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Migration stopover behaviour of Sooty Falcons *(Falco concolor)* during their southward journey

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Abstract Five (2 juvenile, 3 adult) Sooty Falcons *(Falco concolor)* were tracked in 2021 and 2022 on their southward migration. Falcons made stopovers along their migratory route where food may have been abundant, but potentially exposed themselves to heightened risks associated with those locations. Juveniles made inland and (SE African) coastal stopovers. Adults did not make inland stopovers, but two did stopover at the coast before crossing to Madagascar. Inland stopovers (n=6) constituted up to 51.4% of migration time of juveniles. Inland and coastal stopovers (n=10) were 42.9–79.4% of southward migration time. Mean duration of inland stopovers was 9.3±7.7 days, 18.0±8.5 days for coastal stopovers. 50% utilization distribution isopleths of inland stops covered 8,437±8,674 km^2, and 53,638±18,672 km^2 for coastal stops. The most important habitats were Shrubland, Tree cover, and Grassland. We found no link between weather and stopover behaviour, whether inland or on the coast. The data identify the location of stopovers, and suggest their relative importance for feeding and potential for heightened risks, at least in the years of tracking. Analysing data from a larger sample over more years, coupled with information on prey (e.g. locusts and Quelea) and threats (e.g. pesticide use) would clarify the ecological role of migratory stopovers, potential areas of risk, and enable targeted conservation action.

Keywords: staging, mortality risk, feeding, poisoning, threats

Összefoglalás Öt (2 fiatal és 3 öreg) hamvas sólyom *(Falco concolor)* dél felé irányuló vonulását követtük nyomon 2021-ben és 2022-ben. A sólymok megállóhelyeket (stopover) iktattak be a vonulási útvonaluk mentén, ahol feltehetően bőséges táplálék állt rendelkezésre, ugyanakkor ezek a helyek potenciálisan fokozott kockázatoknak is kitehették őket. A fiatal madarak a szárazföld belsejében és (Délkelet-Afrikában) a tengerparton is megálltak. Az öreg madarak nem álltak meg a szárazföld belsejében, azonban kettő közülük megállt a tengerparton, mielőtt átkelt Madagaszkárra. A szárazföldi megállók (n=6) a fiatalok vonulási idejének legfeljebb 51,4%-át tették ki. A szárazföldi és tengerparti megállók együtt (n=10) a dél felé tartó vonulási idő 42,9–79,4%-át adták. A szárazföldi megállók átlagos hossza 9,3±7,7 nap, míg a tengerparti megállóké 18,0±8,5 nap volt. Az 50%-os kihasználtsági eloszlási kontúrvonalak (utilization distribution isopleths) kiterjedése a szárazföldi megállóknál 8437±8674 km^2, a tengerparti megállók esetében 53 638±18 672 km^2 volt. A legfontosabb élőhelytípusok a cserjések, a fás vegetációjú területek és a gyepek voltak. Az adatok megmutatták a megállóhelyek pontos helyét, és rávilágítottak ezek relatív jelentőségére a táplálkozás szempontjából, valamint a potenciálisan megnövekedett kockázatokra, legalábbis a vizsgált években. A több évből és nagyobb mintából származó adatok, valamint a zsákmányállatokról (pl. sáskák és szövőmadarak) és a veszélyekről (pl. peszticidhasználat) szóló információk együttes elemzése segítené a megállóhelyek ökológiai szerepének, a potenciális kockázati területeknek és a célzott természetvédelmi beavatkozások lehetőségeinek pontosabb megértését.

Kulcsszavak: megállóhely, mortalitási kockázat, táplálkozás, mérgezés, veszélyeztető tényezők

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Introduction

Although migration must be advantageous to species that undertake it, migration can be hazardous to individuals (Newton 2008, 2025). Nevertheless, the movements between summering and wintering areas may also offer opportunities to feed, which could enhance survival. Consequences of the annual cycle of movement by migratory species include that their diet and preferred food may change, and the threats they face may vary (Newton 2008). For many migratory species, the path of migration is not direct, the pace of migration is not constant, and individuals may pause their migration at locations along the migratory path. Pauses in the migration can have many functions, including improved foraging opportunities and avoidance of bad weather (Schmaljohann *et al.* 2020).

Sooty Falcon *(Falco concolor)* is a medium-sized (about 298–350 g, Orta *et al.* 2020) falcon that migrates between breeding grounds in the Middle East and northeast Africa, and non-breeding grounds on Madagascar (mostly in the SW), with some few birds apparently wintering on the SE African coastal mainland (Gschweng 2013, BirdLife International 2025). Sooty Falcon feeds on small birds and insects. On the summering grounds birds are the predominant prey, on the wintering grounds insects are more important. Sooty Falcons feed while migrating. The species is considered Vulnerable (BirdLife International 2025), and the population is thought to number 1400–2000 breeding pairs (Gallo-Orsi *et al.* 2014, Leonardi *et al.* 2024, 2026). There is some uncertainty in past (Gaucher *et al.* 1995, Kavanaugh & King 2008) and current population estimates. Mark-recapture analyses of Sooty Falcons from Oman determined that mortality of juvenile falcons was high during their first migration, and estimated that falcon mortality rates, especially of adult falcons, was not consistent with population stability (McGrady *et al.* 2016).

