Quman (47%), followed by Ghawar (17%), Breem (11%), Sheybarah South (10%), Suwayhill (7%) and Mardunah (3%). The other islands had only one nest each *(Table 1)*.

The distribution of nests seemed more colonial on certain islands than others. In islands with more than one nest, it was possible to calculate nearest neighbour distance (NND) between nests for multiple years *(Figure 2)*. For a better interpretation of the results, *Table 1* shows the number of breeding pairs on each island in each year of the survey. The minimum NND overall was found on Breem in 2024, at 12.8 m, followed by Quman in 2023 at 17.0 m, all distances are shown in *Supplementary material 2*. Breem was also the island where the maximum NNDs were found: 4.8 km in 2024 followed by 3.9 km in 2023. There was no significant difference in NND within the same island across years except at Ghawar ($p=0.027$, $F=3.63$) and Suwayhill ($p=0.0001$, $F=22.72$). The results revealed substantial differences in spatial patterns, with overall mean distances (±SD) ranging from 141 m (±124) in Quman to 3199 m (±0) in Suwayhill, indicating varying degrees of clustering and dispersion. The analysis of NNI and *z-score* assessed that nests were always significantly clustered (across years) only in Quman and always significantly dispersed in Breem, Ghawar and Mardunah. A mix of significant clustering and dispersion was found in Suwayhill, and clustering and dispersion were found significant only for 2 years in An Numan and 3 years in Sheybarah South respectively *(Supplementary material 2)*. We are aware that the NNI and NND are more reliable and statistically meaningful at 10 or more points, therefore these results should be taken as only an indicative distribution of Sooty Falcon nests at this stage. Moreover, the suitable habitat is limited on certain islands, and the clustering can be a result of the distribution of the nesting habitat. *Supplementary material 3* show the distribution of nests in each island and an attempt to show the suitable nesting habitat. In certain islands, like Breem, Ghawar and partially Quman, there is enough breeding habitat for pairs to breed solitary. In the former two islands they are indeed more dispersed, while in the latter the breeding pairs could breed solitary, or at least with more distance between the nests, but they don't.

