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Home range and habitat selection of Cape Vultures *Gyps coprotheres* in relation to supplementary feeding

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ABSTRACT

Capsule: Supplementary feeding stations provide a useful conservation benefit for vultures, without disrupting their natural movement ecology.

Aims: To understand the effects of providing supplementary food on the movement ecology of vultures.

Methods: We used Global Positioning System tracking devices to monitor the movements of 28 Cape Vultures *Gyps coprotheres* using feeding stations in South Africa. We calculated home range values and then performed a habitat selection analysis.

Results: We show that aside from roost sites, vulture feeding stations are the most important environmental variable that explains vulture movements. However, we found that the birds ranged over areas without supplementary food and their mean home range values were comparable to those measured before the inception of feeding stations.

Conclusion: Our findings suggest that the use of supplementary feeding sites did not significantly impact on the natural foraging behaviour of the species.

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Ensuring the conservation of birds is frustrated by their tendency to range over large areas (Choi *et al.* 2015, Runge *et al.* 2015). This can be exacerbated by habitat fragmentation which typically causes an increase in foraging range (Haskell *et al.* 2002). Conservationists may counter such human–wildlife conflict by providing supplementary food, an action that is also practiced by the public (Robb *et al.* 2008). Indeed, such actions have allowed for the re-establishment of Red Kites *Milvus milvus* in the UK (Orros & Fellowes 2015); can increase breeding productivity (Robb *et al.* 2008) and have been cited as the reason for the success of vultures in the Western Palearctic relative to populations elsewhere (Donazar *et al.* 2009). This strategy is not without its shortcomings though; a dependency on human-supplied food can have disastrous consequences if the supply is terminated (Donazar *et al.* 2009). It has also been linked to changes in foraging behaviour, disease spread and territory defence behaviour (Robb *et al.* 2008 and references therein).

In the case of vultures, their dependence on ephemeral carrion means they have especially large ranges (Ruxton & Houston 2004) which can result in them moving into countries with different wildlife management agendas (Kane *et al.* 2015). Dedicated supplementary feeding stations for these scavengers, termed ‘vulture restaurants’, have historically been used to sustain their numbers and contain populations within protected areas (Piper 2005). They were initially set up as a conservation tool for the Cape Vulture *Gyps coprotheres* in the 1970s (Mundy *et al.* 1992) and the number of such feeding sites has increased significantly since then (Piper 2005). This strategy appears to have had beneficial effects on vultures by increasing juvenile survival (Piper *et al.* 1999, Margalida *et al.* 2014) and providing supplemental nutrients for growing chicks (Mundy *et al.* 1992). But questions about their potential negative impact on the target species remain. Of great consequence is the danger of poisoning if the supplementary food is not properly regulated such that it is contaminated by pesticides, drugs, and so on

(Piper 2005). Here, we aim to investigate the effect of this commonly used conservation technique on the movement ecology of the Cape Vulture.

Our focal species is a large (9 kg), obligate scavenging vulture endemic to southern Africa (Mundy *et al.* 1992). Like other *Gyps* vultures the bird is known to be wide-ranging (Bamford *et al.* 2007). Seasonal and age differences in home range have been illustrated before in *Gyps* vultures (Monsarrat *et al.* 2013, Phipps *et al.* 2013a, 2013b). This is significant for conservation measures because specific life stages can have a disproportionate impact on the population growth rate, with the adult stage being most sensitive in the case of the Cape Vulture (Monadjem *et al.* 2014).

Old World vulture populations have come under increasing pressure across much of their range from a variety of different threats including direct and indirect poisoning, persecution, habitat loss, electrocution and collisions with energy infrastructure (Carrete *et al.* 2012, Ogada *et al.* 2012, Kendall *et al.* 2014). Although not all species have been similarly affected, the general trend has been towards a reduction in the number of vultures (Ogada *et al.* 2012). Most vulture populations in Africa have been in decline for several decades and the rate of decline appears to have increased recently in parts of the continent (Virani *et al.* 2011).

