ORIGINAL ARTICLE

The potential use of artificial nests for the management and sustainable utilization of saker falcons (*Falco cherrug*)

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Abstract Artificial nests are a commonly used management technique to increase the breeding population and/or productivity of birds with nest site limited populations. We compared nest survival of saker falcons breeding in artificial nests erected in a flat steppe landscape with those breeding in natural nests on rocks and cliffs in adjacent hills of central Mongolia. We found no significant difference in daily nest survival during the egg and nestling stages of the breeding cycle. Nest survival varied across years and was higher at artificial than natural nest sites, primarily because of higher survival rates during the egg stage at artificial nests. However, fledgling productivity was not significantly different although artificial nests produced an average of 3.2 fledglings compared to 2.3 at natural nest sites. We found no significant differences in offspring sex ratios and fledgling mass at artificial and natural nest sites. Provision of artificial nests can increase the range, size and productivity of saker falcon breeding populations, a globally endangered species subject to high mortality and trapping for falconry. This management technique can be used for incentive-driven conservation initiatives, whereby sustainable harvest quotas can be generated from demographic models based on parameters derived from a managed and monitored population breeding in artificial nests.

Keywords Saker · *Falco cherrug* · Falcon · Nesting success · Artificial nests · Wildlife utilization

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Zusammenfassung

Der mögliche Einsatz von Kunstnestern für das Management und die nachhaltige Nutzung von Sakerfalken (*Falco cherrug*)

Kunstnester werden häufig beim Artenmanagement eingesetzt, um die Brutpopulation und/oder die Produktivität von Vögeln mit limitierten Nistplätzen zu steigern. Wir haben in der zentralen Mongolei das Überleben der Nester von Sakerfalken, die in Kunstnestern in flachen Steppenlandschaften brüteten, mit dem von in natürlichen Nestern auf Felsen und Klippen in angrenzenden Hügeln brütenden Falken verglichen. Wir fanden keinen signifikanten Unterschied im täglichen Überleben des Nests während der Bebrütungs- und Nestlingsphase. Das Nestüberleben unterschied sich zwischen verschiedenen Jahren und war an künstlichen Nistplätzen höher als an natürlichen, hauptsächlich da Kunstnester höhere Überlebensraten während des Bebrütungsstadiums aufwiesen. Die Flügglingsproduktion unterschied sich jedoch nicht signifikant, obwohl Kunstnester im Durchschnitt 3,2 Flügglinge produzierten und natürliche Nester nur 2,3. Wir fanden zwischen Kunst- und Naturnestern keine signifikanten Unterschiede im Geschlechterverhältnis der Nestlinge und in der Körpermasse der Flügglinge. Die

Bereitstellung von Kunstnestern kann Verbreitung, Größe und Produktivität von Brutpopulationen des Sakerfalken erhöhen, einer global gefährdeten Art, die hohe Mortalität aufweist und für die Falknerei gefangen wird. Diese Managementmethode kann für anreizgetriebene Schutz-initiativen verwendet werden, wobei nachhaltige „Ernte-quoten"anhand von demographischen Modellen errechnet werden können, die auf Parametern basieren, welche von einer gemanagten und überwachten in Kunstnestern brü-tenden Population abgeleitet sind.

Introduction

Human utilization of wildlife resources is a widespread, established and often culturally important practice (Bolton 1997). Sustainable use and the fair and equitable sharing of the benefits arising out of the utilization of wildlife resources are principal objectives, in conjunction with conservation, of the Convention on Biological Diversity (2013). Sustainable and commercial use of wildlife can provide a basis for developing a greater understanding of species biology and ecological interactions (Holling 1993) and encourage the conservation of species and their natural habitats (Aebischer and Ewald 2010). However, biological resources are often over-exploited and their commercial use poorly regulated, and this unsustainable use can threaten the viability of populations (Zahler et al. 2004). Consequently, discussions about the sustainable use of wildlife are often polarized (Hutton and Leader-Williams 2003; Cooney and Jepson 2006), with the potential con-servation benefits of sustainable harvesting (e.g., Beis-singer and Bucher 1992) leaving many conservationists unconvinced, especially when overuse is often a primary factor in species declines (Milner-Gulland and Mace 1998).

