

# Reinventing mutualism between humans and wild fauna: insights from vultures as ecosystem services providers

Laura Gangoso<sup>1</sup>, Rosa Agudo<sup>1</sup>, José Daniel Anadón<sup>2</sup>, Manuel de la Riva<sup>1</sup>, Ahmed Saeed Suleyman<sup>3</sup>, Richard Porter<sup>4</sup>, & José Antonio Donazar<sup>1</sup>

<sup>1</sup> Department of Conservation Biology, Estación Biológica de Doñana (CSIC), Avda. Américo Vespucio s/n, E-41092 Sevilla, Spain

<sup>2</sup> Department of Ecological Modeling, UFZ–Centre for Environmental Research, D-04301 Leipzig, Germany

<sup>3</sup> Socotra Archipelago Conservation and Development Programme, P.O. Box 16494, Sana'a, Yemen

<sup>4</sup> BirdLife International, Wellbrook Court, Girton Road, Cambridge CB3 0NA, UK

## Keywords

Conservation dilemma; economic development; ecosystem services; Egyptian vulture; human-vulture mutualism; Socotra; urban biomes; waste management.

## Correspondence

Laura Gangoso, Department of Conservation Biology, Estación Biológica de Doñana (CSIC), Avda. Américo Vespucio s/n, E-41092 Sevilla, Spain. Tel: +34 954466700; Fax: +34 954621125. E-mail: laurag@ebd.csic.es

## Received

10 May 2012

## Accepted

9 August 2012

## Editor

Dr. Rudolf de Groot

doi: 10.1111/j.1755-263X.2012.00289.x

## Abstract

In parallel with economic and social changes, mutualism in human-vulture relations has virtually disappeared worldwide. Here, we describe the mutualistic relationship between humans and the globally threatened Egyptian vulture in Socotra, Yemen. By analyzing both the spatial distribution of vultures and the amount of human byproducts they consume, we show that human activities enable the maintenance of the densest population of this rare scavenger, whereas vultures provide a key regulating service by disposing of up to 22.4% of the organic waste annually produced in towns. Globalization is impacting the archipelago, and therefore policies that better integrate societal needs and biodiversity conservation are urgently needed. We propose a win-win solution that relies on the restructuring of the mutualism, shifting from regulating services toward cultural services. Our study highlights the necessity of reconciling trade-offs between biodiversity conservation and economic development in a framework of global change affecting Middle Eastern countries.

## Introduction

Ecosystem services are defined as the benefits people obtain from ecosystems (Millennium Ecosystem Assessment 2005). The populations or species responsible for providing a particular ecosystem service can be described as service-providing units (Luck *et al.* 2003). Higher vertebrates and birds in particular are well-known ecosystem service providers (Whelan *et al.* 2008). Services may arise via bird-products (meat, guano, clothes, etc.), which are classified as provisioning services, or via behavior, mainly foraging behavior, which provides regulating services (scavenging of carrion and waste, controlling pest populations, pollinating and dispersing plants) and supporting services (cycling nutrients and contributing to soil formation). Finally, the mere presence of birds provides

cultural services (role of birds in art and religion or bird-watching tourism) (Whelan *et al.* 2008).

The ecosystem services provided by birds mainly occur beyond urban boundaries, but can occasionally take place within highly anthropized (human-altered) environments. Urban areas represent particular ecosystems that, in general, bring about a drastic modification of natural conditions at multiple scales (Grimm *et al.* 2008). Urbanization causes generalized habitat (H) degradation and biodiversity loss, potentially leading to the disappearance of natural processes. Urban-related alterations also include pollution as well as the proliferation of infrastructures (e.g., roads, power lines, etc.) and alien species. Although most species are displaced from human-altered environments, some synanthropic ones may be able to thrive in these a priori hostile

HS (McKinney & Lockwood 1999), and even become widespread and locally abundant (Marzluff 2001) by obtaining benefits from either bottom-up (e.g., increase in food abundance) and/or top-down effects (e.g., decrease in predation/persecution). Occasionally, these species are considered pests and the targets of eradication campaigns to avoid nuisance and the spread of infectious diseases (e.g., Battersby *et al.* 2002; Lavine 2011). However, urban species may also provide key ecosystem services, although this is often overlooked by ecologists and natural resource managers (Wenny *et al.* 2011, but see Markandya *et al.* 2008). Therefore, in the case of threatened species, the identification, comprehension, and preservation of mutualistic relationships could be critical from a conservation perspective.