Sooty Falcons have been tracked via satellite (Javed *et al*. 2012, Al Jahdhami *et al.* 2020, Red Sea Global, M. Gschweng unpublished data). During southward migration, tracked falcons have flown at variable speeds along indirect, mostly inland routes across a broad front through eastern Africa, and eventually on to Madagascar. The duration of those migrations varied: 13 days from United Arab Emirates (Javed *et al.* 2012), 36–58 days from northern Oman (Al Jahdhami *et al.* 2020). Pauses in migration were detected in some falcons.

NEOM is a large development project in NW Saudi Arabia that includes islands and mainland areas *(Figure 1)* where Sooty Falcons breed (https://www.neom.com/en-us). NEOM has committed to adhering to International Finance Corporation (IFC 2012) sustainability standards (Performance Standard 6), which "*recognizes that protecting and conserving biodiversity, maintaining ecosystem services, and sustainably managing living natural resources are fundamental to sustainable development*". Sooty Falcon has been identified by NEOM as a key species to conserve in the development area. NEOM

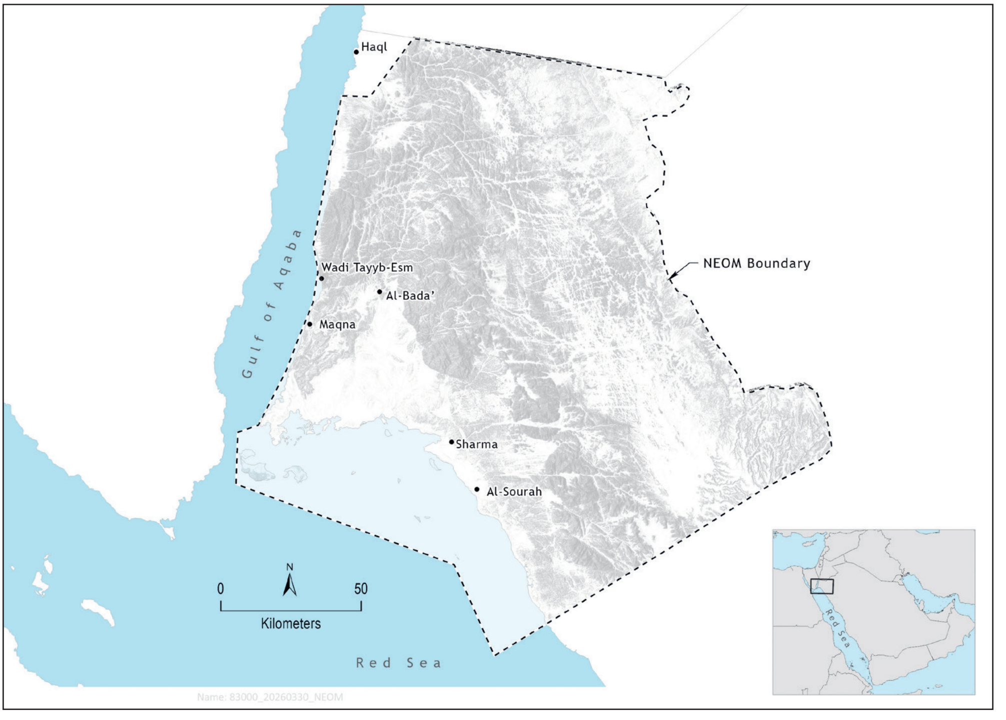

Figure 1. The NEOM development area, which includes mainland and island areas used by Sooty Falcons for nesting

1. ábra A NEOM fejlesztési terület, amely magában foglal szárazföldi területeket és szigeteket, ahol a hamvas sólyom költ

conducts surveys and research on Sooty Falcons in order to underpin decision-making and conservation activities in the area and across the Sooty Falcon's range (Foster *et al.* 2026).

Disturbance on the breeding grounds and loss of nesting habitat is considered a major cause of the decline in the Sooty Falcons. However, as a migratory species, factors contributing to their apparent population decline could be occurring anywhere in their annual range (Gallo-Orsi *et al.* 2014, CMS 2023, Leonardi *et al.* 2024).

Heretofore the threat of disturbance at nesting sites and loss of nesting habitat have been main foci of conservation concern and action because some developments (mostly coastal) overlap with falcon breeding areas, and efforts to avoid and mitigate impact can be initiated. Although breeding-ground threats are real and obvious, survival estimates (McGrady *et al.* 2016) and tracking data (Al Jahdhami *et al.* 2020) point to the possibility that high falcon mortality occurs away from the breeding areas and may be an important factor in Sooty Falcon population decline. In order to initiate effective conservation activities to support improvements in the status of Sooty Falcon it is important to better understand the main threats and where they occur.

