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Island accessibility and distance from beach influence nesting success of Sooty Falcons *Falco concolor* in Oman

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Colonial island-breeding birds can be particularly vulnerable to anthropogenic disturbance, which can adversely affect their nesting success. We studied Sooty Falcons *Falco concolor* breeding on 10 ground-predator-free islands in the Sea of Oman during 2007–2014 and evaluated spatio-temporal trends in the number of breeding pairs occurring on the islands and the factors influencing nesting success. The number of breeding pairs on the islands declined during the study, due mostly to the decline on accessible islands; the rate of decline on islands accessible to humans was double that on inaccessible ones. The number of nests with one or more eggs declined during the study period, and the percentage of nests with eggs that produced one or more chicks showed an increasing trend over time. Sooty Falcon nests located farther away from beaches experienced a significantly higher probability of nesting success than those located closer to beaches. Our results suggest that the number of breeding Sooty Falcons on the islands of northern Oman is declining and that human disturbance may be a contributing factor; this probably mirrors the situation in other parts of the breeding range of this species.

Keywords: breeding pairs, human disturbance, island area, nest failure, reproductive success.

Human disturbance, intentional or not, can negatively affect breeding birds, causing nest failures and reducing reproductive success (Newton 1979, 1998, Giese 1996, Beale & Monaghan 2004). The effects of such disturbance can be direct (e.g. failure of eggs to hatch and mortality of chicks) or indirect (e.g. reduced prey availability; Frid & Dill 2002) and may induce changes in nest attendance or foraging (Gill & Sutherland 2000). Ground-nesting birds are particularly susceptible to disturbance, and in colonial nesting species even spatially limited disturbances can have a substantial impact because they can affect many pairs (Burger 1981). Insular colonies can be under particular threat of disturbance because islands are often popular with tourists (Apostolopoulos & Gayle 2002, McElroy 2003). Although most studies of human disturbance of colonial nesters relate to water birds (e.g. Carney & Sydeman 1999, Burton 2007), disturbance also affects raptors adversely (Richardson & Miller 1997, Martínez-Abraín *et al.* 2010), including colonially nesting falcons (Eleonora's Falcon *Falco eleonorae*, Walter 1979a; Lesser Kestrel *Falco naumanni*, Negro & Hiraldo 1993, Catry *et al.* 2009; Red-footed Falcon *Falco vespertinus*, Horváth 1975).

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The Sooty Falcon *Falco concolor* is a small predator, mostly of birds and insects, that breeds in the Middle East and north-east Africa during the late boreal summer. On the mainland it is a solitary nester and on some islands it breeds in loose colonies (del Hoyo *et al.* 1994, BirdLife International 2016). The proportion of the total breeding population that is colonial is thought to be substantial, although population estimates, and thus estimates of the proportion that are colonial, are probably imprecise (Gaucher *et al.* 1995, Kavanagh & King 2008, Gallo Orsi *et al.* 2014, BirdLife International 2016). The Sooty Falcon is categorized as Near Threatened on the IUCN Red List (IUCN 2001, BirdLife International 2016) and the Convention on Migratory Species (CMS) lists it as a Category 1 species under the Raptors MOU initiative (http://www.cms.int/raptors/en/page/agreement-text).
Oman is considered a nesting stronghold for Sooty Falcon (Gallo Orsi *et al.* 2014), the main concentration of which is found at three locations: Fahal Island, the nine islands of the Daymaniyat archipelago and the seven Sawadi Islands (Walter 1979b, M.J. McGrady *et al.* unpubl. data; Fig. 1).

Sooty Falcons nest in small holes, on ledges under overhangs and under vegetation (Walter 1979b, Gaucher *et al.* 1995) and such nest-sites are abundant on most of the islands in the Sea of Oman (Walter 1979b). Some nests are located at walk-in sites that are easily accessible to humans and thus may be susceptible to disturbance. There are records of human disturbance (e.g. egg-collecting, chick removal, camping near nests) of Sooty Falcon nest-sites in Oman (Walter 1979b) and the Red Sea (PERSGA/GEF 2003, Coles & Williams 2004). A range-wide questionnaire survey identified disturbance (e.g. tourism, camping, fishing, egg and nestling collection) and development as negative influences on geographical distribution, population size and nesting success (Gallo Orsi *et al.* 2014). Islands are often the focus of residential and commercial development (Apostolopoulos & Gayle 2002, Davenport & Davenport 2006, Gladstone *et al.* 2013), which can cause habitat loss, introduce terrestrial predators and disturb nesting birds. These conditions may be rendering areas previously occupied by Sooty Falcons on islands in Oman and other countries less suitable for their breeding, which may undermine population persistence. Conversely, the absence of general human disturbance at nests can facilitate persistence of breeding pairs, as was found on islands in Abu Dhabi, United Arab Emirates (Shah *et al.* 2008).

Until very recently, there were only a few, rather old, published studies of Sooty Falcons from Oman (Walter 1979b), Saudi Arabia (Gaucher *et al.* 1995) and Israel (Frumkin & Pinshow 1983, Frumkin 1984, 1988); in most cases these studies had small sample sizes or were conducted over a short period. Survival estimates from Oman (McGrady *et al.* 2016), information on reproductive rates and population dynamics in Oman (McGrady *et al.* 2017) and Bahrain (Kavanagh & King 2008) and information on mortality from tracking via satellite (http://sootyfalconoman.blogspot.co.at/; http://sootyfalcon.blogspot.co.at/) raise concerns about the status of Sooty Falcon and its conservation prospects. Currently, there exists no quantitative assessment of factors influencing Sooty Falcon nesting success, and this, in conjunction with the poor population estimates mentioned above, may have undermined Sooty Falcon conservation. Also, maintaining breeding distributions and promoting nesting success are important to the conservation of this and any other species (IUCN 2001, Green 2004), but little is known about spatio-temporal trends in the number of territorial pairs and nesting success of Sooty Falcons in Oman or elsewhere.