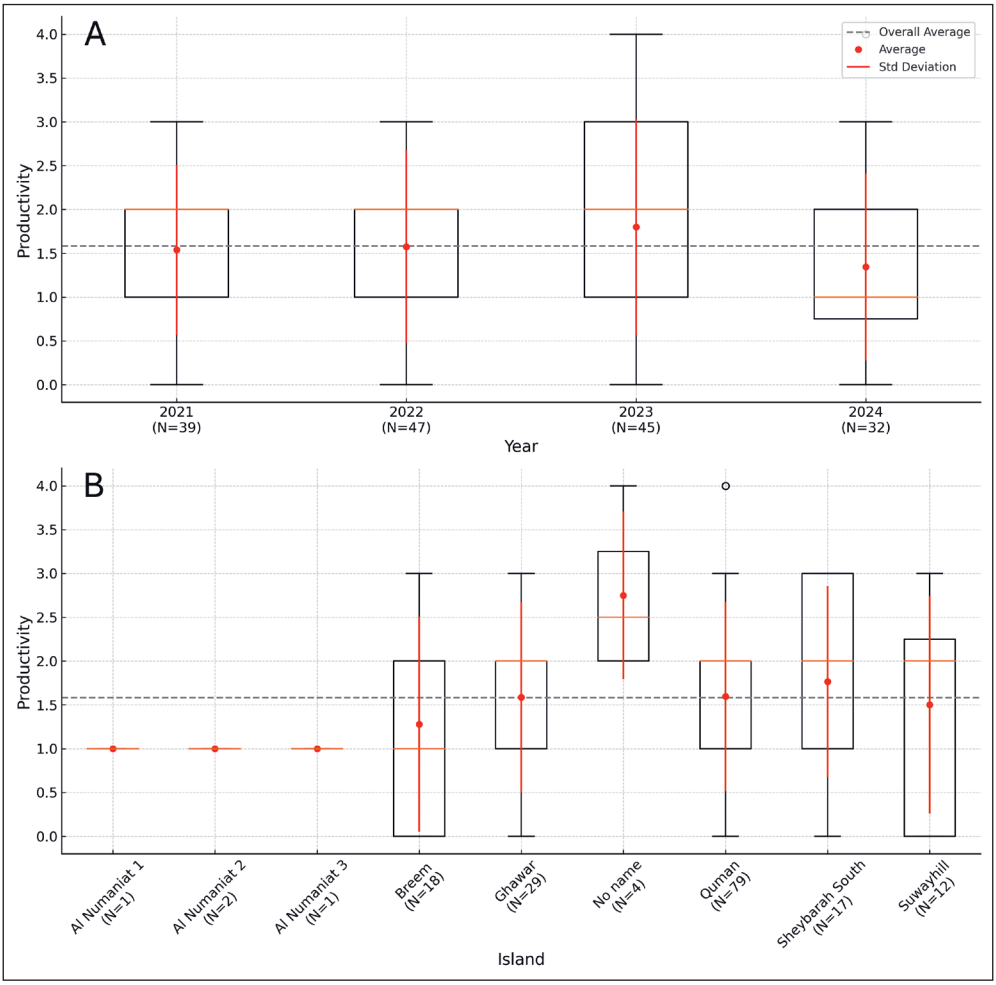

Figure 3. Comparison of productivity (average number of fledglings per recorded breeding attempts grouped by year (A) and by island (B). n = number of nests

3. ábra A produktivitás összehasonlítása évenként (A) és szigetenként (B). n = a fészkek száma

Of the 214 nests censused during the four years of survey, only the 163 located on the Al Wajh Bank Islands were monitored to assess breeding success and productivity. This because nest accessibility was limited on An Numan and Mardunah. Clutch size ranged from one to four eggs with a mean (±SD) of 2.48 (±0.77, n=143 nests). Brood size varied from one to four nestlings with a mean (±SD) of 1.82 (±0.82) if all monitored nests are considered (n=163). If nests that hatched no nestlings are excluded, the mean (±SD) brood size is 2.19 (±0.82, n=136). More failures occurred at the egg stage (116 eggs) compared to the nestling stage (40 nestlings). Overall hatching success (number of nestlings hatched/number of eggs laid) was 68% and fledging success (number of nestlings fledged/number of nestlings hatched) was 87%. Of the 163 monitored nests during 2021 to 2024 seasons, 136 (83%) hatched at least one nestling, of which 126 (93%) produced at least one large nestling

that could fledge. 77% of the monitored nests fledged at least one nestling. Productivity ± SD (average number of fledglings per productive nest, as indicated by McGrady *et al.* 2017) was 2.05±0.79 per nest. However, if failed nests are included, productivity (±SD) decreases to 1.58 (±1.10) per nest, most likely providing a more valid representative of true productivity (this will be the parameter used for further analysis and comparisons).

Across years, average island-level breeding success (percentage of nests that fledged at least one nestling) ranged from 75.8% to 86.6%, while across islands it ranged from 62.5% to 100%. Similarly, the average number of fledglings per nest varied between 1.50 and 1.68 across years and between 1.00 and 2.75 across islands.

The most productive year (if calculated as total number of nestlings fledged/total number of nests monitored for breeding success) was 2023 (1.80±1.22) followed by 2022 (1.57±1.09). However, 2021 was the year where more nests fledged at least one nestling (79%) whereas 2024 had the lowest breeding success at 75%. Sheybarah (1.76±1.06), Quman (1.59±1.08) and Ghawar (1.59±1.07) were overall the most productive islands *(Figure 3)*, excluding islands with only one nest per year); however, Sheybarah showed a decline in fledging success in 2024, with one out of the two nests being unsuccessful. Overall, there was significant difference in productivity between islands (ANOVA $F=3.27$, $p=0.03$), however the only significant pairwise difference was between Breem and 'No name' islands ($p=0.02$) with Breem productivity lower than 'No name' *(Figure 3B)*. Islands with less than three nests across the study period were excluded from the analysis. We did not find any significant difference in productivity between years ($p > 0.05$) *(Figure 3A)*.