The migration route of individual Sooty Falcons is not the shortest possible, and the pace of migration is not constant (Javed *et al.* 2012, Gschweng 2013, Al Jahdhami *et al.* 2020, https://sootyfalcon.blogspot.com/, this study). At times, falcons slow their migratory progress markedly, may stopover in spatially constrained areas for some time, and might even backtrack on their migratory route for some distance.

We postulate that at least some digressions from a direct migration route and slowing of rate of migration will be related to the Sooty Falcon's need to feed while on migration. Further, at least some migratory stopovers will result from encounters with abundant food (insects and small birds), including swarming/flocking prey like locusts (Orthoptera) or Quelea (*Quelea* sp.) that are also agricultural pests.

While stopover locations may suggest increased benefits to the Sooty Falcons in the form of abundant food, the falcons will also be exposed at those locations to any threats that exist. If agricultural pests are abundant at stopovers, the likelihood of pest control campaigns, including the use of agricultural poisons, will be greater at those locations. Sooty Falcons could be killed by such pesticides either through primary (avicides) or secondary (insecticides) poisoning. Poisons could also reduce fitness in the long-term, and could affect falcon survival.

So as to better understand the threats that Sooty Falcons may face during their migration, including potential for increased risk of poisoning, we examine the migratory stopovers during the southward migration of Sooty Falcons tracked from breeding locations at NEOM, and propose next steps in closing knowledge gaps that might benefit Sooty Falcon conservation.

Materials and Methods

Twelve Sooty Falcons were captured in 2021 (5 juvenile, 2 adult) and 2022 (1 juvenile, 4 adults) on the islands in the northern Red Sea that are part of the NEOM development *(Figure 1)*. They were fitted, using backpack harnesses (Meyburg & Fuller 2007), with solar-powered GPS tracking devices (Lotek Pinpoint Argos, 6.6 g) that weighed < 3% the birds' body masses. The devices were programmed to collect locations every two hours, though gaps in the data occurred due to technical reasons, including insufficient solar charging. The birds were tracked until data were no longer uploaded, or until birds had apparently either died or shed their tracking devices.

Five of the 12 falcons were tracked at least until Madagascar. Data from those falcons were analysed to identify time periods when directional migratory progress was paused (e.g. when stopovers occurred). Stopovers were defined by us as strings of location data spanning at least three nights that were directionally variable and random, and resulted in a reduced rate of movement in the main migratory direction (southward). Stopovers could be of long or short duration, and were measured in number of nights, thereby accounting for the possibility that some birds arrived at the stopover location late in the day or departed the stopover location early the next morning. We separated stopovers into two categories: those that occurred inland and those that occurred near the coast. Inland stopovers could be spatially constrained movements by rather settled falcons (consecutive night roosts close to one another) or spatially expansive movements by falcons that wandered (consecutive night roosts distant from one another). We distinguished coastal stopovers from inland stopovers because of the possibility that falcons may have waited at the coast for favourable weather to make the crossing (Slack & Slack 1981, McGrady *et al.* 2006).

We describe where Sooty Falcon stopovers occurred geographically and temporally. Keeping in mind that the number of locations at some stopovers was low (see Discussion), we applied dynamic Brownian Bridge Moment Models (dBBMM) (Kranstauber *et al.* 2012) to the tracking data to estimate the Utilization Distributions (UDs), and calculated the 50% and 95% isopleths. Window size of 7, and margin size of 3 were used. Raster size was set to 250 m in all but one case; raster size for the inland stopover 1 by SF01 was set at 25 m because the UD was small. The time step was the mean time between locations for the migration period divided by 20. We mapped UDs and described the habitats that occurred under the 50% UD isopleth using 10 m resolution landcover data from the European Space Agency (ESA, WorldCover 10 m 2021 v200; Zanaga *et al.* 2022). Information on weather during stopovers was extracted from the ERA5 hourly database (https://cds.climate.copernicus.eu, accessed 08 December 2025; 0.25° × 0.25° resolution). We used U and V vectors for wind at 100 m above ground to calculate wind speed (m/s) and direction. Rain was measured as the sum of rain at the time-stamped locations comprising the stopover.

Results

Four of the five falcons (SF01, SF03: juveniles in 2021 and SF11, SF12: adults in 2022), which were tracked over their complete southward migrations *(Table 1, Figures 2, 3)*, made stopovers on the African mainland. SF05 (adult in 2021) seemed not to make any stopovers, but data were lacking between its breeding territory and northern Sudan (straight line distance=664 km) *(Figure 2, Table 1)*.

Falcons departed breeding islands on similar dates (n=4, range: 29 October – 6 November). The migration paths varied. SF01, 05, 11, 12 followed similar inland paths through East Africa, SF03 migrated via a more westerly route that passed through western Sudan-South Sudan and the Democratic Republic of Congo. Adults in both years arrived earlier (8, 10, 22 Nov) at the coastal stopovers than juveniles in 2021 (1, 24 Dec). The adults also departed for Madagascar from the coastal stopovers earlier (19 Nov, 14 and 22 Dec) than the juveniles (31 Dec, 15 Jan).