We analysed data on the number of breeding Sooty Falcons and their nesting success during 2007–2014 on 10 islands in the Sea of Oman. Recent findings showed that survival of prebreeders is low (McGrady *et al.* 2016), the Sooty Falcon population in Oman is most likely declining and numbers of breeding pairs are declining elsewhere in Arabia (Kavanagh & King 2008), possibly due to human disturbance (Shah *et al.* 2008). In the light of these worrying signs, our objective was to assess breeding performance of Sooty Falcons in Oman and to investigate factors influencing nesting success. Our expectations were: (1) numbers of breeders would decline with time, (2) declines would be greatest on accessible islands, (3) nesting success would decline over time, (4) nesting success would show the greatest decline on accessible islands and (5) success would be lowest at nests located closer to beaches where boats can land.

METHODS

Study area and field methods

The study area has been described by Walter (1979b) and McGrady *et al.* (2016). It comprised

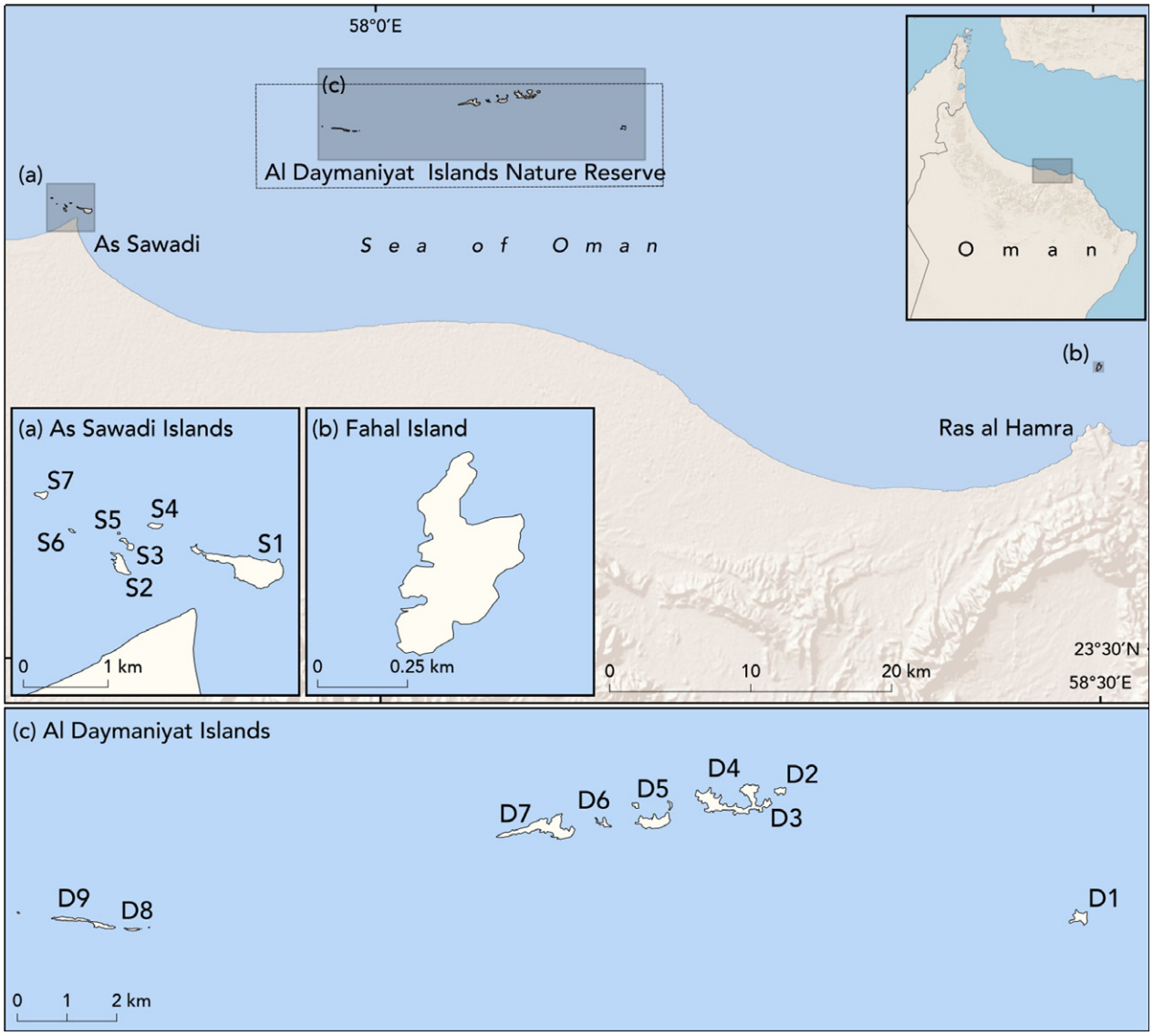

Figure 1. Study area. Upper panel: Inset right = regional scale (study area shaded); background = local scale showing relative positions of the Sawadi Islands (a), Fahal Island (b) and the Daymaniyat Islands (c). The Daymaniyat Islands Nature Reserve is outlined. Lower insets (a), (b) and (c) are zoomed in maps of the Sawadi Islands (S1–S7), Fahal Island and Daymaniyat Islands (D1–D9), respectively.