Discussion

The breeding season of the Sooty Falcon in the Al Wajh Bank Islands, always starting in August, and with the majority of eggs laid around mid-August, was slightly delayed compared to previous reports of egg laying starting in late July across the Arabian Peninsula (Jennings 2010) and in Egypt (Habib 2019). Notably, the relatively early breeding season in 2024, being 7–10 days earlier than in 2021 to 2023, coincided with an unusually hot year in which temperatures rose rapidly early in the year (coralreefwatch.noaa.gov). Further study could provide valuable insights into the potential impacts of warmer and earlier summers on breeding timing and success rates, for example by altering the timing of peak southbound autumn migration of prey species.

Based on best estimates published in 2010 (Jennings 2010, BirdLife International 2021), our study area would hosts 3 to 4% of the global population and 11.6% of the Arabian peninsula population, of which 2–3% and 8.5% are in the Al Wajh Bank respectively (half of which is concentrated on Quman Island). The area also hosts 16.6% and 19.3% of the Arabian Red Sea and Saudi Arabian Red Sea population, respectively. More recent global estimates (Leonardi 2026) report a global population of 1206 (1053–1358 CI) breeding pairs. In such case the importance of our study area population increases having 4.8% of the global population, of which 3.5% in the Al Wajh Bank alone. Therefore it is clear that the Al Wajh Bank and An Numan island area is still a stronghold for the Sooty Falcon in the Red Sea and globally. The

importance of our study islands for the species probably reflects the strategic location, which is relatively close to the African continent, and closer to Madagascar sites where Sooty falcon spend the northern hemisphere winter than most known breeding sites in the Arabian Peninsula. The islands also provide a largely predator-free breeding area, therefore with reduced nesting sites failure and abandonment. Although quantitative information is not available, our own impressions along with the high abundance of breeding pairs and good breeding success, may also reflect high availability of migratory birds passing through the area during the breeding season. Additionally, as the highest density of breeding pairs recorded on the Egyptian side of the Red Sea was at Wadi el Gemal (Habib 2019), at the same latitude as the Al Wajh Bank, the northern Red Sea is confirmed particularly important for this species.

Although timeseries data are limited, where quantitative data are available, Sooty Falcon populations have declined: by 60% in 13 years in UAE (Shah *et al.* 2008), 33% in eight years in Bahrain (Kavanagh & King 2008), 27–33% in nine years in Oman (McGrady *et al.* 2023), and 27% in 15–20 years in Egypt (Habib 2019). Declines are also suspected in Israel (Goren *et al.* 2023).

Against that background, the decline in Sooty Falcon breeding pairs on in the Al Wajh Bank observed in 2024 is concerning. However, we cannot know if this represents a persisting decline or just natural year to year variability. The decline mostly occurred on Sheybarah South and on Ghawar, respectively 73% and 65% lower in 2024 than the average of the previous three years. The causes of those declines are not clear, but, on Sheybarah South, construction activities not far from breeding sites could be factor. There, the number of adults counted in 2024 was 12, comparable with the number recorded in previous years, but adults were not actively mobbing, and only two pairs were found with nests. All visits were carried out during the same phenological phase, at egg-laying stage. Sooty falcons had successfully nested on Sheybarah from 2021 to 2023 despite the development, with one nest only 170 m away from a construction road in 2022 and others about 1 km from construction activities. However, construction intensified in 2024 before the resort's completion at the end of the year, and so increased disturbance may have deterred some breeding pairs from nesting. Cats were also recorded on the island for the first time at the end of 2023 and one nest was predated at nestling stage in 2024. Most of the cats were removed during 2024 with one remaining loose until it was removed before the beginning of the 2025 breeding season. On Ghawar, we suspect the population decline is related to presence of Black Rats *(Rattus rattus)* there; as it is the one Sooty Falcon breeding island in our area where rats have been recorded. Disturbance and invasive predators are known to be deleterious elsewhere. In Bahrain, Sooty Falcon doesn't breed on Hawar Island due to the presence of feral cats, and no longer breed on Zarka, Dalma and Sir Bani Yas Island in the Gulf due to a combination of the oil industry and sizeable human populations establishing there since about 1980 (Jennings 2010). 2024 was also much hotter than previous years, with summer coming earlier in the year than typical (coralreefwatch.noaa.gov), which could also have contributed to low breeding numbers that year. On islands such as An Numan, where construction activities have yet to start and predators are absent, low numbers in 2024 could be related to a range of factors including a decrease of food availability or migration shift, low recruitment and mortality at migration and/or wintering locations that we have no data on.