The saker falcon (*Falco cherrug*) is the only species in the genus *Falco* with an endangered listing in the IUCN red list, because a population trend analysis has indicated that it may be undergoing a very rapid decline, particularly in Central Asia, with unsustainable capture for the falconry trade considered to be one of the causal factors (IUCN 2012). The Mongolian government has permitted an annual harvest quota of saker falcons for the Arabian falconry market, with this trade being conducted under the auspices of the Convention on International Trade in Endangered Species (CITES). Trappers typically arrive in Mongolia in August to trap saker falcons up until October or November after the falcons have dispersed from their natal sites or summering areas. Figures collated by the UNEP World Conservation Monitoring Centre (UNEP-WCMC) in the CITES trade database indicate that Mongolia has exported an average of 286 (range 25–402) saker falcons per annum

over the period 1997–2010 (Dixon et al. 2011). National and international concern over the sustainability of this Mongolian saker falcon harvest (Zahler et al. 2004) has stimulated the development of a conservation management programme for this species, enabling harvest quotas to be determined by productivity and survival of saker falcons in a monitored population occupying artificial nests (Dixon et al. 2011).

The availability of nest sites can be a major limiting factor for species like saker falcons that do not build their own nests (Newton 1994). Increasing the availability of secure nest sites can lead to an increase in the size and distribution of the breeding population and/or breeding success of species whose numbers or presence are limited by nest site availability (Marsden and Jones 1997; Bolton et al. 2004). Furthermore, it has been demonstrated that individuals breeding in nest boxes can have better survival prospects than those in natural sites (Libois et al. 2012). The provision of artificial nests has formed part of con-servation strategies for various endemic or threatened bird species (Cade and Temple 1995; Jones 2004; Deng et al. 2005; Libois et al. 2012). However, artificial nest site supplementation may also have negative effects, due to the specific characteristics of the artificial nests, the habitats in which they are placed or the subsequent behaviour of the occupants. Thus, conservation programmes employing this technique need to be carefully evaluated (Mänd et al. 2005; Klein et al. 2007; Björklund et al. 2013).

In this study we report on the response of saker falcons to the provision of artificial nests in nest site limited areas and compare nest survival and fledgling productivity at artificial and natural nest sites. We discuss our results in relation to the potential use of artificial nests to underpin a sustainable harvest of saker falcons for falconry.

Materials and methods

Study areas

We monitored the breeding success of saker falcons at two study areas in Töv province, central Mongolia, comprising natural nest sites in the Sergelen district and artificial nests distributed across Bayan and Bayantsagaan districts (Fig. 1). Natural nests were located in a block of hills surrounded by flat and undulating plains and were situated in old or usurped nests built by other species on rock outcrops or cliffs. We established a study area of artificial nests in nest sites in a limited, flat and undulating land-scape. Despite the topographical difference between the natural and artificial nest study areas, they were both characterized by grazed, steppe grassland that supported a similar range of rodent and avian prey species. Whilst the
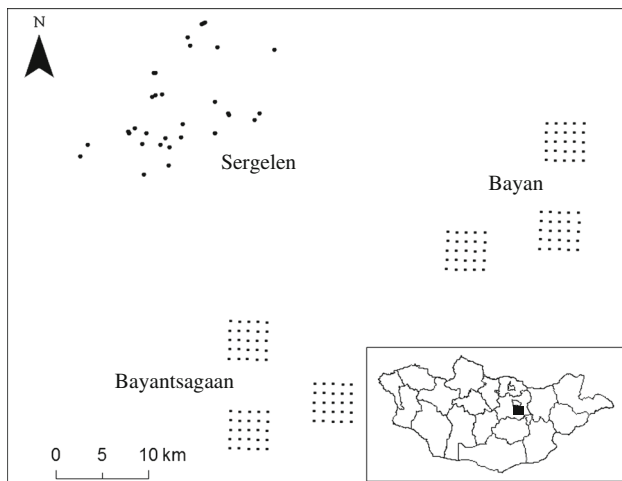
Fig. 1 Location of artificial nest grids (*squares*) and natural nest sites (*circles*) in Mongolia