The two juvenile birds, both tracked in 2021 (SF01, SF03), each made three inland stopovers, and a coastal stopover in Mozambique. The three adult birds (SF05, SF11, SF12) made no inland stopovers, and two stopped over on the Mozambique coast. The location of inland stopovers, distance between them and the breeding islands, and duration of stopovers varied *(Table 1)*. However, inland stopovers constituted an important proportion of the overall time that juveniles took to reach the coastal staging area. Duration of inland stopovers comprised 31.7% and 51.4% of the total migration time from breeding islands to the departure from the African mainland for juveniles SF01 and SF03, respectively. Inland and coastal stopovers constituted 42.9–79.4% (n=4) of the migration time of adult and juvenile falcons between departure from breeding islands and departure from the African mainland toward Madagascar (though see also information from SF05). More time was typically spent at coastal stopover

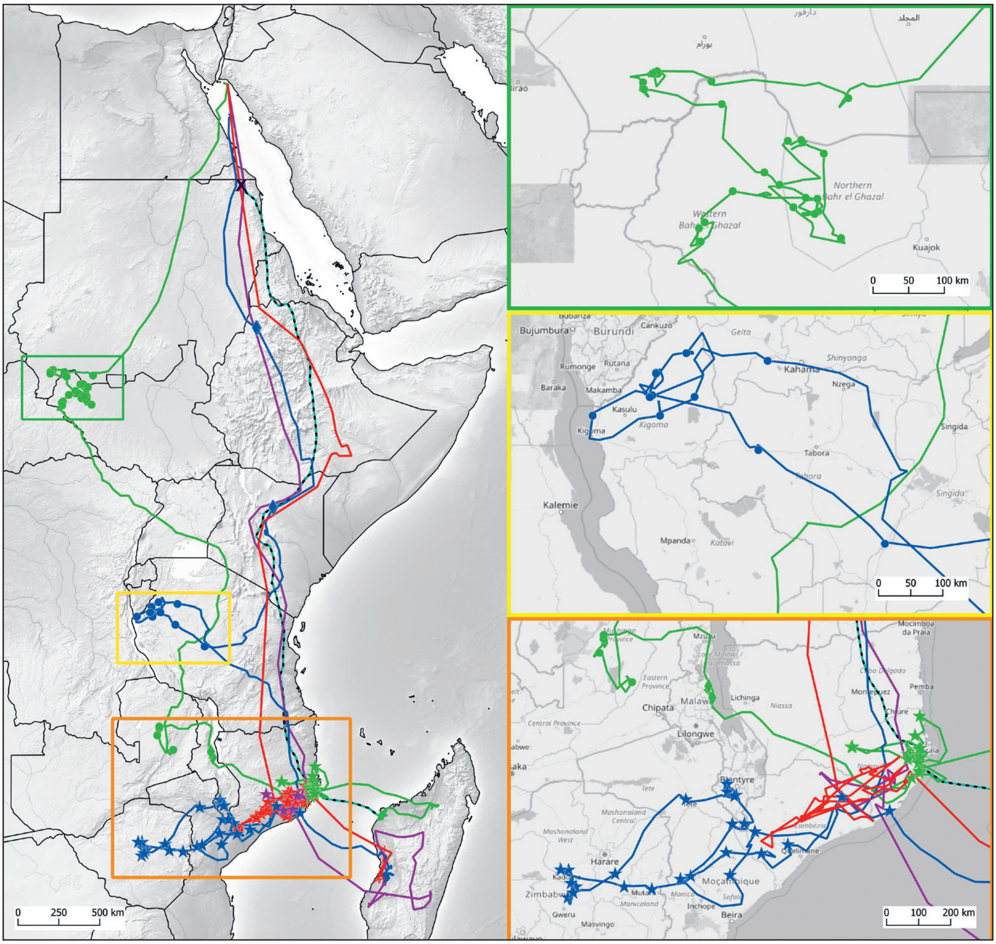

Figure 2. (left) Southward migration of five Sooty Falcons from breeding islands in the northern Red Sea in 2021 (SF01, juvenile, blue; SF03, juvenile, green; SF05, adult, dashed line) and 2022 (SF11, adult, purple; SF12, adult, red). (right) Zoomed in views of two inland stopovers made by juveniles (SF01, SF03), and the area in which both two adult and two juvenile falcons made stopovers on the coast. See also *Figure 3*.

2. ábra (balra) Öt hamvas sólyom 2021-es (SF01 – fiatal, kék; SF03 – fiatal, zöld; SF05 – öreg, szaggatott vonal) és 2022-es (SF11 – öreg, lila; SF12 – öreg, piros) déli irányú vonulása a Vörös-tenger északi részén található fészkelőhelyekről (szigetek) kiindulva. (jobbra) Nagyított részletek két fiatal madár a szárazföld belsejében lévő megállójáról (SF01, SF03), valamint arról a tengerparti területről, ahol két öreg és két fiatal sólyom is megállót tartott. Lásd *3. ábrát* is

areas than at inland stopovers. Mean duration of inland stopovers was 9.3±7.7 days (n=6); mean duration of coastal stopovers was 24.5±10.1 days (n=4).