the nine islands of the Daymaniyat archipelago (D1–D9: 0.01–0.37 km^2, *c.* 15 km offshore), and Fahal Island (0.11 km^2, 4 km offshore; Fig. 1). The Daymaniyat Islands and Fahal Island are free of mammalian predators. Walter (1979b) reported data on Sooty Falcon occurrence and breeding for 1978 from Fahal Island, the Daymaniyat Islands and the seven Sawadi Islands (0.0008–0.21 km^2, < 2 km offshore, Fig. 1). We visited the Sawadi Islands in 2007, 2008 and 2014 and could access only a very few nests. Thus, data from those islands were too sparse to include in our analyses but provide useful ancillary information on Sooty Falcons during the study period.

Nest searches and surveys for apparent breeders were made by one to six observers walking through nesting habitat. On islands with larger cliffs, surveyors were supported by one to four boat-based observers using binoculars, who helped guide surveyors to some nests and identified

places where adult Sooty Falcon behaviour suggested the presence of a nest. All locations of birds and nests in accessible locations were recorded using a GPS receiver, otherwise they were plotted on a map and the coordinates determined later. Fahal Island is rugged, and parts are inaccessible by foot and could not be observed directly from boats or from other parts of the island (McGrady *et al.* 2017). Because of its ruggedness, on Fahal Island in any given year we could not access or get a direct view of nest locations for 20–30% of the pairs; nest locations for these were estimated by watching Sooty Falcons, especially during food passes and pair changeovers during incubation, and mapped. Our assessments of the number of breeding pairs on Fahal are thus less precise than those on the Daymaniyat Islands, where almost all nests could be visited or approached closely.

During 2007–2014, we surveyed annually in two periods: early August, during incubation, and in late September–early October, during rearing of young. A nest or site was considered to be occupied if at least one adult Sooty Falcon was in attendance near a nest or potential nest-site that we could not access, or if there were signs of breeding (e.g. food passes, incubating adult, nest scrape, eggs or egg fragments, chicks). Pairs were considered successful if they produced one or more chicks to ringing age (minimum of about 10 days old, but more typically $\geq$ 2 weeks old, Steenhof & Newton 2007). Failed pairs laid eggs but no young survived to ringing age. Surveys were carried out during 5–22 August and 18 September–5 October, but the exact dates in each year and the order in which islands were surveyed varied depending on weather, tides and boat availability (McGrady *et al.* 2017). Fahal and D9 required more than 1 day for each survey but all other islands required only one visit during each period. Most nests were first found during August and were visited only twice during the season. A few (eight during the study period) were first found during the second survey period; however, this was the result not of later nesting but rather of missing the nest in the earlier survey. Judging from the age of chicks at ringing, Sooty Falcon nesting appeared to be highly synchronous and we did not encounter any newly laid eggs during the second survey period.

We classified islands as either 'accessible' or 'inaccessible' based on our subjective knowledge of how easy it was to land and on our observations during 2007–2014 of human use. Accessible islands were those that have more developed beaches on which to land. Although no islands were totally inaccessible (as we could access them), inaccessible islands have no beaches, beaches only at low tide or small, steep beaches on which landing is difficult.

Statistical analysis

We used a generalized linear mixed model (GLMM; Zuur *et al.* 2009, Agresti 2015) with a Poisson distribution and log link to test for the fixed effect of accessibility of islands, island area and survey year on the number of pairs of Sooty Falcons occurring on the Daymaniyat and Fahal Islands; we used island group (Fahal or Daymaniyat) as a random effect. We treated survey year as a continuous variable to test for the linear temporal trend and included an interaction between island accessibility and year to test whether the temporal trend in the number of breeding pairs differed between inaccessible and accessible islands. To account for possible temporal autocorrelation, we included as an offset the number of breeding pairs of Sooty Falcons in the previous year, but this model did not converge. However, preliminary analyses to assess the year effect only, and to account for temporal autocorrelation by including the year as an offset, showed the trend to be consistent with that of the full model; in fact, it provided evidence of an even stronger decline than was suggested by the full model (Table S2).

To examine factors influencing nesting success, we classified each pair as successful if it had one or more chicks reach ringing age during a nesting season (coded '1') and as unsuccessful if not (coded '0'). We then tested for the effect of distance from each nest to the nearest beach (measured to the centre high-tide waterline), accessibility of the island to people and year of data collection on the probability of nesting success using GLMMs with binomial distribution and logit link. We included the random effect of nest code (i.e. coded to identify each nest individually) to account for non-independence of repeated observations in some nests over the study period.

Island coastlines were digitized from Quickbird high-resolution satellite images (acquired 3 April 2008). Digitization and calculation of areas of

islands and distances between beaches and nests were performed using ArcGIS 10.1. All continuous variables were scaled to a mean of zero and standard deviation of 1.0 to improve model convergence. GLMMs were fitted using the *lme4* package (Bates *et al.* 2016) in R v. 3.2.5 (R Core Team 2014).