Habitat preference in our study were consistent with what has been recorded in previous studies (Booth 1961, Clapham 1964, Walter 1979, Semere *et al.* 2008, Goren *et al.* 2023) with crevices and rocky outcrops being the preferred nesting habitat. We didn't find any nests in vegetation or mangrove, similar to other studies in South of Saudi Arabia, Eritrea and Egypt (Gaucher *et al.* 1994, Semere *et al*. 2008, Habib 2019). The distribution of breeding pairs across the study area is probably dictated by a combination of availability of nesting sites (crevices in rocky outcrops) and the locations of areas with high prey influx. Although Ghawar and Breem Islands have abundant suitable nesting habitat, Sooty Falcons were only found to be highly colonial on Quman Island, probably due to the central position of the island within the lagoon and the limited availability of suitable nesting habitat there and on other islands in that sector. On Quman, the overhanging ancient coral reef facing north was preferred to the same habitat facing east. This could be due to cooler temperature in north-facing nests from direction of prevailing winds, and greater visibility of prey, which also predominantly come from the north. On Quman and Breem, nests were also found very close to each other (minimum distance 12.8 m and 17 m respectively), much closer than NND in the Negev desert in Israel (closest nests 1.2 km apart, Goren *et al.* 2023), but at a comparable distance with what was reported by Gaugher *et al.* (1994) in the South Saudi Arabian islands where mean NND was 25 m with minimum of 7 m. Jennings (2010) also reported that on Hazwarah and Jun Islands 11 and 13 nests respectively were found along one km of coastline. However, such differences in NNI and NND for Sooty Falcons among breeding locations could reflect constraints from the distribution of suitable nesting habitat rather than active nest-site selection. Consequently, observed patterns may not reflect intrinsic behavioural spacing. Quman may also be preferred because of its proximity to preferred foraging grounds, which are mainly inland, since the coast is only about 12 km from the island (Calabrese *et al. in prep.*). The relative stability of the breeding population on Quman corroborates our understanding of this island as a highly suitable breeding location. However, despite the number of pairs being stable, productivity there was slightly below the study average in 2021, 2022 and 2024. This could be linked to the presence of mice on Quman, as associated disturbance to ground nesting birds in other parts of the globe (Cuthbert & Hilton 2004, Bolton *et al.* 2014). It could also be linked to greater competition for prey or resources among breeding pairs on the island. How these and other are influencing Sooty Falcon breeding success at our study sites and globally remain worthy of further study.

In terms of breeding parameters, the overall clutch size found here tends to be slightly lower than most previous studies (summarized in McGrady *et al.* 2017). However, all studies so far (including ours) must work with temporally and/or spatially limited datasets and a low sample size (maximum of 100 monitored nests in previous studies), therefore the following direct comparisons between surveys should be taken with precaution. The brood size presented here for 136 nests that hatched at least one chick (2.19±0.07 or 2.19±0.82) is comparable with what was reportedfor 130 nests surveyed in Oman over 8 years (2.11±0.07, McGrady *et al.* 2017). However, fledglings per successful nest (the parameter used in McGrady *et al.* 2017, that excludes failed nests) was 2.05±0.07 in our study, lower than 2.43±0.06 reported from Oman. The other breeding study we know of from Saudi Arabia

(Gaucher *et al.* 1994) for islands north of Al Lith reported average clutch size of 2.34, fledging success of 86.7% and productivity of 2.02 – all of which are higher than found in this study except for clutch size. However, the number of monitored nests in Gaucher *et al.* (1994) is also lower (81 in three years) than the numbers monitored here. Therefore, breeding and demographic parameters in the Al Wajh Bank may be somewhat lower than other locations, but it is also possible that these differences represent wider decline in such parameters over time, given other studies are based on surveys made more than 7 years, often more than 20 years earlier.