Here, we describe an exceptional case of a mutualistic relationship between humans and one of the most threatened vulture species worldwide, the Egyptian vulture (*Neophron percnopterus*), which occurs in the Socotra archipelago, a recognized insular biodiversity hotspot (UNEP/WCMC 2008). To disentangle human-vulture mutualism, we first assessed whether vulture abundance and distribution is influenced by human settlement (HS) distribution. We then quantified the magnitude of the regulating service provided by vultures. Because understanding the trade-offs among biodiversity conservation, economic development and societal needs is critical for developing effective conservation strategies, we finally propose policy choices to better reconcile vulture conservation and socioeconomic development on Socotra Island. This example provides an exceptional opportunity to gain insight into the study of bird-human relationships with important implications for the fields of urban ecology, ecosystem services, biodiversity conservation, and environmental economics.

## Methods

### Study system

The Socotra archipelago is located about 100 km east of the Horn of Africa and 380 km south of the coast of Yemen. The archipelago is considered a biodiversity hotspot and endemism is high at the species level in both plant and animal kingdoms (Van Damme & Banfield 2011). There are no indigenous medium or large-bodied mammals on the archipelago (Cheung & DeVantier 2006), except for domestic herbivores introduced 11,000 years ago (Cerny *et al.* 2009). Currently, it is estimated that around 9,000 cows (*Bos taurus*), 300,000 goats (*Capra hircus*), and 92,000 sheep (*Ovis aries*), as well as 1,300 donkeys (*Equus asinus*) and 1,300 camels (*Camelus dromedarius*) are present on the largest island, also called Socotra (F. Pella & M. Fasola, personal communica-



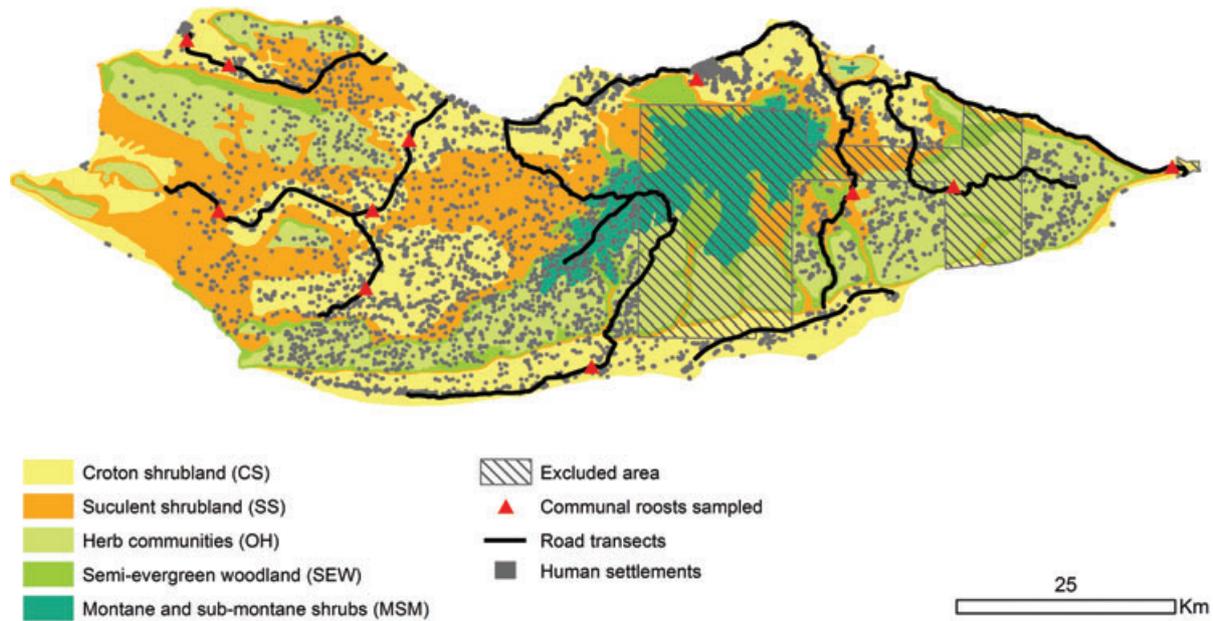
**Figure 1** Socotra has the highest density of Egyptian vultures known worldwide. These vultures are appreciated and not persecuted by local people, probably contributing to the success of the vulture-human mutualistic relationship.