RESULTS

Sooty Falcons bred on eight of the nine Daymaniyat Islands and on Fahal Island (i.e. all islands except D1). Over the 8-year study period, 517 breeding pairs were observed. Of these, 175 Sooty Falcon breeding pairs were observed on accessible islands and 342 breeding pairs on inaccessible islands; 311 breeding pairs were observed on Fahal Island and 206 breeding pairs were observed on islands of the Daymaniyat archipelago (Table S1). The number of Sooty Falcon pairs breeding on accessible islands declined from 32 in 2007 to 17 in 2014, a decline of 46.87%. Similarly, Sooty Falcon pairs breeding on inaccessible islands declined from 48 in 2007 to 37 in 2014, a decline of 22.92% (Fig. 2). Island area positively influenced the number of breeding Sooty Falcons (i.e. more Sooty Falcons bred on larger than on smaller islands) and fewer pairs occurred on accessible than on inaccessible islands (Table S1). The number of breeding pairs declined significantly over time. The interaction effect of accessibility and year approached significance, suggesting that the rate of decline differed between accessible and inaccessible islands (Table 1).

We observed 231 Sooty Falcon nests with at least one egg, 87.0% of which produced at least one nestling (i.e. 30 nests failed at the egg stage). The number of nests with at least one egg declined from 45 in 2007 to 21 in 2014, a decline of 53.33%. Nesting success (the proportion of nests with one or more eggs that successfully produced one or more hatchlings of ringing age) ranged from 11% in 2009 to 100% in 2011–2013, with an overall increasing trend (Fig. 3). GLMM results showed that nesting success increased significantly during the study period; distance to beach positively influenced nesting success but island area or accessibility did not significantly influence nesting success (Table 2). The probability of nesting success increased steadily with distance from the beach, approaching 1.0 for nests located ≥ 500 m from the nearest beach (Fig. 4).

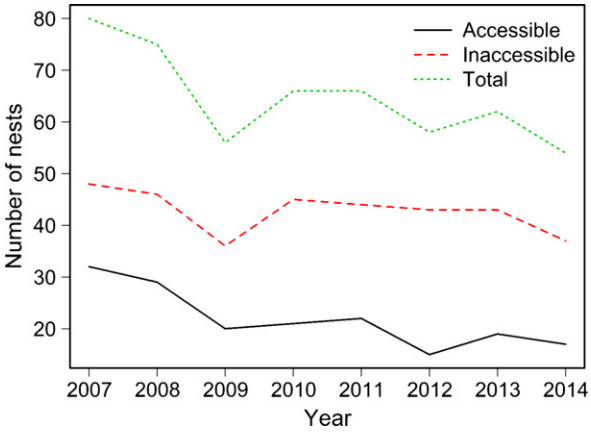

Figure 2. The number of breeding pairs of Sooty Falcons occurring on 10 islands in the Sea of Oman (D1—D9, Fahal), 2007–2014, relative to island accessibility.

Table 1. Results of generalized linear mixed model testing for the effect of island area, distance to beach, accessibility of the islands and linear temporal trend on the number of Sooty Falcon breeding pairs in Oman. Island group (Daymaniyat or Fahal) was included as a random effect in the model. 'Trend' treated year of study as a continuous variable and tested whether the number of breeding pairs increased or decreased linearly over the study period. An interaction between year and island accessibility was included to test whether the temporal trend was different between accessible and inaccessible islands. A colon (:) indicates an interaction effect.

Effect	Estimate	se	*z*	*P*
Accessibility[a]	−1.032	0.242	−4.273	< 0.001
Year	−0.214	0.077	−2.778	0.005
Island area	0.343	0.111	3.107	0.002
Accessibility:Year	0.168	0.094	1.779	0.075

[a]Accessible islands were used as the reference level.

DISCUSSION

Our expectation that numbers of breeding Sooty Falcons would decline over time was supported by the data, although declines seemed also to have occurred prior to 2007 (Table S1). The average number of breeding pairs observed during 2007–2014 on Fahal, the Daymaniyats and Sawadi Islands was 38.8, 25.7 and 4.0, respectively. Comparing these values with those reported by Walter (1979b) suggests declines in numbers of pairs of 17.3% on Fahal, 41.5% on the Daymaniyats and 84.7% on the Sawadi Islands. However, caution should be used when interpreting these data because of the small sample sizes for historical

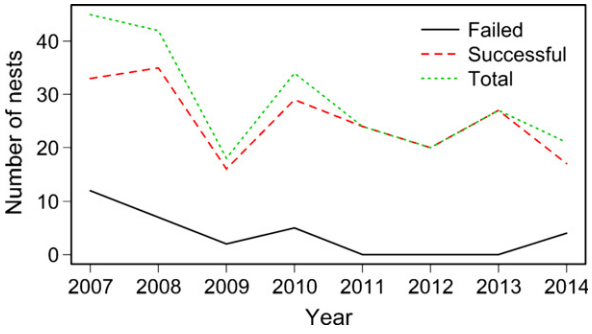

Figure 3. Annual rate of nesting success for Sooty Falcons on 10 islands in the Sea of Oman (D1–D9, Fahal), 2007–2014. The number of nests monitored during 2007–2014 was 45, 42, 18, 34, 24, 20, 27 and 21, respectively.

Table 2. Results of generalized linear mixed model testing for the effect of island area, distance to beach, accessibility of the islands and linear temporal trend on Sooty Falcon nesting success. Results are presented based on models that included the fixed effect of island area, distance to beach, island accessibility and linear temporal trend, and a random effect of nest code. 'Trend' treated year of study as an integer and tested whether the nesting success increased or decreased linearly over the study period.

Effect	Estimate	se	*z*	*P*
Island area	−0.472	0.400	−1.180	0.238
Accessibility[a]	−0.061	0.829	−0.074	0.094
Year	0.674	0.284	2.374	0.017
Distance to beach	1.221	0.355	3.436	< 0.001

[a]Accessible islands were used as the reference level.

data for the Daymaniyat and Fahal Islands, the small sample sizes for the Sawadi Islands during both time periods and the annual variation in numbers of pairs during 2007–2014.