Conservation implications and Conclusion

Our study provides a baseline assessment of population size, distribution and breeding success for the Sooty Falcon population in the Al Wajh Bank and An Numan Island, essential information for conservation and management of this regional stronghold. The main natural predators of raptors such as large owls, carnivores and corvids (Sarasola *et al.* 2018) are naturally absent from our study islands, and so the identified potential threats to falcon populations here come from risk of habitat loss and disturbance as a results of future development, nest-predation by invasive pests, and bycatch or actual targeting from poaching of other falcon species along the coast (Calabrese *pers. obs.*). Currently, important Sooty Falcon nesting islands in the area are not scheduled for further development, so the most important actions to benefit local populations are provision of additional nesting habitat on islands where that is currently limiting, law enforcement to stop illegal killing and capturing of Sooty Falcons along the coast, and complete removal of invasive pest species brought to islands accidentally or deliberately. Additionally, biosecurity plans and preventive measures to avoid the spreading of such species across islands, are critical across the whole area. Notably, Ghawar Island, one of the very few Al Wajh Islands with rats, experienced the greatest decline of Sooty Falcon nesting pairs in our study. As previous studies on rat eradication have shown increases in ground nesting seabirds up to 12-fold (Saunier *et al.* 2024) and high benefits for land birds (Croll *et al.* 2016). There is strong reason to believe that eradication on Ghawar would lead to significant recovery.

More generally, dedicated surveys programs, enhancement of nesting habitat, stopping the illegal trapping of the species along the coastline, as well as eradication of invasive pest species on islands and adoption of strict biosecurity measures are likely the most important conservation actions for the Sooty Falcons across Saudi Arabia. We therefore recommend that the country strategy for the species will lean towards these important actions in the future.

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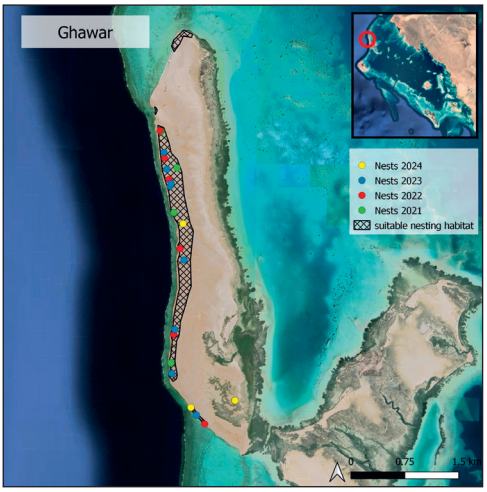
Supplementary material 1. A and B example of Sooty Falcons nests under carbonate rock outcrop. C and D: examples of suitable habitat for Sooty Falcon on Al Wajh islands, which is rocky outcrops, notably carbonate rocks from ancient coral reefs
1. melléklet A és B: hamvas sólyom fészkek karbonátos sziklák alatt, C és D: hamvas sólyom megfelelő élőhelyei ősi korallzátonyok karbonátos sziklái alatt az Al Wajh-szigeteken

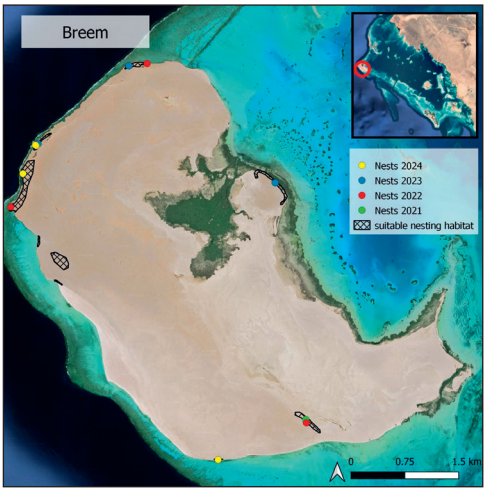
Supplementary material 2. Nearest Neighbor analysis parameters and results per each island and nest
2. melléklet Legközelebbi szomszéd elemzések paraméterei és eredményei szigetenként és fészkenként