In the case of the Cape Vulture, almost the entire breeding population is restricted to cliffs situated in South Africa, Botswana and Lesotho, as it has been extirpated as a breeder in Namibia and Zimbabwe (Mundy *et al.* 1992). Indeed, this species is globally 'Endangered' (IUCN 2015) and faces numerous threats, the most important of which are poisoning and collisions with power lines (Piper *et al.* 1999, Bamford *et al.* 2007). Also of concern is the emerging threat of wind turbines to these vultures (Rushworth & Krüger 2014) as evident with the Griffon Vulture *Gyps fulvus* in Spain (Carrete *et al.* 2012). Many of these threats result in a large number of Cape Vultures being rehabilitated each year (Naidoo *et al.* 2011). This has recently been shown to affect their long-term survival and could result in colony extinction (Monadjem *et al.* 2014). Therefore, high resolution data on the movement of these birds and their habitat associations may be of great benefit to sustaining their numbers (Monsarrat *et al.* 2013). To that end we used a dataset of 28 Global Positioning System (GPS) tracked individuals to examine the association between their movements and the distribution of supplementary feeding sites.

We also used the tracking data to test two intuitive predictions about home range variation. First, we expected that the home range of immature birds would

be larger than that of adults due to: adults being constrained by their young; the competition suffered by immature birds at feeding sites near colonies, forcing them to forage farther afield; and the larger body mass of adults hampering their ability to take off in poor weather conditions (Robertson & Boshoff 1986, Mundy *et al.* 1992). This is in line with previous studies but based on small sample sizes (Bamford *et al.* 2007, Phipps *et al.* 2013a, 2013b). We deemed this worthwhile because such information will enable the better placement of supplementary feeding sites.

Second, we hypothesized that adults would have smaller home ranges during the breeding season compared to the non-breeding season, again because they have dependants as well as poor flying conditions during this period (Mundy *et al.* 1992). The breeding season of Cape Vultures also coincides with the dry season. This is a period during which ungulates experience an increased death rate and carcasses may be easier to locate due to lower vegetation cover, thus providing more carrion to scavengers (Mundy *et al.* 1992). This is another factor that could reduce the home range of the birds given that they would encounter food more often during this period.

Methods

In total, we analyzed the movements of 28 Cape Vultures of which 15 were adults (>6 years) and 13 immatures (<6 years). Of these, six were released from VulPro (25.711741°S 27.954476°E), a vulture conservation organization, and the rest were caught and released from four other sites in South Africa: the Rhino & Lion Nature Reserve (Gauteng Province, 25.96280°S 27.77777°E), Mankwe Game Reserve (North West Province, 25.23406°S 27.31259°E), Moholoholo Rehabilitation Centre (Mpumalanga Province, 24.51338°S 30.90479°E) and the Kalahari Raptor Centre (Northern Cape, 27.43380°S 23.17814°E) (online supplementary Table S1). The captured birds were trapped using a walk-in trap (Diekmann *et al.* 2004, Phipps *et al.* 2013b). GPS-Global System for Mobile Communications trackers were fitted to each of the birds. The devices were fitted using a harness made of teflon ribbon, and enclosed with tubing to limit friction. Once fitted, the device and harness runs from the back along the spine, until it splits to run between each leg, to get held in position with a clip at the sternum. Once clipped at the sternum, the harness then separates again, goes across each furculum to attach once again to the device. The harness is tightened to hold firmly by a knot, which is secured by epoxy resin. The VulPro units transmitted GPS

coordinates once every 15 minutes, the others were programmed to transmit three times a day, at 07:00, 11:00 and 15:00 hours (Greenwich Mean Time +2 hours). The data collected spanned from 2007 to 2013, with the birds tracked for a mean (\pm sd) duration of 318 ± 143 days.

Statistical analysis

Home range

We calculated the home range for each individual using kernel utilization distribution methods (KUD) (set to 95%, such that the most extreme points were removed, and with the default reference bandwidth used to calculate the smoothing parameter h ; Worton 1989). We computed mean and standard deviation summary statistics for these home range areas for the individual birds. We tested for the effect of age by using a general linear model (GLM; home range as a function of days tracked + age; Gaussian error structure with identity link). We then used another GLM to check for an effect of season (wet or dry) on both adult and immature birds by using monthly home ranges (home range as a function of age nested within season; Gaussian error structure with identity link). The dry season was defined as May–August (Cooper *et al.* 1988, Mundy *et al.* 1992). We carried out these analyses using base R (v 3.0.1) and the R package *adehabitatHR* (R-Development-Core-Team 2010, Calenge & Fortmann-Roe 2013).

Habitat selection

The package *adehabitatHS* was used to examine habitat selection by the vultures whereby habitat use was compared to availability, with the aim of looking at the effect of vulture restaurants on their movement ecology (Calenge 2011). We first computed the minimum distance between each of the colonies to the nearest restaurant to determine whether or not they were essentially in the same patch for a foraging vulture. We then ran a compositional analysis on the data to test habitat selection for both vulture restaurants and roost sites. This is the approach proposed by Aebischer *et al.* (1993).

