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Juveniles dispersal and population exchange evidence in the Sooty Falcon *(Falco concolor)* breeding in Saudi Arabia

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Abstract Gene flow among breeding populations is critical for the long-term viability of migratory species, particularly in raptors facing habitat fragmentation and environmental pressures. The Sooty Falcon *(Falco concolor)*, a long-distance migrant breeding on Red Sea islands and wintering in Madagascar, remains poorly studied in terms of juvenile dispersal and population connectivity. Here, we report the first documented case of a juvenile Sooty Falcon ringed in the Al Wajh Bank (Saudi Arabia) in 2022 and resighted as a breeding sub-adult 249 km away at Sila Island in NEOM in 2024. This finding provides direct evidence of natal dispersal between distant breeding populations. Such movement suggests that juveniles may explore alternative breeding areas after returning from their first migration, potentially enhancing genetic flow and resilience. Given the vulnerability of many nesting islands to anthropogenic threats, dispersal may allow recolonization of safer habitats and buffer against local extinctions. Our results underline the importance of long-term ringing and coordinated monitoring to better understand the species' demography and inform regional conservation strategies. This study highlights the role of juvenile dispersal in maintaining connectivity among fragmented populations of a regionally vulnerable raptor.

Keywords: natal dispersal, ringing, migratory species, gene flow, population connectivity

Összefoglalás A költőpopulációk közötti génáramlás kritikus fontosságú a vonuló fajok hosszú távú életképessége szempontjából, különösen az élőhelyük feldarabolódásával és környezeti nyomással szembesülő ragadozó madarak esetében. A hamvas sólyom *(Falco concolor)* esetében, ami egy hosszútávú vonuló, a Vörös-tenger szigetein költő és Madagaszkáron telelő faj, továbbra sem kutatott a fiatalok diszperziója és a populációk kapcsolata. Dolgozatunkban bemutatjuk az első dokumentált esetet, amikor egy fiatal hamvas sólymot 2022-ben gyűrűztek az Al Wajh-Bank területén (Szaúd-Arábia), majd 2024-ben 249 km-re, a NEOM-i Sila-szigeten subadult madárként észleltek. Ez a megállapítás közvetlen bizonyítékot szolgáltat a távoli költőpopulációk közötti fiatalkori diszperzióra. Az ilyen mozgás arra utal, hogy a fiatalok az első vonulásukból való visszatérés után alternatív költőhelyeket fedezhetnek fel, ami potenciálisan fokozhatja a genetikai áramlást és az ellenálló képességet. Tekintettel számos fészkelő sziget antropogén fenyegetésekkel szembeni sebezhetőségére, a diszperzió lehetővé teheti a biztonságosabb élőhelyek újbóli benépesítését, és védelmet nyújthat a helyi kihalásokkal szemben. Eredményeink aláhúzzák a hosszú távú gyűrűzés és az összehangolt monitorozás fontosságát a faj demográfiájának jobb megértése és a regionális természetvédelmi stratégiák kidolgozásának elősegítése érdekében. Ez a tanulmány kiemeli a fiatal egyedek diszperziójának szerepét a regionálisan sebezhető faj fragmentálódott populációi közötti kapcsolatok fenntartásában.

Kulcsszavak: fiatalkori diszperzió, madárgyűrűzés, vonuló faj, génáramlás, populációk közötti kapcsolat

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Introduction

Gene flow between populations is a key ecological process that enhances genetic diversity, increases adaptability, and contributes to species resilience (Slatkin 1987, Lowe *et al.* 2005). In ecological terms, a population is defined as a group of individuals of the same species occupying a particular geographic area and capable of interbreeding (Begon *et al.* 2006). In wild bird populations, especially those exposed to dynamic environments and anthropogenic pressures, gene flow plays a critical role in maintaining viability across the species' range (Haig *et al.* 2011).

By facilitating the exchange of genetic material, population connectivity can boost the adaptive potential of a species, enabling it to better respond to emerging threats such as climate change, habitat loss, and disease outbreaks (Garant *et al.* 2007, Frankham 2015). Additionally, connected populations tend to be demographically more stable, with a lower risk of local extinctions due to their ability to recover from stochastic events through immigration (Hanski & Gilpin 1991, Gilpin & Hanski 2012).

In falcons and other wide-ranging raptors, population exchange is often influenced by their dispersal ability, migratory behaviour, and reliance on spatially variable resources (Newton 2024). Despite the importance of these traits, the degree of connectivity among breeding populations remains poorly described for many species, limiting our understanding of their ecological resilience and conservation needs.

The Sooty Falcon *(Falco concolor)* is a long-distance migratory raptor that breeds on coastal islands and arid habitats in the Middle East and northeastern Africa, and winters in Madagascar (Orta *et al.* 2020). It is considered globally vulnerable due to its limited and fragmented breeding range, small population size, and exposure to multiple threats at many breeding sites and throughout its migratory cycle (BirdLife International 2021). Understanding whether Sooty Falcon populations function in isolation or as a connected network is critical to designing effective conservation strategies.

In this study, we present new insights into population exchange in the Sooty Falcon based on nestlings ringing and resighting in Saudi Arabia.

Methods

Study site

The Al Wajh Bank Important Bird Area (25.6156, 36.7554) consists of 92 low-lying, Red Sea sandy islands ranging in size from <1 ha to over 1,600 ha. Most islands are sparsely vegetated, primarily with halophytic shrubs, and 10 feature rocky outcrops composed of ancient fossil coral. Of these, nine islands offer suitable nesting habitat for the Sooty Falcon. Across four breeding seasons, an average of 42 breeding pairs have been recorded within the archipelago (Calabrese *et al.* 2026a).