tion, 2011). Traditional agricultural, fishing, and livestock practices have persisted until the present, likely favored by the geographic isolation of the archipelago and the existence of strong seasonally reversing monsoon winds (Van Damme & Banfield 2011). Socotra is home to about 50,000 inhabitants, the majority of which live in two towns: Hadiboh (32,300 people) and Qalansiyah (10,600 people) (Cheung & DeVantier 2006).

The Egyptian vulture is a medium-sized (about 2 kg) Old World scavenger (Figure 1) that lives in open landscapes in arid and rugged regions. It breeds territorially but congregates in large numbers at communal roosts and feeding locations (del Hoyo *et al.* 1994). The species' dependence on livestock varies locally, but it can be strong in places that lack native medium-sized and large mammals, such as the Canary Islands (Gangoso *et al.* 2006). The Egyptian vulture maintains continental long-distance migratory populations and sedentary insular demes in Macaronesian, Mediterranean, and Ethiopic archipelagos. Global populations have been reduced to 30,000–40,000 mature individuals and the species are considered “Endangered” (BirdLife International 2011). Socotra has the highest density of Egyptian vultures known worldwide (0.22 breeding pairs (bp)/km<sup>2</sup>; Porter & Suleyman 2012). This value contrasts sharply with the estimated density for the second densest population (Iberian Peninsula: 0.052 bp/km<sup>2</sup>, Cortés Avizanda *et al.* 2009) or to that observed in other insular populations such as the Canary Islands (0.02 bp/km<sup>2</sup>, authors own data) and Sicily (0.0003 bp/km<sup>2</sup>, Sará *et al.* 2009).

### Vulture distribution

To assess what factors are influencing vulture distribution on the island, we performed roadside transects



**Figure 2** Distribution of the main habitat types on Socotra Island (see details in Supporting Information). Road transects, human settlements, and sampled communal roosts are also shown. Note that human settlements have been enlarged for representation purposes. The excluded area (striped polygon) indicates the area where no information on human settlements was available due to cloud cover in the satellite images.

( $n = 11$ ) during an 8-day period, covering a total of 400 km (Figure 2). The relative importance of HSs and H in explaining the abundance and distribution of Egyptian vultures was assessed by means of deviance partitioning analysis. For the analysis, road transects were divided into 1-km units ( $n = 370$ ). Each unit was characterized by a group of variables describing HS and nonanthropogenic attributes of the H. HS variables included: distance to Hadiboh (DHAD) and the percentage of area occupied by HSs in 250, 500, 1,000, 2,500, and 5,000 m radii (designated as HS250, HS500, HS1000, HS2500, HS5000, respectively). H variables included: distance to the coast (DCOAST), altitude (ALT), percentage of every vegetation type within 250, 500, 1,000, and 5,000 m radii (i.e., shrubland [CS]; succulent shrubland [SS]; semievergreen woodland [SEW]; open and wooded herb community [OH]; mountain and semimountain shrubland and woodland [MSM]) (Figure 2). In addition, vulture abundance in villages was estimated by conducting bird counts in HSs. See full methods in Supporting Information.

### Quantification of the service

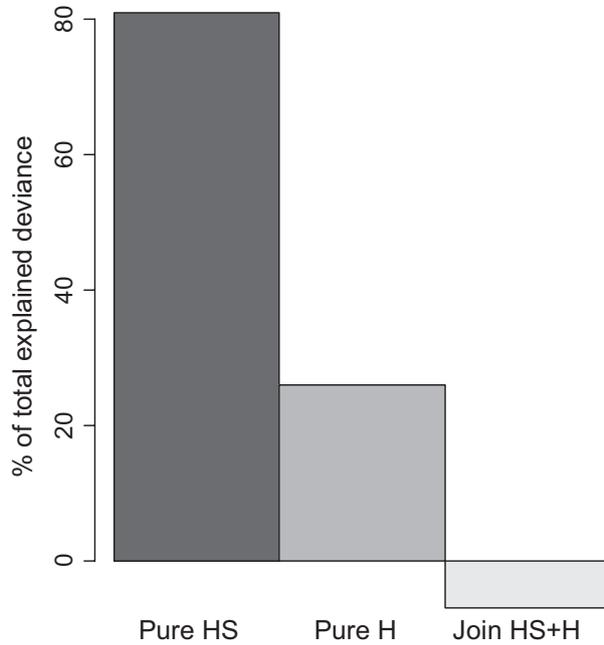
We assessed the contribution of vultures to the regulating service, that is, the disposal of waste, carrion, and excrement, by analyzing the content of pellets ( $n = 332$ ) collected from 11 different communal roosts. In addition,