regional climate was similar, the higher altitude of the hills supporting natural nest sites meant that average temperatures were lower than the adjacent low-lying, flat landscape with artificial nests. Furthermore, potential predators such as the golden eagle (*Aquila chrysaetos*) and the eagle owl (*Bubo bubo*) were more abundant in the natural nest site area (Vaurie 1964; Tumurbat et al. 2009), whilst steppe eagles (*Aquila nipalensis*) occurred in both hilly and flat landscapes (Gombobaatar et al. 2012).

The artificial nest study area consisted of 150 artificial nests erected in six spatially separated grids, each of which was arranged in a 5 × 5 array with nests spaced at 1 km intervals; this grid arrangement enabled us to undertake additional comparative and manipulative studies. For the purpose of this study, we used the Mantel test to determine that there was no autocorrelation in the number of chicks fledged as a consequence of the spatial arrangement of the artificial nests (Chessel et al. 2005). Artificial nests were made from 60 cm diameter steel drums that were cut in half and fitted with a lid, to produce a closed box with a side entrance. Holes were punched in the base for drainage and were lined with a layer of soil and gravel (ca. 5 cm deep), after being bolted on top of a 3 m long steel pole that was fixed in the ground with concrete at a depth of 0.5–0.6 m.

In this study we compare breeding data covering three years from both natural and artificial nests over the period 2007–2009.

Breeding density and territory fidelity

In determining whether or not a nest was occupied we only included nests where at least one egg was known to have been laid. We have expressed annual occupancy levels in terms of the number of breeding pairs in each study region and breeding density (nests/100 km^2). For each year and each study area, we enclosed all nest sites within a minimum convex polygon (MCP) and measured the mean nearest neighbour distance (MNND) between nests. To account for edge effects in our density estimate we drew a circle with a radius of MNND/2 around the outermost nest sites and then enclosed them within a larger 'hypothetical' MCP (e.g., Ratcliffe 1962; Newton et al. 1977).

We used territory fidelity in successive years as a proxy measure of breeding dispersal. At artificial nest grids we considered a territory to be occupied in successive years if the same or an adjacent artificial nest was occupied, whilst in the natural nest study area we considered a territory to be re-occupied when nests in successive years were in the same place or within 2.8 km (chosen because saker falcons are known to move this distance between adjacent sites in a grid of artificial nests spaced at 2 km intervals; Dixon unpublished data). We individually marked 23 breeding saker falcons (13 female and ten male) at 15 artificial nests in 2009 using patagial tags ($N = 13$) and satellite transmitters (PTT, $N = 10$) enabling us to determine nest site fidelity of individuals returning to breed in the artificial nests in successive years.

Nest survival

Over 2007–2009, we monitored a total of 32 artificial nests and 36 natural nests during the nesting period (Tables A1, A2 in Appendix A). Each occupied nest was visited at circa ten days intervals to record the number of eggs and chicks. Chick age was estimated by reference to a photographic chart illustrating 14-stages of growth development for a captive-bred saker falcon chick at 3-days intervals from 1 day to 42 days old. From the nest monitoring data we established a chronology for each nest, where the first egg laying date (FED), unless directly observed, was estimated assuming eggs were laid on alternate days and incubation lasted 35 days from the penultimate egg (Cramp and Simmons 1980; Baumgart 1991). The hatching date, unless directly observed, was estimated by back-dating from an age assessment based on the 14-stage photographic growth chart. Apparent nesting success represents the proportion of successful nests (i.e., where at least one nestling fledged) from all nests with a known outcome.