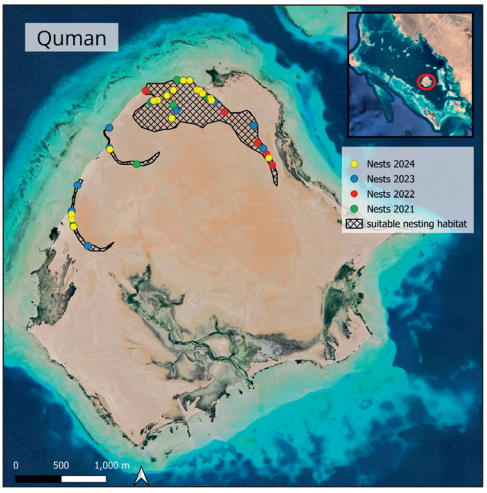
Island	Year	Observed Mean Distance	Expected Mean Distance	NNI	Z-score	Area (m^2)	Significance	Observed Mean Distance SD	Minimum Distance	Maximum Distance	Number of Nests
An Numan	2022	201,9626336	304,2758669	0,663748	-2,72918	6666033,828	Significant Clustering	144,0697542	24,25468731	451,5750475	18
An Numan	2023	239,7016867	328,6904094	0,729263	-2,00597	6482243,113	Significant Clustering	133,9760844	54,02884028	442,781634	15
An Numan	2024	279,9609194	344,2856983	0,813165	-1,28873	6163697,386	Not Significant	241,7539947	101,5042904	982,4730088	13
Breem	2024	1320,351978	862,9780152	1,529995	2,027835	11915696,88	Significant Dispersion	2344,068117	12,78167055	4823,942046	4
Breem	2023	1828,810324	981,5879047	1,863114	3,692191	19270296,29	Significant Dispersion	1484,392771	464,0402348	3939,868003	5
Breem	2022	1920,83314	1014,74992	1,892913	3,819662	20594348,01	Significant Dispersion	1034,315369	945,5769915	3374,000936	5
Breem	2021	2334,971352	1075,70905	2,170635	4,479012	18514399,37	Significant Dispersion	786,2375924	1703,229304	3325,960247	4
Ghawar	2023	382,8571595	214,5859678	1,784167	4,500498	1657696,953	Significant Dispersion	252,4534352	40,61458107	673,1384581	9
Ghawar	2022	465,7383374	343,2790792	1,356734	2,04737	4242258,943	Significant Dispersion	221,2181117	298,5883846	976,7337303	9
Ghawar	2021	597,4321841	371,1947942	1,609484	3,084909	3857996,106	Significant Dispersion	347,6826137	217,8124072	1033,897969	7
Ghawar	2024	1269,135469	392,8612425	3,230493	7,390816	1852079,47	Significant Dispersion	1121,113733	621,8601533	2563,6861	3
Mardunah	2024	448,8921918	78,25274536	5,73644	12,81439	48987,93725	Significant Dispersion	0	448,8921918	448,8921918	2
Quman	2023	141,8488078	219,938392	0,644948	-3,03765	3869831,702	Significant Clustering	124,6042222	17,00739406	424,78014	20
Quman	2022	145,0218328	219,7835834	0,659839	-2,98212	4057605,177	Significant Clustering	77,08343349	54,41743429	307,8568832	21
Quman	2024	146,5706412	221,2294818	0,662528	-2,73908	3523858,82	Significant Clustering	248,8346731	22,54952036	896,82911	18
Quman	2021	157,733587	217,0340694	0,726769	-2,33763	3768302,981	Significant Clustering	136,1139211	19,68064711	503,881494	20
Sheybarah South	2023	166,2521089	149,2367231	1,114016	0,534285	534518,3883	Not Significant	187,3520101	35,76308651	407,8541778	6
Sheybarah South	2022	340,8784612	237,4449661	1,43561	2,04129	1353122,686	Significant Dispersion	392,3963469	35,41304184	1062,453582	6
Sheybarah South	2021	435,2329729	210,9973284	2,062742	3,521431	534238,4713	Significant Dispersion	553,4766913	115,6830562	1074,332806	3
Sheybarah South	2024	951,9728672	152,8863507	6,22667	14,1407	186993,8899	Significant Dispersion	0	951,9728672	951,9728672	2
Suwayhill	2022	312,8241177	586,1134765	0,533726	-1,9946	6870580,146	Significant Clustering	292,6293011	160,4600374	834,8324262	5
Suwayhill	2023	1521,595337	628,6305039	2,420492	4,706851	4742115,725	Significant Dispersion	602,8181594	1173,558111	2217,66979	3
Suwayhill	2024	1596,259008	613,4710444	2,602012	5,308322	4516160,667	Significant Dispersion	538,1575236	1285,553617	2217,66979	3
Suwayhill	2021	3199,095016	765,9946576	4,176393	8,593699	4693982,523	Significant Dispersion	0	3199,095016	3199,095016	2