The areas under the 95% UD isopleths at stopovers were highly variable *(Table 1)*, and positively correlated with the duration of the stopover, whether inland or coastal (correlation coefficient=0.781). 95% isopleths for coastal stopovers (n=4, mean=53,638±18,672 km^2) were larger than those for inland migratory stopovers (n=6, mean=8,437±8,674 km^2).

Table 1. Summary of stopovers during southward migration by Sooty Falcons from the northern Red Sea during 2021 and 2022. SF05 was not tracked during its complete migration

1. táblázat A Vörös-tenger északi térségéből 2021-ben és 2022-ben dél felé vonuló hamvas sólymok megállóhelyeinek összefoglalása. Az SF05 egyed vonulását nem sikerült teljes egészében nyomon követni

Falcon ID	Age	Start of migration	Type and ID of stopover /	Mean latitude of stopover	Arrival	Departure	Nights	Straight line distance from start	Min. distance travelled from start	50% UD area	95% UD area	% of migration* spent at stopover
SF01	Juvenile	2021-10-29	Inland 1	13.0	2021-11-02	2021-11-05	3	1645	2194	309	1724	4.8
			Inland 2	2.1	2021-11-07	2021-11-12	4	2862	3769	68	747	6.3
			Inland 3	-4.5	2021-11-14	2021-11-27	13	3762	5203	918	20513	20.6
			Coastal	-17.7	2021-12-01	2021-12-31	30	4911	8692	1621	69121	47.6
SF03	Juvenile	2021-11-06	Inland 1	9.3	2021-11-08	2021-12-03	25	2107	2423	1415	19904	35.7
			Inland 2	-11.7	2021-12-11	2021-12-17	6	4490	7634	507	7618	8.6
			Inland 3	-12.8	2021-12-17	2021-12-22	5	4528	8622	2	116	7.1
			Coastal	-14.9	2021-12-24	2022-01-15	22	4856	9524	458	23399	31.4
SF05**	Adult	Exact date unknown (2021)	None	–	–	–	–	–	–	–	–	–
SF11	Adult	2022-10-29	Coastal	-15.8	2022-11-10	2022-11-19	9	4793	5243	9236	52906	42.9
SF12	Adult	2022-10-27	Coastal	-16.1	2022-11-08	2022-12-14	36	4838	5580	13502	69128	75.0

* migration = days between start date at breeding site and departure across the Mozambique Straits toward Madagascar

** A significant gap in data occurred at the beginning of SF05's migration. For the rest of the migration, until departure from the African mainland, SF05 did not make any stopovers. Stopover metrics were not calculated

* Vonulás = a költőhelyről való indulás és a Madagaszkár felé történő, Mozambiki-szoroson való átkelés közötti napok száma

** Az SF05 vonulásának kezdetén jelentős adathiány lépett fel. A vonulás hátralévő részében – egészen az afrikai szárazföld elhagyásáig – az SF05 nem tartott megállókat. A megállóhelyekre vonatkozó mutatókat ezért nem számítottuk ki