We used an information-theoretic approach to evaluate the effect of nest site type, year and egg laying date on nest survival at two distinct stages of the nesting period i.e., the egg stage and the nestling stage. Our candidate models evaluated whether or not daily nest survival was constant or varied within these temporal periods (Table A3 in Appendix A). We used the akaike information criterion (AIC) to select the most parsimonious models using ΔAIC_c

to objectively rank sets of candidate models (Burnham and Anderson 2002) and we used normalized AIC_c weights (w_i) to evaluate the strength of evidence for each model considered. Models with $\Delta AIC_c \leq 2$ were considered to be equally parsimonious.

We calculated daily survival rate (DSR) from the weighted average of models that had a normalized AIC weight (w_i) > 0, using the nest survival model in MARK 5.1 (White and Burnham 1999; Dinsmore et al. 2002). Comparisons of DSR between egg and nestling stages were made using CONTRAST (Hines and Sauer 1989). We estimated the cumulative probability of a nest surviving the egg stage (S_e) from first-egg to hatching for a modal clutch size of four eggs by raising DSR to the power 39 (where 39 represents the number of days from first egg to hatching) and for the nestling stage (S_n) from hatching to fledging by raising DSR to the power 44 (where 44 represents the mean number of days of the nestling period). We calculated standard error (SE) using the delta method (Powell 2007).

Fledged brood size, body mass and nestling sex ratios

To calculate fledged brood size (N_{fl}), we considered nestlings that were observed to have successfully fledged from the nest or that were at least 30 days old on the last monitoring visit; no nestlings at least 30 days old were known to have died before fledging ($N = 126$ nestlings). We determined offspring sex using genetic markers (Griffiths et al. 1998; Zhan unpublished data) and compared the overall sex ratio and mean body mass of chicks aged 36–42 days old that fledged from artificial and natural nest sites in 2008 only. There was no significant difference in the mean weight of chicks that were 36 days old and those that were 42 days old for both male ($t = -1.4$, $N = 62$, $P = 0.16$) and female ($t = -086$, $N = 56$, $P = 0.39$) nestlings.

We investigated the influence of nest site type and year on fledged brood size at successful nests in a generalized linear mixed model assuming a Poisson (log link) distribution. We set nest identity and year as random variables because there were observations from the same nesting ranges in different years, and annual variation in environmental factors, such as food availability, can potentially influence brood size. Sex ratios were compared using the χ^2 test and body mass of chicks using the Student's t test. All analysis was carried out using R Development Core Team, 2003.

Fledgling productivity

We calculated the productivity of fledglings i.e., the product of nest survival rates at the egg stage (S_e) and nestling stage (S_n) multiplied by the mean number of young
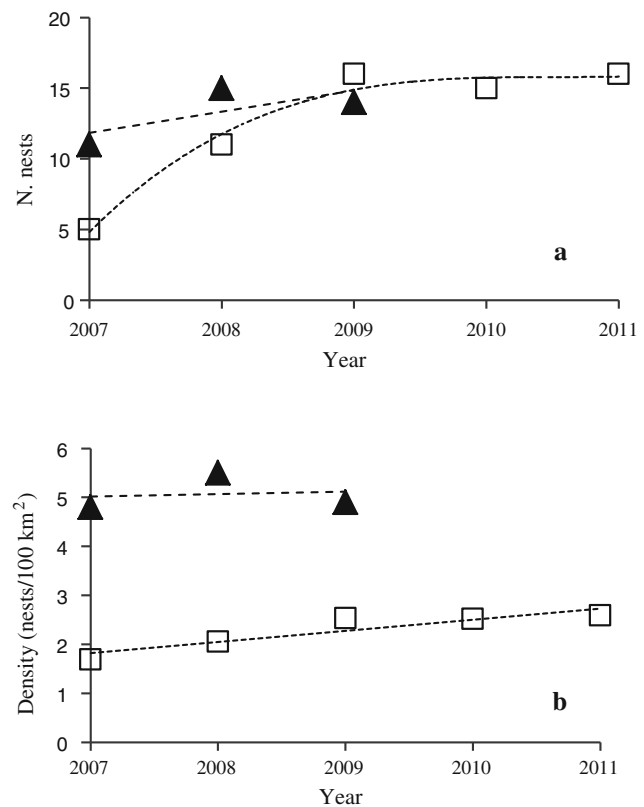

Fig. 2 a Number of saker falcon nests and **b** saker falcon breeding density per 100 km^2 for artificial nests (*squares*) and natural nests (*triangles*)

fledged from successful nests (N_{fl}) at artificial and natural sites: $= S_e \times S_n \times N_{fl}$.