The decline in the presence of breeding pairs in the study area since 2007 (and probably since 1978) is consistent with indications of decline from other studies (McGrady *et al.* 2016, 2017) and with the view that the Sooty Falcon is suffering an ongoing, slow to moderate population decline globally (BirdLife International 2016). Our preliminary analyses revealed that Sooty Falcon population decline became even steeper when we accounted for temporal autocorrelation, suggesting that the population decline is real and not a consequence of temporal autocorrelation. National populations elsewhere in the Arabian Gulf have declined (−33% in Bahrain, Kavanagh & King 2008; −64% in UAE, Shah *et al.* 2008), although

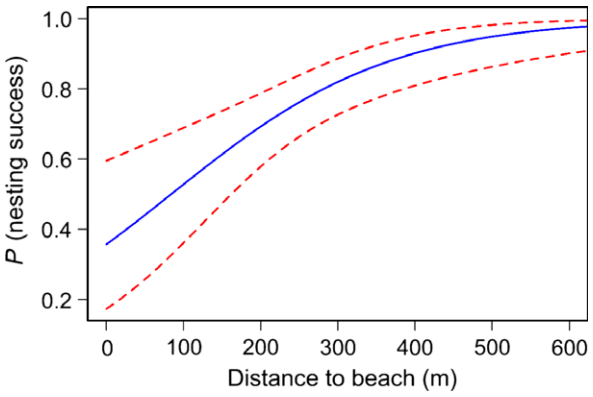

Figure 4. Probability of Sooty Falcon nesting success in relation to distance from beach on islands in the Sea of Oman, 2007–2014. Dashed lines indicate 95% confidence interval.

the mainland breeding population in Israel seems to be stable (M. Goren pers. comm.). Data from other national populations are lacking.

Consistent with our expectation, the decline in the number of breeding pairs in the study area was caused mostly by declines on accessible islands rather than inaccessible islands. Although there are no data on breeding numbers or nesting success on the islands during 1979–2006, it seems likely that declines occurred prior to 2007, especially on accessible islands. Assuming that the difficulty of landing on some islands protected them from human interference, it may be that declines on inaccessible islands that occurred during our study reflect range-wide population declines (BirdLife International 2016) and the inter-related effects of lower survival and lower recruitment in the Oman population (McGrady *et al.* 2016, 2017).

In 1978, travel to Oman was strictly controlled and tourism was almost non-existent. Since then the human population has increased approximately four-fold, to 4.6 million (National Centre for Statistics and Information 2017), and pursues more outdoor leisure activities such as diving, snorkelling and camping. Since 1974, commercial and artisanal fishing in Oman has grown, increasing by about 6% annually during 2009–2012 (Belwal *et al.* 2015), faster than the 3.2% global average (FAO 2016), and the country has become a popular destination for international tourists (National Centre for Statistics and Information 2016). The Daymaniyat Islands (where all accessible islands occur) have come under increased visitor pressure (especially recently) despite its designation in 1996 as a National Nature Reserve

(IUCN category IV). About 7000 people were given permission to snorkel or dive in the waters around the islands in both 2016 and 2017 (Ministry of Environment and Climate Affairs unpubl. data). Studies of colonial nesting Lesser Kestrel in Portugal have shown human disturbance to be a factor in colony size reduction (Catry *et al.* 2009). However, unlike colonies of the Lesser Kestrel, Sooty Falcon nesting density is lower, and the islands on which they nest in Oman are separated spatially and differ in their ease of accessibility by people, meaning that any disturbance event affects fewer pairs. It is unclear how disturbance has changed since 1978. On the one hand, more people are pursuing outdoor activities in the study area; on the other, new laws and the presence of rangers may deter some disturbance, and egg-collecting by locals for food has probably decreased (see below).

There was no discernible influence of island size or accessibility on the likelihood of individual islands harbouring breeding Sooty Falcons. Fahal Island and D9 accounted for 76.5% of all breeding pairs observed. Fahal is the fourth largest island in the study area and is inaccessible. D9 is the fifth largest and is accessible. Newton (1979, 1998) noted that nesting place and food availability are two main factors influencing nesting densities in birds in general and in raptors in particular. Even when island size is taken into account, potential appropriate nesting places are abundant on most of the islands (all islands except D1, which has few potential nesting places), especially given that Sooty Falcons in other parts of their range will nest directly on the sand if vegetation is available to provide shade (e.g. Gaucher *et al.* 1995, Semere *et al.* 2008). Although we did not collect data on prey availability, abundant prey (locusts) in July, as evidenced by prey remains, was probably a factor in the relatively high number of nests found in 2007. Other colonial nesting falcons can nest in situations where the distance between nests of multiple pairs is only a few metres (e.g. Negro & Hiraldo 1993); as some Sooty Falcon nests were very close to one another (10–20 m) during this study and more pairs occurred on the islands in 1978 (Walter 1979b), it did not appear that maximum nesting densities were being achieved on any of the larger islands in 2007–2014.

At the nest level, we found reduced probability of success at nests that were on large accessible islands and close to landing beaches. These findings were in line with our expectations (4 and 5) and implicate human disturbance as a factor affecting Sooty Falcon nesting success. Variables associated with potential human disturbance are not, however, entirely independent of one another. Small islands are less likely to have beaches on which to land, so tend to be relatively inaccessible and undesirable destinations for human visitors, and the size of islands influenced the distance of nests from beaches. We recognize that disturbance does not necessarily result in measurable reduction in falcon productivity (Purger 2001) but it may affect factors that are more difficult to measure, including levels of stress-related hormones (Busch & Hayward 2009), post-fledging survival (Strasser & Heath 2013) or subsequent nest-site selection (Hockin *et al.* 1992) as well as the knock-on effects that might arise from them.