Located approximately 300 km northwest of the Al Wajh Bank, the archipelago within the NEOM project (27.9257, 34.9986) includes a group of 41 ecologically important Red Sea islands, managed under a framework emphasizing environmental sustainability (The future of nature). These islands support another important population of Sooty Falcons (Foster *et al.* 2026.). Almost midway between Al Wajh Bank and NEOM lies An Numan Island (27.1061, 35.7666), home to approximately 15 breeding pairs (Calabrese *et al.* 2026a).

Nestling ringing and monitoring

A nestling-ringing program was initiated at Al Wajh Bank in 2022 as part of a long-term monitoring effort to assess the population dynamic of this species. Nestlings were ringed at the nesting sites in September and October using red (plastic) darvic rings inscribed with three white digits, placed on the left leg.

In 2024, a Sooty Falcon monitoring program was active at NEOM. Among the islands surveyed, Sila Island was included, with teams deployed to assess breeding pair numbers and overall reproductive activity.

Results

During the 2022 field season, 44 nestlings were ringed in Al Wajh Bank. Individuals were banded at 25–35 days of age, near fledging but still in the nest.

On 23 August 2024, a monitoring team conducting breeding assessments at NEOM documented a ringed Sooty Falcon departing a nest containing eggs on Sila Island. A clear photograph confirmed the bird's identity via its red darvic ring marked "020" *(Figure 1)*. This individual was originally ringed as a 35-day-old nestling on Ghawar Island (Al Wajh Bank) in 2022, at a weight of 323 g. At the time of resighting, the bird was almost two years old and breeding approximately 249 km from its natal site.

Figure 1. Picture of the ringed Sooty Falcon taken on Sila Island on the 23/08/2024 that allowed the identification of the individual

1. ábra Fotó a 2024. augusztus 23-án, Sila-szigetén megfigyelt gyűrűs hamvas sólyomról, ami lehetővé tette az egyedi azonosítást

Discussion

We report the first recorded case of a juvenile Sooty Falcon ringed as a nestling and resighted as a breeding sub-adult roughly 250 km away from its natal site. This provides valuable evidence of population exchange over long distances in this species.

Research in Oman suggests low juvenile survival (mainly based on five juveniles equipped with satellite tags) and high breeding site fidelity in adults (McGrady *et al.* 2016). Similarly, its close relative, the Eleonora's Falcon *(F. eleonorae)*, shows strong site fidelity and limited juvenile dispersal (Ristow *et al.* 1991). Other falcon species, both small and large, generally exhibit high levels of philopatry (Leonardi 2020).

Preliminary data from Al Wajh Bank (Calabrese *et al.* 2026a) indicate that Sooty Falcons nest in colonies. This may also apply to the NEOM project, where suitable nesting habitat is similarly concentrated on offshore islands. If the two regions are considered distinct populations, our findings demonstrate that individuals born in one population can disperse and successfully breed in another, up to a minimum of 250 km away. Technically, this makes the Al Wajh Bank and NEOM birds belonging to the same population.

The mixing of individuals breeding in different parts of the breeding range is probably already happening in their wintering grounds, considering that most Sooty Falcons spend the winter in Madagascar. Our finding suggests that birds do not only mix in wintering grounds but also in breeding locations. This dispersal may be facilitated by shared wintering grounds where juvenile mixing may begin. Most probably juveniles experience post-fledging dispersal and explore different nesting areas after returning to breeding grounds from their first complete migration. This allows them to select nesting sites different from their natal colony. This behaviour is corroborated by preliminary telemetry data on juveniles from Al Wajh Bank (Calabrese *pers. comm.*).

Juvenile dispersal is also documented in other small falcons. For example, in the Lesser Kestrel *(F. naumanni)* natal dispersal distances are greater than breeding dispersal distances, with juveniles moving more frequently and over longer distances (> 950 km) than adults (Bounas *et al.* 2016). The Lesser Kestrel is similar in size, has a similar colonial behaviour to the Sooty Falcon and its juveniles dispersal likelihood decreases with age and increases with population density at natal sites (Negro *et al.* 1997, Calabuig *et al.* 2008). Similar mechanisms may influence Sooty Falcon dispersal, although further research is needed.

The Sooty Falcon is a vulnerable species and currently many of its nesting sites are located on islands in the Red Sea, which may be threatened with future development, poaching and invasive species (Calabrese *et al.* 2026a). From a conservation perspective, the ability of Sooty Falcons to establish breeding territories outside their natal colonies provides resilience in the face of local environmental threats. For instance, Ghawar Island – the natal site of the ringed individual – harbours invasive Black Rats *(Rattus rattus)*, a known predator of bird eggs and nestlings (Calabrese *et al.* 2026a). Dispersal away from such sites may increase individual breeding success and foster colonization of more favourable habitats increasing their adaptive potential. In addition, since the Sooty Falcon was found breeding in artificial nesting sites (Calabrese *et al.* 2026b), colonization of artificial colonies built in the frame of conservation initiatives can be possible thanks to this juveniles behaviour. Dispersal also supports genetic exchange, a key process enhancing adaptability and long-term viability (Slatkin 1987, Lowe *et al*. 2005). If such gene flow exists between Al Wajh Bank and NEOM, it may also occur among other populations, including those in southern Saudi Arabia and/or elsewhere in the breeding range of this species. Quantifying the scale and frequency remains a key conservation priority.

This study represents an important first step in documenting juvenile recruitment and inter-population connectivity in Sooty Falcons. These findings highlight the importance of managing Red Sea island networks as an interconnected system rather than isolated breeding sites. Continued ringing programs and coordinated monitoring – both at breeding sites and across migratory and wintering ranges – will be essential to unravel the species' full population dynamics. Multiregional coordinated ringing and resighting efforts should be promoted across its home range to inform and guide conservation actions for this vulnerable raptor.

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