We further developed our analysis with a ‘design 2’ study such that habitat availability was measured at the population level whereas habitat use was measured for individual birds (Calenge 2011). We included seven environmental variables in the analysis: altitude of landscape (metres above sea level), biome (as classified by the World Wildlife Fund), land use (as classified by

the Global Land Cover Dataset 2000), protected status of the land (as classified by the World Database on Protected Areas) and topographical ruggedness (which is the difference in altitude between adjacent cells) including the binary variables of supplementary feeding site and breeding colony which were set as having a 2 km radius in our analysis. This owes to the fact that the birds can detect these features from such a distance (Jackson *et al.* 2008). Altitude and topographical ruggedness were numeric variables, whereas the rest were defined as categories.

We used the Outlying Mean Index (OMI) analysis (Dolédéc *et al.* 2000) to determine habitat selection by the vultures. OMI measures the distance between the mean habitat used by the animals and the mean habitat in the sampling area available to the animals (Calenge 2011). Based on this, a principal components analysis was performed to find where the marginality (i.e. the difference between habitat use and habitat availability) was greatest on average (Calenge 2011). In this way it was possible to identify the preferred habitat variables included in the model.

Results

Home range

The tracking data of all birds is shown in Figure 1. With this we showed mean KUD home ranges were $295\,379\text{ km}^2$ ($\text{sd} = 295\,856\text{ km}^2$) for immature birds and $110\,181\text{ km}^2$ ($\text{sd} = 130\,464\text{ km}^2$) for adults (online supplementary Table S1, Figure 2). Mean KUD values for adults during wet and dry season were $75\,162\text{ km}^2$ ($\text{sd} = 130\,832\text{ km}^2$) and $31\,040\text{ km}^2$ ($\text{sd} = 45\,598\text{ km}^2$), respectively (Figure 2). Mean KUD measures for immatures during wet and dry season were $62\,629\text{ km}^2$ ($\text{sd} = 77\,029\text{ km}^2$) and $76\,448\text{ km}^2$ ($\text{sd} = 100\,808\text{ km}^2$), respectively (Figure 2). The average number of restaurants per home range was 21 for adults and 34 for immature birds.

A visual inspection of diagnostic plots from an initial GLM of home range as a function of days tracked and age, revealed three potential outlying data points. The model was run with and without these, and gave similar results; the model without outliers is summarized in Tables 1 & 2. We re-ran the model without them and again found a significant effect of age but no effect of number of days tracked (Table 1). The results of the regression model exploring season for \log_{10} of home range per month indicated a significant effect between season and adult home range, but not season and immature home range (Table 2).