It is possible that we missed some early nest failures (i.e. eggs laid, then lost before our fieldwork) from natural or human-related causes, resulting in overestimates of nesting success. Although our surveys in August started when most clutches were recently completed, it took up to 2–3 weeks to complete the surveys and therefore some nests might have been first visited well into the incubation period. This possibility is suggested by the fact that occasionally we encountered what appeared to be newly created, but empty, scrapes with adults in attendance (although Sooty Falcons sometimes make scrapes and do not lay, and make an alternative to the scrape that is actually used). Also, Sooty Falcons can nest directly on rock and so it is possible that some early clutches could have been laid and lost without a trace. An additional possible effect, which our fieldwork could not ascertain, was that human disturbance caused the non-occupation of traditional (optimal) sites.

Contrary to our expectation that Sooty Falcon nesting success would decline over time, we found that it actually increased during the study period, with 100% success in 2011–2013 compared with a relatively low success rate in 2007 (Fig. 3). The number of breeders and nesting success are influenced by food availability (Newton 1979, 1998, Dawson & Bortolotti 2000, Hoy *et al.* 2016). Food shortages early in the breeding season may deter Sooty Falcons from settling in some areas or sites might be abandoned early; conversely, food surpluses may result in higher numbers of breeders and more pairs laying eggs. Adequate food supplies during incubation and nestling can support nesting

success and shortages can cause abandonment or reduction of clutches or broods. The number of nests with eggs in 2007 was high (perhaps because of the availability of early-breeding season locusts, see above) but nest success in that year was not commensurately high (McGrady *et al.* 2017) (Fig. 3). We had no objective measure of food availability during the study, however, which hindered our ability to account for it in our analyses.

Historical information on Sooty Falcon nest locations exists only for the most western of the Daymaniyat Islands (Fig. 5, D9; Walter 1979b). Mean distances between nests and the beach on D9 in 1978 (352 m, se = 35.2, $n = 20$) and during 2007–2014 (409 m, se = 14.9, $n = 61$) were not significantly different (Welch's t-test: $P = 0.15$). D9 is an accessible island with a large beach and attractive diving areas nearby and on many occasions we encountered people visiting the island. Whereas most visitors remained in their boats or stayed on the beach away from Sooty Falcon nests, some few (fewer than five individuals/groups) were seen within 60 m of nests and some camped overnight.

Walter (1979b) reported that Sooty Falcon eggs and nestlings were being taken by humans in 1978, especially on the Sawadi Islands. Although we made few visits to the Sawadi Islands, available evidence suggests that Sooty Falcon numbers have declined there as well (Table S1); all nests we found there were in inaccessible locations. Despite their nature reserve status, we found evidence that Sooty Falcon chicks had been taken from at least one nest on the Daymaniyat Islands during our study (McGrady *et al.* 2017). Even though summer temperatures sometimes exceed 50 °C, it seems likely that visitors to the islands will increase, which may result in an increased disturbance of nesting Sooty Falcons.

Oman's breeding Sooty Falcon population primarily occurs on the islands in the Sea of Oman (Walter 1979b, M.J. McGrady *et al.* unpubl. data), which is important because of its size and location. Those islands are designated as Important Bird Areas (IBAs), largely because of the falcons (Evans 1994). Our results suggest that anthropogenic disturbances reduce nesting success and adversely affect the Sooty Falcons breeding on the islands. Although the Daymaniyat Islands are patrolled by rangers and landing on the islands is restricted from 1 May to 31 October, improved ranger training, seasonal increases in the number of rangers during the nesting season, and the amount and consistency of patrolling could help minimize disturbance to nesting falcons. Seasonal patrolling of the Sawadi Islands, increased public education and adding conservation components to pre-dive talks by dive boat operators also could be beneficial. Initiating these rather simple improvements in protection, monitoring and conservation education could reduce disturbance and improve the national conservation prospects for Sooty Falcons in Oman.

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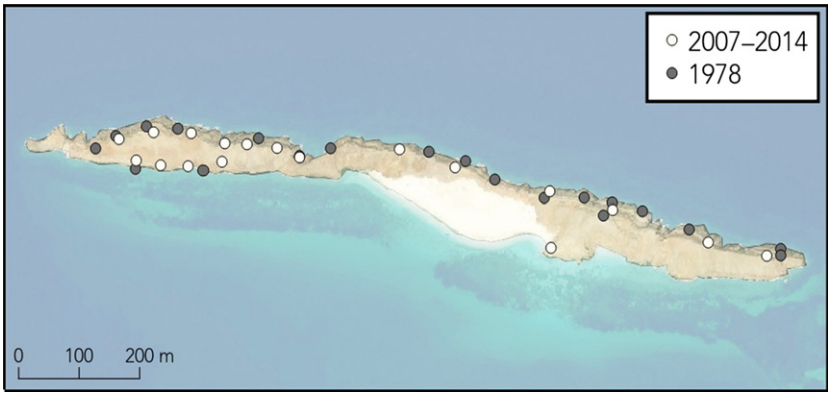

Figure 5. Locations of breeding Sooty Falcons in 1978 (Walter 1979b) and 2007–2014 on D9, Daymaniyat Islands, Oman. NB: Not all nest-sites during the 2007–2014 period were occupied in all years.