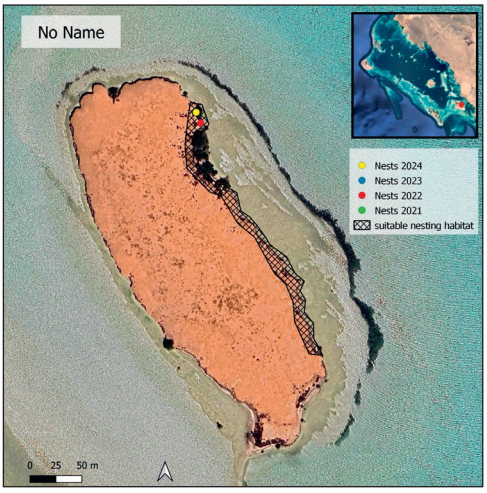
Supplementary material 3. Distribution of Sooty Falcon nests in each island of the Al Wajh Bank and estimated suitable nesting habitat. Mangrove areas were not included even if there were cases of Sooty Falcon nesting under mangrove cover. We did not include mangroves as suitable nesting habitat because none of the breeding pairs in Al Wajh Bank or An Numan selected mangroves as nesting sites. Some nests were used for multiple years in a row, therefore the most recent nests could "mask" the previous years

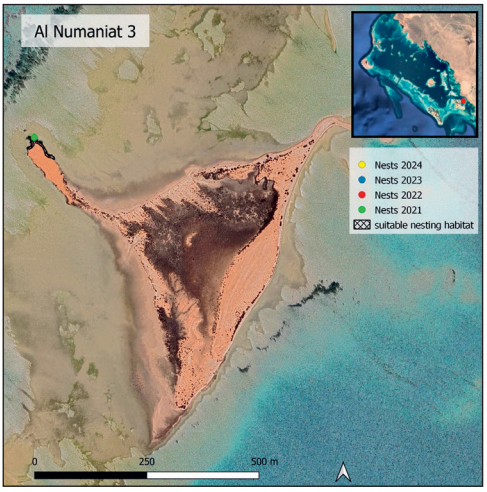
3. melléklet A hamvas sólyom fészkek eloszlása az Al Wajh egyes szigetein és a becsült alkalmas fészkelőhelyek. A mangrove területeket nem vettük figyelembe, még akkor sem, ha voltak esetek, amikor a hamvas sólyom mangroveerdő alatt fészkelt. A mangroveerdőket nem vettük figyelembe alkalmas fészkelőhelyként, mivel az Al Wajhnál vagy az An Numanban a költőpárok egyike sem választotta mangroveerdőt fészkelőhelyként. Egyes fészkeket több egymást követő évben használtak, ezért a legutóbbi fészkek „elfedhetik" az előző éveket.