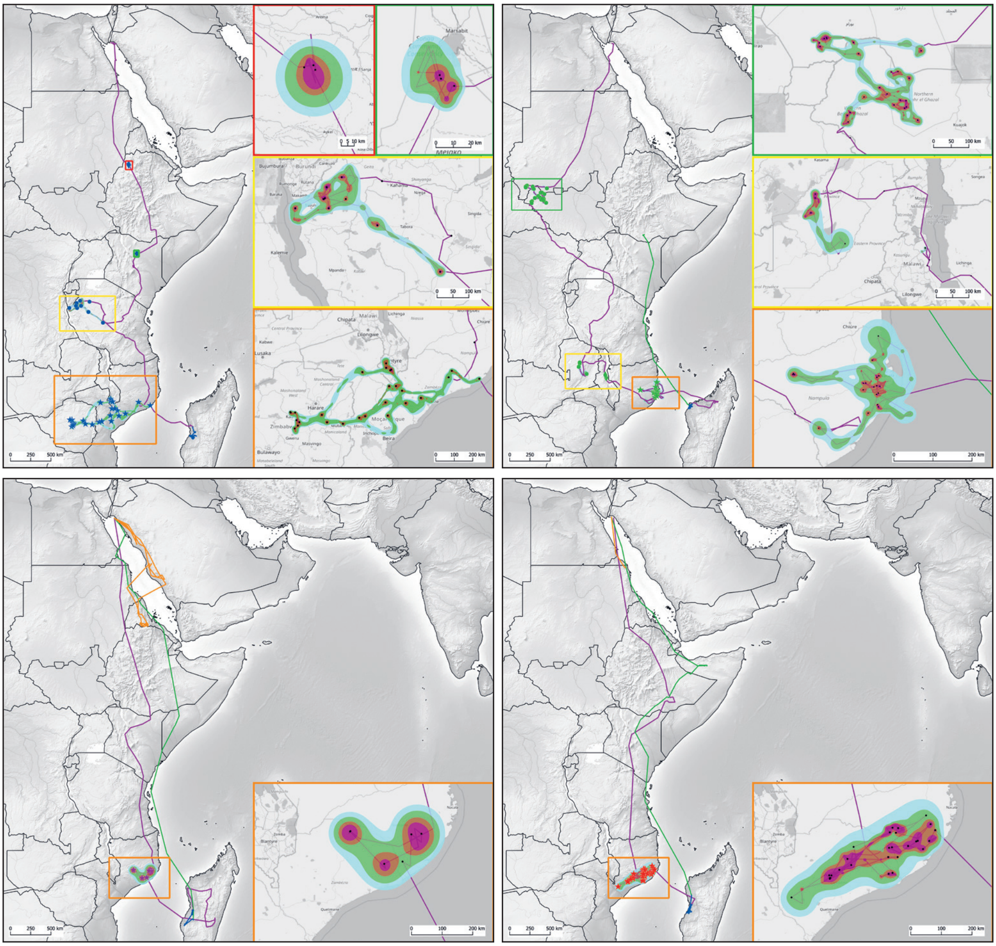

Figure 3. Migratory movement and Brownian Bridge Movement Models (dBBMM) of inland and coastal stopovers by four southward migrating Sooty Falcons in 2021 and 2022. Top left: SF01 (juvenile), Top right: SF03 (juvenile); Bottom left: SF11 (adult), Bottom right: SF12 (adult). Purple line=southward migration, Blue line=wintering, Green line=northward migration. Note: Two breaks occur in the yellow box of SF03. Only one of those had sufficient locations to apply a dBBMM. Utilization Distribution Isopleths: Purple=50%, Red=75%, Green=95%, Light blue=99%.

3. ábra A vonulási útvonal és a Brownian Bridge Movement Modellek (dBBMM) négy, dél felé vonuló hamvas sólyom szárazföldi és tengerparti megállóhelyeiről (2021 és 2022). Bal felső: SF01 (fiatal), jobb felső: SF03 (fiatal); bal alsó: SF11 (öreg), jobb alsó: SF12 (öreg). Lila vonal = déli irányú vonulás, Kék vonal = telelő terület, Zöld vonal = északi irányú tavaszi vonulás. Megjegyzés: Az SF03 sárga keretezett területén két megszakítás látható. Ezek közül csak az egyikben volt elegendő lokalizációs adat a dBBMM alkalmazásához. A területhasználati pontok eloszlási kontúrvonalai: Lila = 50%, Piros = 75%, Zöld = 95%, Világoskék = 99%

Table 2. Habitat composition (%) under 50% UD isopleths at stopovers made by Sooty Falcons on southward migration in 2021, 2022

2. táblázat Élőhelyösszetétel (%) az 50%-os területhasználati eloszlási kontúrvonal alatt a hamvas sólymok által a 2021-es és 2022-es déli vonulás során használt megállóhelyeken

Falcon ID /	Age	Type and ID of migratory pause	Shrubland	Tree cover	Grassland	Cropland	Herbaceous wetland	Built-up	Permanent water bodies	Bare/Sparse vegetation	Mangrove
SF01	Juvenile	Inland 1	17.5	27.8	22.8	31.9	0.0	0.0	0.0	0.0	0.0
		Inland 2	72.1	0.7	27.0	0.0	0.0	0.0	0.0	0.2	0.0
		Inland 3	16.3	26.1	23.0	28.0	2.4	0.4	3.7	0.1	0.0
		Coastal	38.1	29.0	22.3	9.7	0.0	0.3	0.3	0.2	0.0
SF03	Juvenile	Inland 1	43.3	9.7	46.9	0.0	0.0	0.0	0.0	0.0	0.5
		Inland 2	19.3	65.3	13.2	1.2	0.8	0.1	0.0	0.0	0.0
		Inland 3	52.1	45.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0
		Coastal	32.2	26.8	31.8	8.0	0.0	0.5	0.1	0.0	0.0
SF11	Adult	Coastal	36.1	31.6	22.2	9.9	0.0	0.1	0.0	0.0	0.0
SF12	Adult	Coastal /	33.1	32.7	22.6	11.2	0.0	0.3	0.1	0.1	0.0

Table 3. Mean occurrence (%) of the three most abundant habitats under the 50% UD isopleth of stopovers made by Sooty Falcons in 2021, 2022. Note that inland stopovers were made only by juveniles, which were tracked only in 2021. Coastal stopovers were made by both juveniles and adults in the years they were tracked

3. táblázat A három leggyakoribb élőhelytípus átlagos előfordulása (%) a hamvas sólymok által 2021-ben és 2022-ben használt megállóhelyek 50%-os területhasználat eloszlási kontúrvonalak alatt. Megjegyzés: Szárazföldi megállókat csak a fiatal madarak használtak, és őket csak 2021-ben követtük nyomon. Tengerparti megállókat mind a fiatal, mind az öreg madarak használtak azokban az években, amikor nyomon követtük őket