Results

Breeding density and territory fidelity

Prior to establishment of the artificial nests, there were no saker falcons known to be breeding in this flat and undulating area. In the first year after nest sites had been provided, five pairs bred in our study area and the number of breeding pairs increased in the following two years to reach 15–16 breeding pairs in subsequent years to 2011 (Fig. 2a), corresponding to a breeding density of 2.5–2.6 breeding pairs/100 km^2. At natural sites annual breeding density ranged from 4.8 to 5.5 breeding pairs/100 km^2 and remained relatively stable over our study period (Fig. 2b).

At artificial nest grids, 77 % of saker falcon nests ($N = 47$) were either in the same place or an adjacent artificial nest 1.0–1.4 km away in successive years, whilst at natural nest sites 86 % of nests ($N = 40$) were either in the same place or <2.8 km away, suggesting a high degree of territory fidelity and limited breeding dispersal. At
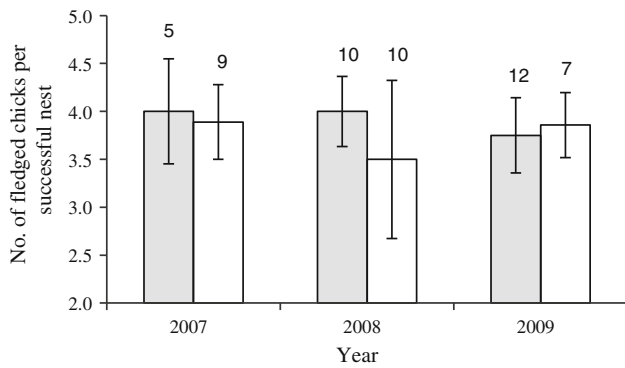
Fig. 3 Mean number of fledglings (±SE) per successful nest at artificial (*grey column*) and natural nest (*white column*) sites. Values above *columns* show number of nests

Table 1 Daily nest survival rate models at different stages of the nesting period (*N* number of nests)

Nest stage	Model	AIC$_c$	ΔAIC$_c$	w_i	K
Egg stage (*N* = 61)	S (.)$_{Site\ type}$	49.61	0.00	0.63	2
	S (.)$_{Site\ type\ +\ Year}$	51.52	1.91	0.24	3
	S (.)	53.38	3.77	0.10	1
	S (.)$_{FED}$	55.35	5.74	0.03	2
	S (.)$_{Year}$	55.36	5.75	0.04	2
Nestling stage (*N* = 60)	S (.)$_{Year}$	51.28	0.00	0.63	2
	S (.)$_{Site\ type\ +\ Year}$	52.87	1.59	0.29	3
	S (.)	55.99	4.71	0.06	1
	S (.)$_{FED}$	57.89	6.61	0.02	2
	S (.)$_{Site\ type}$	57.97	6.69	0.02	2

All models feature a time trend term of constant survival (.). Models are ranked by ascending ΔAIC$_c$ with a difference <2 indicating equal fit; w_i is the normalized AIC weight and K is the number of parameters

artificial nest sites, none of the individually marked breeding adults dispersed further than 4 km from their nest site of the previous year and the mean breeding dispersal distance was 1.07 km (±0. 22 km; *N* = 9). We found that 89 % of returning saker falcons (*N* = 9) bred either in the same place or an adjacent artificial nest 1.0–1.4 km away in successive years, corresponding closely to breeding dispersal inferred by nest site shifts across years.