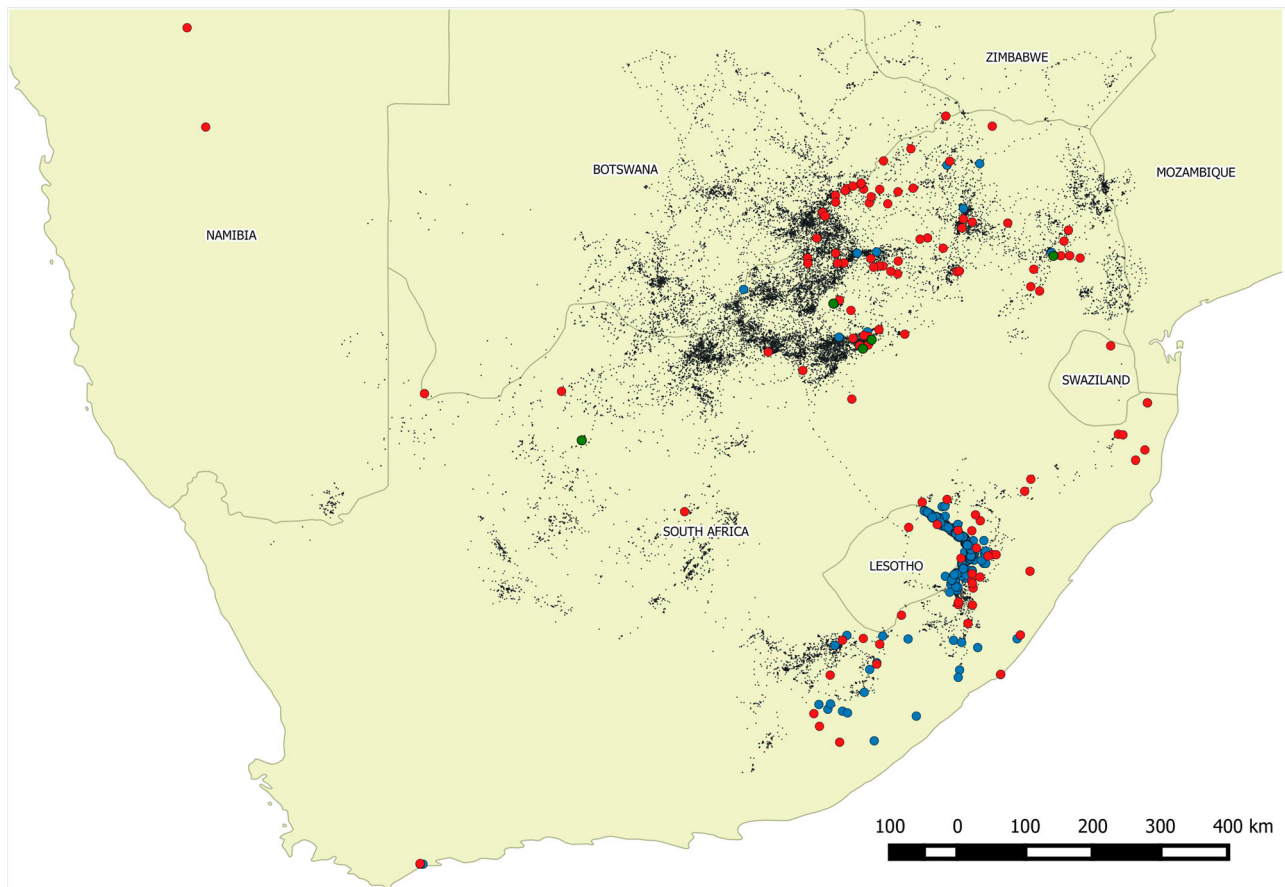


Figure 1. A map of southern Africa showing the distribution of the vulture restaurants (red dots), Cape Vulture roosting/breeding colonies (blue dots), capture sites (green dots) and fixes of the birds tracked in this study (black dots).

Habitat selection

Our compositional analyses found significant habitat selection for both the restaurants (randomization test, $\lambda = 0.072$, $P < 0.05$) and the roost sites (randomization test, $\lambda = 0.35$, $P < 0.05$). In [Figure 3](#) we can see the preference of the birds for their colonies and for vulture restaurants which gives the output of the OMI analysis: this allows us to visualize the association of the individual birds with the environmental variables. The ‘variables’ panel (A) indicates which type of environment the animals favoured. The first axis here is characterized by an association with roosts whereas the second is related to the presence of the vulture restaurants. The ‘samples and species’ panel (B) shows the relationships of each of the 28 tracked birds with the measured environmental variables. From this we can see that one of the birds (AM234B) was strongly associated with the restaurants while many of the others showed an association with the presence of a colony. The two main axes accounted for approximately 98% of the marginality (85% and 13% for the first and second, respectively). We should note that the average

minimum distance between colony and restaurant was 461 ± 290 km (mean \pm sd), indicating that these areas can be treated as different patches and are not, therefore, spatially confounded.

Discussion

Cape Vulture home ranges measured in this study are of the same order of magnitude to those reported in the 1970s, a time when the use of vulture restaurants was only beginning (Jarvis *et al.* 1974). This suggests that, at least in terms of area covered, Cape Vultures are not affected by the presence of these supplementary feeding sites, although it should be noted that these early studies used radio-tracking telemetry which tends to underestimate home ranges. Furthermore, as our map of fixes demonstrates, the birds range over vast areas where there are no restaurants ([Figure 1](#)). This is consistent with the findings of Monsarrat *et al.* (2013) who demonstrated that Griffon Vultures ranged widely despite the availability of supplementary food. Our habitat selection analysis supports this as well; only a single bird seems to have been strongly affected in