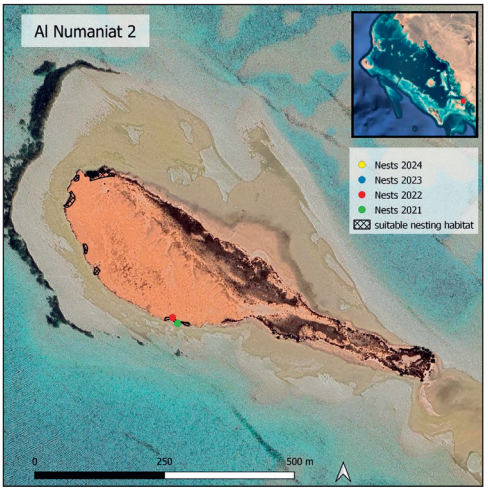


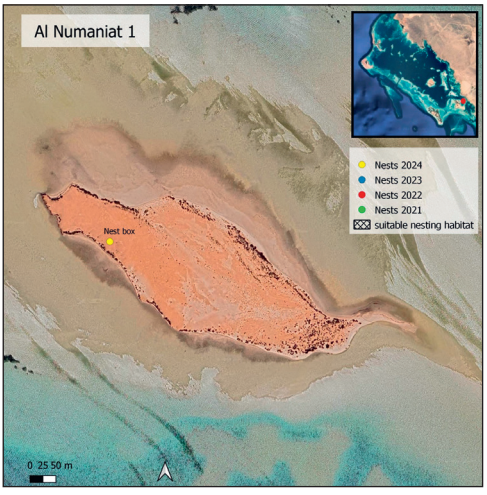


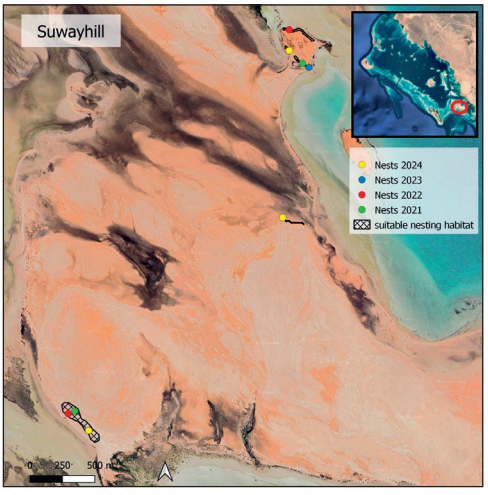


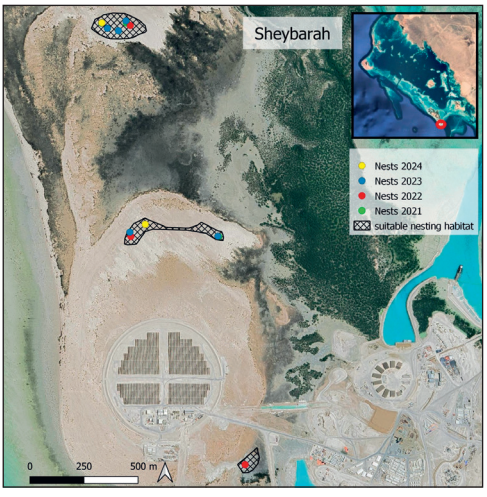


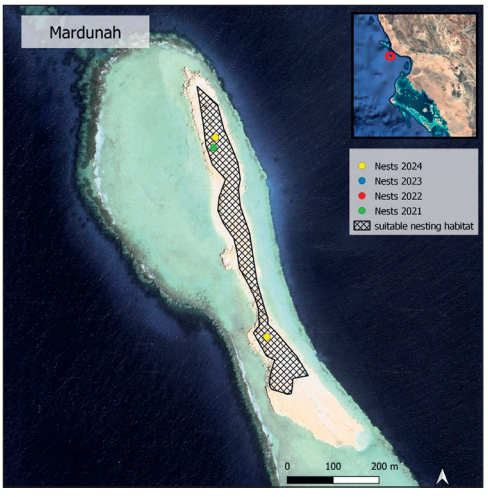

Al Numaniat 3
Nests 2024
Nests 2023
Nests 2022
Nests 2021
suitable nesting habitat
0
250
500 m


Al Numaniat 2
Nests 2024
Nests 2023
Nests 2022
Nests 2021
suitable nesting habitat
0
250
500 m


Al Numaniat 1
Nests 2024
Nests 2023
Nests 2022
Nests 2021
suitable nesting habitat
Nest box
0 25 50 m


Suwayhill
Nests 2024
Nests 2023
Nests 2022
Nests 2021
suitable nesting habitat
0
250
500 m


Sheybarah
Nests 2024
Nests 2023
Nests 2022
Nests 2021
suitable nesting habitat
0
250
500 m


Mardunah
Nests 2024
Nests 2023
Nests 2022
Nests 2021
suitable nesting habitat
0
100
200 m