permission to land on Fahal Island by the Royal Oman Police. We would particularly like to thank the captains and crew of the *Al Noores* and the MECA rangers for their hospitality and logistical support. M. Al Balushi, A. Al Owisi, Q. Al Rawahi and Z. Abdusalaam were regular assistants to the work on the islands. We would also like to thank Y. Al Salami, A. Spalton, N. Al Sharji, A. Al Amri, A. Al Raisi, J. Knapp, A. Al Kyumi, F. Al Lamki, P. McGrady, A. Thorpe and N. Williams. The help provided by S. Al Sayabi of the Royal Yachts was vital to the success of the work. The work was performed in accordance with the laws of the Sultanate of Oman. All applicable international, national and institutional guidelines for the care and use of animals were followed. We thank D. Chamberlain, K. Burnham, M. Amezian and an anonymous referee for many helpful suggestions.

REFERENCES

Agresti, A. 2015. *Foundations of Linear and Generalized Linear Models*. Hoboken: John Wiley & Sons.

Apostolopoulos, Y. & Gayle, D.J. (eds) 2002. *Island Tourism and Sustainable Development: Caribbean, Pacific and Mediterranean Experiences*. London: Praeger.

Bates, D., Maechler, M., Bolker, B., Walker, S., Christensen, R.H.B., Singman, H., Dai, B., Grothendieck, G. & Green, P. 2016. *Package lme4*. Available at: https://github.com/lme4/lme4/ (accessed 18 February 2018).

Beale, C.M. & Monaghan, P. 2004. Human disturbance: people as predation-free predators? *J. Appl. Ecol.* **41**: 335–343.

Belwal, R., Belwal, S. & Al Jabri, O. 2015. The fisheries of Oman: a situation analysis. *Mar. Policy* **61**: 237–248.

BirdLife International. 2016. *Species factsheet: Falco concolor*. Available at: http://www.birdlife.org (accessed 10 November 2016).

Burger, J. 1981. Effects of human disturbance on colonial species, particularly gulls. *Colon. Waterbirds* **4**: 28–36.

Burton, N.H.K. 2007. Landscape approaches to studying the effects of disturbance on waterbirds. *Ibis* **149**(Suppl. 1): 95–101.

Busch, D.S. & Hayward, L.S. 2009. Stress in a conservation context: a discussion of glucocorticoid actions and how levels change with conservation-relevant variables. *Biol. Conserv.* **142**: 2844–2853.

Carney, K.M. & Sydeman, W.J. 1999. A review of human disturbance effects on nesting colonial waterbirds. *Waterbirds* **22**: 68–79.

Catry, I., Alcazar, R., Franco, A.M. & Sutherland, W.J. 2009. Identifying the effectiveness and constraints of conservation interventions: a case study of the endangered lesser kestrel. *Biol. Conserv.* **142**: 2782–2791.

Coles, T. & Williams, N.P. 2004. *Sooty Falcon Falco concolor: baseline breeding survey, Wadi El Gemal Island and the Qulân Archipelago*. Wadi El Gemal National Park, Red Sea Governorate, 3–10 September, 2004.

Davenport, J. & Davenport, J.L. 2006. The impact of tourism and personal leisure transport on coastal environments: a review. *Estuar. Coast. Shelf Sci.* **67**: 280–292.

Dawson, R.D. & Bortolotti, G.R. 2000. Reproductive success of American Kestrels: the role of prey abundance and weather. *Condor* **102**: 814–822.

Evans, M.I. 1994. *Important Bird Areas in the Middle East*. Cambridge: BirdLife International.

FAO. 2016. *The State of World Fisheries and Aquaculture 2016. Contributing to Food Security and Nutrition for All*. Rome: FAO.

Frid, A. & Dill, M.L. 2002. Human-caused disturbance stimuli as a form of predation risk. *Conserv. Ecol.* **6**: 11. Available at: http://www.consecol.org/vol6/iss1/art11/ (accessed 18 February 2018.)

Frumkin, R. 1984. The Sooty Falcon in Israel. *Land and Nature* **9**: 138–143.

Frumkin, R. 1988. Biologie und Bestimmung des Schieferfalken *Falco concolor*. *Limicola* **2**: 83–109.

Frumkin, R. & Pinshow, B. 1983. Notes on the breeding ecology and distribution of the Sooty Falcon *Falco concolor* in Israel. *Ibis* **125**: 251–259.

Gallo Orsi, U., Williams, N.P., Javed, S. & McGrady, M. 2014. *International single species action plan for the Sooty Falcon Falco concolor*. CMS Raptors MoU Draft.

Gaucher, P., Thiollay, J.-M. & Eichaker, X. 1995. The Sooty Falcon (*Falco concolor*) on the Red Sea coast of Saudi Arabia: distribution, numbers and conservation. *Ibis* **137**: 29–34.

Giese, M. 1996. Effects of human activity on Adélie Penguin *Pygoscelis adeliae* breeding success. *Biol. Conserv.* **75**: 157–164.

Gill, J.A. & Sutherland, W.J. 2000. Predicting the consequences of human disturbance from behavioural decisions. In Gosling, L.M. & Sutherland, W.J. (eds) *Behaviour and Conservation*: 51–64. Cambridge: Cambridge University Press.

Gladstone, W., Curley, B. & Shokri, M.R. 2013. Environmental impacts of tourism in the Gulf and the Red Sea. *Mar. Pollut. Bull.* **72**: 375–388.