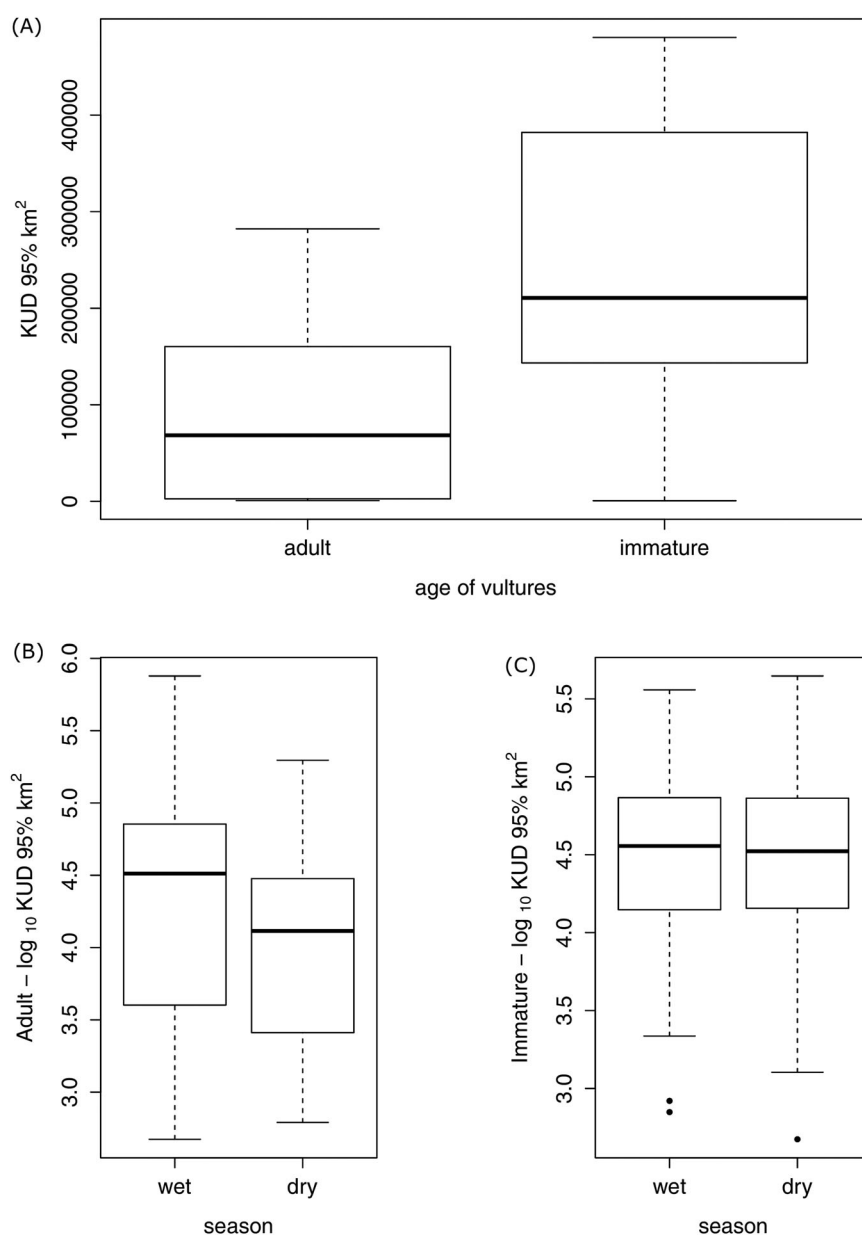


Figure 2. Boxplots of KUD home range as a function of age (a) and of \log_{10} KUD home range as a function of season for adults (b) and immatures (c). Extent of boxes show the interquartile range, the horizontal bar within the box shows the median, the whiskers show the minimum and maximum values excluding outliers.

Table 1. Summary of the generalized linear model of total home range as a function of age and days tracked.

Explanatory variable	Slope	Standard error	t Value	P	df
Days tracked	264.3	170.8	1.547	0.1361	1
Age (immature)	165 966.2	48 408.5	3.428	0.0024	1
Residual df = 22					

terms of its movements by the presence of the restaurants (Figure 3).

The management of supplementary feeding sites in general, and vulture restaurants specifically, is not trivial. Aspects such as their location and the frequency with which they are supplied can have a

significant bearing on the animals they attract (López-López *et al.* 2014, Yarnell *et al.* 2014, Moreno-Opo *et al.* 2015). An important point to bear in mind is that these sites impact adult and immature birds in different ways depending on how they are managed. Duriez *et al.* (2012) showed that adult Griffon Vultures dominated young individuals at artificial feeding sites that were close to colonies and regularly stocked with food. By contrast, 'light' feeding sites, located farther from colonies with less food that was supplied irregularly, were preferred by immature birds. Similarly, Monsarrat *et al.* (2013) showed the same species preferentially searched for regularly stocked

Table 2. Summary of the generalized linear model of \log_{10} home range per month as a function of age, nested within season. Here we allow for separate intercepts to be fitted.