Nest survival

For nests with a known outcome, apparent nest survival was higher at artificial sites (0.844, *N* = 32) than natural sites (0.684, *N* = 38), though not statistically significant (χ^2 = 1.6, *df* = 1, *P* = 0.20). We recorded two (6.2 %) nest failures during the egg stage and three (9.3 %) during the nestling stage at artificial sites, and the corresponding nest failures at natural sites were nine (23.7 %) and three (7.9 %), respectively. The cause of nest failure at the egg stage in artificial sites was nest desertion (*N* = 1) and clutch infertility (*N* = 1), whilst at natural sites failure was caused by predation (*N* = 2), death of adult female (*N* = 3), clutch disappearance (*N* = 3) and clutch infertility (*N* = 1). During the nestling stage the cause of failure at artificial sites was chick disappearance (*N* = 2) and predation (*N* = 1), whilst at natural sites failure was caused by chick disappearance (*N* = 3).

The models that best explained variation in nest survival were based on constant survival; during the egg stage of the nesting period the most parsimonious models included site type as a covariate, with year as an additive covariate, whilst during the nestling stage the best fitting models included year as a covariate, with site type as an additive covariate (Table 1). We found no significant difference in DSR between the egg and nestling stages both at artificial (χ^2 = 0.082, *df* = 1, *P* = 0.77) and natural sites (χ^2 = 2.27, *df* = 1, *P* = 0.13). Survival was higher at artificial sites compared to natural sites during the egg stage, consequently overall nest survival was higher 0.834 ± 0.074 (95 % CI: 0.689–0.978) at artificial sites than natural sites 0.615 ± 0.108 (95 % CI: 0.403–0.827; Table B1 in Appendix B).

Fledged brood size, body mass and nestling sex ratios

We found no influence of year or site type on the number of nestlings fledged from successful nests at artificial and natural sites (Site: *Z* = −0.34, *P* = 0.73; Year: *Z* = −0.25, *P* = 0.79; Fig. 3).

Although more males were produced at artificial nests, the sex ratio of nestlings at artificial and natural nests was not significantly different (1:0.6, *N* = 33 and 1:1.6, *N* = 31 for male: female ratios in artificial and natural sites respectively; χ^2 = 2.25, *df* = 1, *P* = 0.12). We also found no significant difference in the body mass of nestlings of 36–42 days old at artificial and natural nest sites for both sexes (Male: artificial 924 ± 15.9 g, *N* = 50; natural 930 ± 7.4 g, *N* = 12; *t* = −0.71, *df* = 12.2, *P* = 0.49. Female: artificial 1,096 ± 23.2 g, *N* = 37; natural 1,156 ± 24.3 g, *N* = 19; *t* = −0.51, *df* = 22.4, *P* = 0.61).

Productivity

Productivity at fledging was higher at artificial nests than natural nests, though not significantly so, with an average of 3.24 ± 0.34 fledglings produced at artificial sites compared to 2.29 ± 0.43 fledglings at natural sites (*Z* = 1.73, *df* = 1, *P* = 0.08).

Discussion

The use of artificial nests is a well-documented conservation technique that can be used to increase breeding distribution and density (Cade and Temple 1995). In our study, saker falcon breeding density increased following the erection of artificial nest sites, with no evidence of breeding dispersal from adjacent natural nests, indicating that this management technique can be used to create new breeding populations in areas where no birds or only non-breeding birds existed previously. Non-breeding adults are known to be prevalent in stable raptor populations (Newton 1979, 1998; Kenward et al. 2000). As expected, observed nest survival was similar to modelled survival at artificial nests (0.84 cf. 0.83), but was higher at natural sites (0.68 cf. 0.62) because not all nests were found at the same time, with some being found at later stages in the breeding cycle (see Mayfield 1975). Daily nest survival rates were dependent on nest site type and annual variation, but despite producing more fledglings than natural nests, there was no significant difference in productivity at artificial and natural nests. Nevertheless, this result confirms that artificial nests can be used as a management tool to increase the size of saker falcon breeding populations and, hence, overall productivity. Previous studies have also demonstrated that nesting success of raptors at artificial nests is higher or similar to those in natural nests (e.g., American kestrel *Falco sparverius*: Toland and Elder 1987; Katzner et al. 2005; Eurasian kestrels *Falco tinnunculus*: Charter et al. 2007). Recruitment into artificial nests could potentially reduce the non-breeding population and have a negative impact on the stability and dynamics of the breeding population (Penteriani et al. 2005), although any initial reduction could be compensated by productivity of the newly recruited breeding pairs at artificial nests.