Green, R.E. 2004. Breeding biology. In Sutherland, W.J., Newton, I. & Green, R.E. (eds) *Bird Ecology and Conservation*: 57–83. Oxford: Oxford University Press.

Hockin, D., Ounsted, M., Gorman, M., Hill, D., Keller, V. & Barker, M.A. 1992. Examination of the effects of disturbance on birds with reference to its importance in ecological assessments. *J. Environ. Manage.* **36**: 253–286.

Hoy, S.R., Millon, A., Petty, S.J., Whitfield, D.P. & Lambin, X. 2016. Food availability and predation risk, rather than intrinsic attributes, are the main factors shaping the reproductive decisions of a long-lived predator. *J. Anim. Ecol.* **85**: 892–902.

del Hoyo, J., Elliott, A. & Sargatal, J. 1994. *The Handbook of Birds of the World*, **2**: Barcelona: Lynx Edicions.

IUCN 2001. *IUCN List of threatened species. 2001 Categories & Criteria (version 3.1)*. Available at: http://www.iucnredlist.org/static/categories_criteria_3_1 (accessed 15 November 2016).

Kavanagh, B. & King, H. 2008. Observations from 1998–2006 on the breeding population of Sooty Falcons *Falco concolor* on the Hawar Islands, Kingdom of Bahrain. *Sandgrouse* **30**: 70–76.

Martínez-Abraín, A., Oro, D., Jiménez, J., Stewart, G. & Pullin, A. 2010. A systematic review of the effects of

recreational activities on nesting birds of prey. *Basic Appl. Ecol.* **11**: 312–319.

McElroy, J.L. 2003. Tourism development in small islands across the world. *Geogr. Ann.* **85**: 231–242.

McGrady, M., AlFazari, W., AlJahdhami, M.H. & Oli, M.K. 2016. Survival of Sooty Falcons (*Falco concolor*) in Oman. *J. Ornithol.* **157**: 427–437.

McGrady, M.J., AlFazari, W.A., AlJahdhami, M., Nicoll, M.A.C. & Oli, M.K. 2017. Sooty Falcon *Falco concolor* reproduction and population dynamics on the islands in the Sea of Oman. *Ibis* **159**: 828–840.

National Centre for Statistics and Information 2016. *Tourism Index Report*. Muscat: National Centre for Statistics and Information.

National Centre for Statistics and Information 2017. *Population analysis*. Available at: http://www.data.gov.om/en/DataAnalysis (accessed 12 June 2017).

Negro, J.J. & Hiraldo, F. 1993. Nest-site selection and breeding success in the Lesser Kestrel *Falco naumanni*. *Bird Study* **40**: 115–119.

Newton, I. 1979. *Population Ecology of Raptors*. Berkhamstead: T & AD Poyser.

Newton, I. 1998. *Population Limitation in Birds*. London: Academic Press.

PERSGA/GEF 2003. *Status of breeding seabirds in the Red Sea and Gulf of Aden*. PERSGA Technical Series No. 8. Jeddah: PERSGA.

R Core Team 2014. *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Richardson, C.T. & Miller, C.K. 1997. Recommendations for protecting raptors from human disturbance: a review. *Wildl. Soc. B* **25**: 634–638.

Semere, D., Hagos, T., Seleba, G., Gebrezgabhier, Y., Haile, Z., Chiozzi, G. & De Marchi, G. 2008. The status of breeding seabirds and waterbirds on the Eritrean Red Sea islands. *Bull. Afr. Bird Club* **15**: 228–237.

Shah, J.N., Khan, S.B., Ahmed, S., Javed, S. & Hammadi, A. 2008. Sooty Falcon in the United Arab Emirates. *Falco* **32**: 16–19.

Steenhof, K. & Newton, I. 2007. Assessing nesting success and productivity. In Bird, D.M. & Bildstein, K. (eds). *Raptor Research and Management Techniques*: 181–192. Surrey: Hancock House.

Strasser, E.H. & Heath, J.A. 2013. Reproductive failure of a human-tolerant species, the American Kestrel, is associated with stress and human disturbance. *J. Appl. Ecol.* **50**: 912–919.

Walter, H. 1979a. *Eleonora's Falcon: Adaptations to Prey and Habitat in a Social Raptor*. Chicago: Chicago University Press.

Walter, H. 1979b. The Sooty Falcon (*Falco concolor*) in Oman: results of a breeding survey, 1978. *J. Oman Stud.* **5**: 9–60.

Zuur, A.F., Ieno, E.N., Walker, N., Saveliev, A.A. & Smith, G.M. 2009. *Mixed Effects Models and Extensions in Ecology with R*. New York, NY: Springer.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. Numbers of breeding pairs of Sooty Falcon on Fahal and the Daymaniyat Islands (D1–D9), Oman, during 2007–2014, and as reported by Walter (1979b) for 1978. A = Accessible; I = Inaccessible. Data from limited field work on the Sawadi Islands (S1–S7; ca. 23.788°N, 57.789°E) and from Walter (1979b) are also given. Data from the Sawadi Islands were not used in analyses. Mean (±se) island area = 9.79 ± 11.19 ha, median = 2.91 ha.

Table S2. Results of generalized linear mixed model (GLMM) testing for the effect of island area, distance to beach, accessibility of the islands and linear temporal trend on Sooty Falcon nesting success. Island group (Daymaniyat or Fahal) was included as a random effect in the model, and 'year' of study was used as a continuous variable. A colon (:) indicates an interaction effect. To account for potential temporal autocorrelation in our data, we used year as an offset.