Type of migratory pause	N	Shrubland	Tree cover	Grassland
Inland	6	19.1±0.21	17.5±0.21	9.7±0.10
Coastal	4	35.5±0.02	29.1±0.02	25.4±0.04

Habitats under the 50% UD isopleths are summarized in *Table 2*. Shrubland, Tree cover and Grassland were the three most abundant habitats under the isopleths. Combined across both inland and coastal stopovers, Shrubland constituted 36.0% of the habitat under the isopleths, Tree cover 29.5%, and Grassland 23.5%. The habitat composition of inland stopover areas was not different than at coastal stopovers. Shrubland, Tree cover and Grassland comprised 36.8%, 29.1% and 22.6% of the habitat under the 50% UD isopleth at inland stopover areas, respectively. The values for those habitats at the coastal stopover areas were 34.9%, 30.0% and 24.7%. Habitat composition at inland stopovers was more variable than at the coastal stopovers, though the most abundant habitats were the same, as was their order of abundance *(Table 3)*.

Table 4. Weather conditions at stopover locations used by Sooty Falcons during southward migration in 2021, 2022. Rainfall (mm) = sum of rainfall at each falcon location during the stopover period

4. táblázat A hamvas sólymok által használt megállóhelyekre vonatkozó időjárási táblázat 2021-ben és 2022-ben. A csapadék (mm) = az egyes helyeken, a megállás időtartama alatt mért csapadék összege

Falcon ID	Stopover /	Start date / Indulás dátuma	End date	Cumulative rainfall	Mean wind speed	Median wind speed	Maximum wind speed	Mean wind direction	Median wind direction	Consistency of wind direction	Most frequent wind direction	Wind direction at last location
SF01	Inland stopover 1	2021-11-02	2021-11-05	0.0	2.6	2.9	3.7	152.2	135.4	0.7	SE	SE
SF01	Inland stopover 2	2021-11-07	2021-11-12	0.1	6.9	7.0	8.7	115.5	114.6	1.0	SE	SE
SF01	Inland stopover 3	2021-11-14	2021-11-27	3.4	3.0	2.6	10.0	206.0	217.7	0.2	SW	SW
SF01	Coastal stopover	2021-12-01	2021-12-31	13.4	4.8	4.8	11.4	89.4	90.2	0.7	E	NE
SF03	Inland stopover 1	2021-11-08	2021-12-03	0.0	4.8	4.8	9.1	41.2	35.8	0.7	NE	E
SF03	Inland stopover 2	2021-12-11	2021-12-17	0.0	3.0	2.9	6.1	47.4	50.8	0.6	NE	NE
SF03	Inland stopover 3	2021-12-17	2021-12-22	2.6	3.4	3.0	8.8	150.3	159.4	0.8	S	SE
SF03	Coastal stopover	2021-12-24	2022-01-15	5.3	3.6	3.3	12.1	32.8	33.8	0.7	NE	W
SF11	Coastal stopover	2022-11-10	2022-11-19	0.0	4.4	4.9	7.5	60.9	70.3	0.7	E	NE
SF12	Coastal stopover	2022-11-08	2022-12-14	0.8	4.5	4.4	9.1	94.4	93.5	0.4	NE	N

Weather at stopover sites was variable *(Table 4)*. Mean wind speeds at inland stopovers varied between light breezes and moderate winds: 2.6–6.9 m/sec; wind directions at inland stopovers were variable across stopovers, but mostly consistent at individual sites. Speed and direction of wind at the four coastal stopovers were also variable. In three of four cases, the direction of the wind at the last locations on the coastal stopovers did not correspond to tailwinds (i.e. having a westerly component) that would be favourable for the sea crossing to Madagascar. Sooty Falcons experienced wetter conditions at coastal stopovers than at inland stopovers.

Discussion

The limited data from five falcons (2 juveniles and 1 adult in 2021, 2 adults in 2022) suggest that adults and juveniles may behave differently on their southward migrations. Although, adult and juvenile falcons commenced southward migration at about the same time, only juvenile birds made inland stopovers, and adults arrived at and departed from coastal staging location towards Madagascar earlier than juveniles. Those differences could reflect age-related characteristics, such as juvenile inexperience and hunting inefficiency (Newton 2008, 2025). However, due to the low sample size and the possibility of year-related effects, differences in behaviours between juveniles and adults is not proven, and more research is necessary. Nevertheless, stopovers during migration occur, and it is reasonable to conclude that falcons may benefit from them (better feeding opportunities), but may also suffer higher exposure to any threats active at those locations. Supporting the conclusion that stopovers are related to prey availability is the fact that juvenile birds made their first inland stopovers at locations where they encountered moister landscapes (SF01: the Ethiopian Highlands, SF03: the Nile-Sudd wetlands) than those from which they departed (Newton 2008, Meyburg *et al.* 2023). Coastal stopover duration was generally longer than inland stopovers, and could have been influenced by disadvantageous weather causing falcons to be reluctant to making the water crossing (Slack & Slack 1981, McGrady *et al.* 2006).