The observed difference in nest survival was due mainly to higher rates of failure during the incubation stage of the breeding cycle at natural nest sites. Common causes of nest failure at natural nest sites included predation and the unexplained disappearance of eggs/nestlings; it is likely that most of the eggs and chicks that disappeared were also predated. At natural sites, eagle owls were important nest predators, sometimes killing and eating brooding adults as well as nestlings (Dixon personal observation; Tumurbat et al. 2009). Fargallo et al. (2001) also reported higher predation levels at natural nest sites compared to nest boxes for Eurasian kestrels in Spain. Another cause of nest failure at natural sites was the death of three females during egg-laying, possibly a consequence of 'cold-stress' due to the exacerbating effect of wind chill at very low ambient temperatures. The enclosed nest boxes provided a degree of protection against strong wind and differences in micro-climate at nest sites can potentially have consequences for reproductive success (Butler et al. 2009; Charter et al. 2010; but see Wiebe 2001).

Artificial nests can increase saker falcon breeding populations only in nest site limited areas where there is a surplus of non-breeding adults available to occupy the nests (Newton 1998). Consequently, the technique is of limited value for conservation management of breeding populations that are declining due to factors other than nest site availability. However, enhancing the range, size and productivity of breeding populations can have a conservation benefit by ameliorating the impact of density-independent mortality factors such as electrocution (Dixon et al. 2013; Lehman et al. 2007) and illegal trapping (Zahler et al. 2004; Zhang et al. 2008). Furthermore, our study indicates that artificial nests can potentially be used to establish a readily monitored population to compensate a regulated harvest for international trade of saker falcons, as an alternative to unregulated illegal trade (Dixon et al. 2011). In a monitored population, where vital rates can be determined and modelled, it is possible to derive quotas to support a managed and sustainable saker falcon harvest for falconry whilst maintaining a stable population.

Falconry is an important aspect of regional cultural heritage in the Arabian Gulf, with the use of wild saker falcons regarded as a cultural norm by many Arabian falconers (Seddon and Launay 2008; Wakefield 2012). There is no incentive for nest robbery at artificial nests because free-flying falcons are harvested for Arabian falconry, preferentially juvenile females that are trapped away from the natal area after post-fledging dispersal (Barton 2000), a bias that must be incorporated into demographic models for harvest quotas (Ginsberg and Milner-Gulland 1994). Debate about conservation of the saker falcon is polarized, in common with similar debates for other iconic species subject to utilization (e.g., marine turtles: Campbell 2002; African elephant *Loxodonta Africana*: Stiles 2004; and tiger *Panthera tigris*: Lapointe et al. 2007; Gratwicke et al. 2008a, b). The apparent dichotomy between use and conservation has been at the centre of a CITES significant trade review for the saker falcon and the resolution of this conflict is an objective of the saker task force established by the convention of migratory species (Dixon 2012). Sustainable use is a key element of the convention of biological diversity, yet incentive-driven conservation based on utilization is rarely implemented and remains controversial (Abensperg-Traun 2009; Harris et al. 2013; Weinbaum et al. 2013). The technique of population management described in this study, combined with the application of demographic modelling, provides a rare opportunity to develop a model conservation programme based on sustainable use.

Conclusions

This study establishes that artificial nests can be used as a management technique to enhance saker falcon productivity by increasing the breeding population in areas where lack of nest sites is the primary limiting factor and there are pre-existing non-breeding recruits available to occupy the artificial nests. Artificial nests can potentially be used to establish a readily monitored population, from which demographic parameters can be modelled to establish quotas for the sustainable harvest and international trade of saker falcons for Arabian falconry. Concomitantly, management deploying artificial nests will increase the overall breeding and non-breeding population to mitigate against the potential impact of density-independent mortality on the population.

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