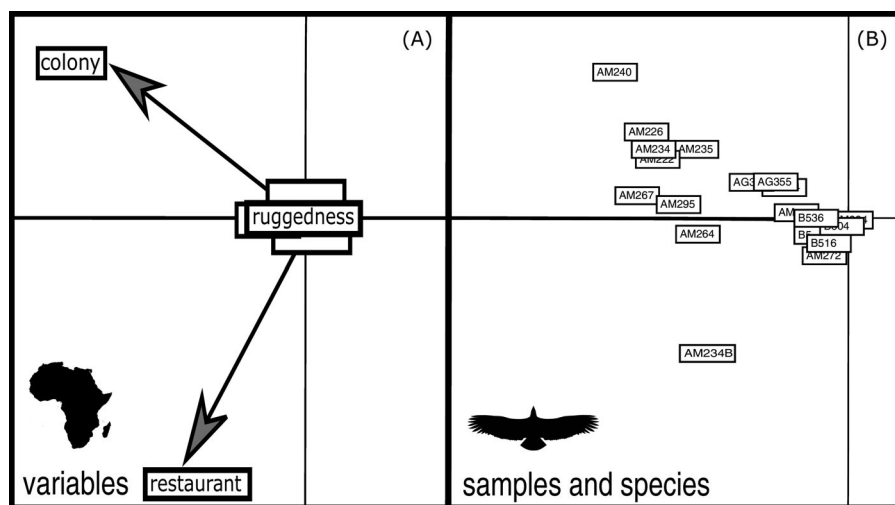
Explanatory variable	Intercept	Slope	Standard error	t value	P-value
Age (adult)	4.02806	–	0.09040	44.556	<0.0001
Age (immature)	4.52904	–	0.09641	46.977	<0.0001
Age (adult) \times season (wet)	–	0.29005	0.11671	2.485	0.0136
Age (immature) \times season (wet)	–	–0.03333	0.12530	–0.266	0.7904
Residual df = 266					

supplementary feeding stations during difficult conditions, either because of low natural food availability which occurs during the European summer or because of poor flying conditions in winter. Conservationists should therefore use a mix of ‘light’ and ‘heavy’ feeding sites if they are to effectively manage both age stages. Unfortunately, we do not have data on the frequency of food supply to the restaurants across our study area (but see below). However, the knowledge we have on the variation in home range size over time, that is the effect of both age and season, should help conservationists in their placement of vulture restaurants. We suggest that the ‘light’ sites be placed outside of the foraging radius of breeding colonies. By knowing where they forage, how much food they require and the drivers of variation in their home range, conservationists are better placed to sustain Cape Vulture populations in southern Africa.

We can compare our results with those of a UK-based Red Kite study which showed that the birds regularly use supplementary food (Orros & Fellowes 2015). This was to the extent that they were observed in residential areas significantly more so than other habitats. It was

also true that the release sites were close to feeding sites which impacted the subsequent expansion of the birds. A greater reliance by the kites on such supplies may be expected because of the relatively lower potential for birds to discover natural carrion in the intensively impacted habitats of the UK compared to southern Africa. Accordingly, we need to be wary of drawing sweeping comparisons with other, decidedly, different species.

With these caveats in mind we can also remark upon the benefits these feeding sites have in raising public awareness about the plight of threatened birds. Indeed, it is often the lay public who are involved in feeding the birds and, in the case of vultures, observing them at restaurants open for tourists. This can feed back into scientific benefits too, for example, the public campaigns run in southern Africa encourage people to report resightings of marked birds, which have helped to create data which can be used to ascertain the health of the bird population (Monadjem *et al.* 2014). This sort of activity could overcome a shortcoming of remote spatial analyses in that we could quantify the frequency with which these birds are using specific sites.

**Figure 3.** The output from the OMI analysis. The variables panel (a) shows that the presence of restaurant and of colony affects the movements of the birds. In the samples and species panel (b), the association of individual birds with these environmental types is displayed. For instance, AM234B is situated in the bottom left of the panel and is therefore associated with restaurants, whereas AM240 is situated in the top left panel and therefore associated with roosts. The first axis accounts for 85% of the marginality and the second axis 13%.

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