UDs at both inland and coastal stopovers showed Shrubland, Tree cover and Grassland to be the most important habitat types. However, the small number of individuals and the low rate of data collection discouraged more detailed analyses. For some stopovers (especially inland stopovers 1 and 2 of SF01 and the coastal stopover of SF11) *(Figure 2)* the numbers of locations are too few to calculate reliable models. Thus, the maps of those stopovers should be considered indicative rather than highly accurate. Future studies of habitat use should use more data from more individuals, and habitat characteristics should be expanded. For example, because termites are a likely source of food for migrating falcons, soil characteristics (clay) and measures of cellulose may be characteristics useful in determining habitat use.

Weather, in particular wind speed and rainfall, might be linked to the availability of food (e.g. locust; Liu *et al.* 2024) for Sooty Falcon, and may play a role the path and speed of overland migration, and when falcons might initiate long water crossings (McGrady *et al.* 2006, Mellone *et al.* 2011). Our tracking data were too few to discern weather effects on migratory path or pace, and there was no clear pattern to weather conditions at the inland stopovers to support the assumption that food was abundant there. Weather data at coastal stopovers did not suggest that falcons initiated their move across the Madagascar Strait when tailwinds occurred. However, coastal stopovers were longer than inland stopovers, which would be consistent with the falcons waiting for improved flying conditions. The tracking devices used in this study collected data every 2 hrs only. That low sampling rate of falcon locations, the few birds that we were able to track all the way to Madagascar, and the potential imprecision of weather data combine to cloud any linkage between stopovers and weather. Future studies should be planned to better understand the relationship between weather and movement of Sooty Falcons.

Sooty Falcons are classified as Vulnerable and the global population appears to be in decline (BirdLife International 2025). The most tangible evidence for decline is the reduction in occupancy of traditional breeding sites, especially on islands and coasts (McGrady *et al.* 2018, 2019, Leonardi *et al.* 2024), which are often desirable places for construction and development, and where human populations congregate. Anthropogenic development and disturbance are identified as highly important threats to Sooty Falcons on the breeding grounds (Gallo-Orsi *et al.* 2014, Leonardi *et al.* 2024). However, the loss of breeding habitat to anthropogenic development may not be the only significant threat at the moment. Data showing reduction in occupancy on islands where development has not occurred is consistent with (but not conclusive evidence of) this possibility (Gaucher *et al.* 1995, McGrady *et al.* 2018). McGrady *et al* (2016) found that high mortality rates were implicated in the population decline in Oman, and the apparent decline resulted in traditional nesting territories (presumed to be still suitable) remaining unoccupied (McGrady *et al.* 2017, 2019).

Threats exist away from the breeding grounds, including intentional killing by humans and reduction in food resources (Gallo-Orsi *et al.* 2014, Leonardi *et al.* 2024, M. Gschweng, unpubl. data, http://sootyfalconoman.blogspot.com/). Because Sooty Falcons will prey upon species that are classified as agricultural pests (e.g. *Quelea* sp. and locusts (Orthoptera)) they are potentially also at risk of poisoning by avicides and insecticides that are used in large quantities over large areas (Rajabu *et al.* 2017, Loha *et al.* 2018) in countries visited by falcons outside the breeding season. An initial step in understanding the exposure of Sooty Falcons to risks away from breeding areas is to understand their movements.

While numbers of Sooty Falcons appear to be reduced and declining, important data on breeding densities from large parts of the mainland distribution are missing. Previously unknown breeding areas on mainland Saudi Arabia have been recently identified (e.g. NEOM, Royal Commission for Alula unpublished data), and Alula may hold over 100 breeding pairs (B. Rubinić *pers. comm*.). The uncertainty about the population size undermines efforts to understand the effects of threats, and makes measuring the efficacy of conservation actions difficult.

In recent years, efforts have increased to better understand the status of Sooty Falcons and their ecology (Leonardi *et al.* 2024). Surveys and monitoring have been conducted in many of the countries in the breeding distribution (e.g. McGrady *et al.* 2017, NEOM, Red Sea Global unpublished data), and on Madagascar (Razafimanjato *et al.* 2025), but those efforts need to be expanded to fill in spatial gaps and to better understand temporal variation in occupancy and nesting success. Sooty Falcons from breeding areas in Saudi Arabia (NEOM, Red Sea Global unpublished data), Israel (M. Goren unpublished data), UAE (Javed *et al.* 2012), and Oman

(Al Jahdhami *et al.* 2020) have been tracked via satellite, and combining those data would progress our understanding more quickly than studies working more or less in isolation. Such cooperation, and an expanded and coordinated ringing program could improve survival estimates and better identify where mortality occurs. A single species action plan has been developed by CMS (Leonardi *et al.* 2024), which should be the beginning of a more year-round, range-wide approach to understanding Sooty Falcon ecology and using that to effectively conserve them. In the spirit of the action plan, it is important that efforts are expanded, coordinated and shared, and published with the shared aim of conserving Sooty Falcons.

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