we calculated field metabolic rate and daily food requirements of individual vultures (see full methods in Supporting Information).

## Results

### Culture distribution

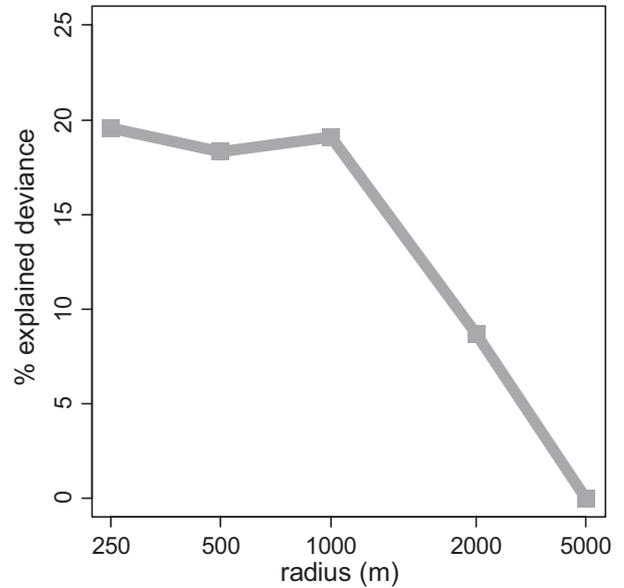
Deviance partitioning analysis showed that the distribution of Egyptian vultures on Socotra was mostly explained by the presence and density of HSs (Figure 3). While variables describing (HS) accounted for 81% of the explained deviance, the pure effect of nonanthropogenic attributes of the H was responsible for 26%. With regard to the single variables considered, multivariate generalized linear models for HS included a positive response to both HS density within a small radius (HS250  $D^2 = 19.58$ ; HS1,000  $D^2 = 22.28$ ) and the DHAD ( $D^2 = 26.34$ ; where  $D^2$  is the accumulated% of deviance explained by the model). This result indicated that the highest abundances of Egyptian vultures were located in close proximity or within HSs, a pattern also supported by the explicative power yielded for every HS variable, which decreased as the considered radius increased (Figure 4). Multivariate models for H included only a negative response to the DCOAST ( $D^2 = 6.55$ ); demonstrating that vegetation/landscape types play a very marginal role in the distribution patterns of Egyptian vultures.



**Figure 3** Results of the deviance partitioning analysis for the abundance of the Egyptian vulture on road transects. Explained deviance values (as a percent of the total explained deviance) are shown as bars.

### Quantification of the service

The minimum food requirement of an Egyptian vulture was calculated as 265 g/day. Considering a total population of 1,900 individuals as suggested by Porter & Suleyman (2012), Egyptian vultures would consume up to 503.50 kg of organic matter per day, or 183.78 tons per year. Our field observations indicated, however, that the estimated size of the population calculated by Porter & Suleyman might be quite conservative. We recorded a total of 996 individuals during the bird counts at villages [fledglings (0.10%), 1–2 years (12.27%), 2–3 years (5.12%), 3–4 years (4.23%), 4–5 years (0.20%), and  $\geq 5$  years old (78.12%)]. In addition, we recorded 1,105, 925, and 1,113 individuals (mean = 1,047.5) in three different counts respectively, flying to roosting sites in Hadiboh. Considering an adult population of 1,000 bp (Porter & Stone 1996) and using the proportion of age classes recorded (see above), we estimated a total population of at least 2,560 individuals on Socotra Island in 2009. Based on these data, vultures would consume up to 247.62 tons of organic matter each year. Our analyses showed that most of this organic matter was derived from human activities (93.3% of the matter identified in the pellets analyzed), in which waste (49.8%) was the most common component, followed by livestock carcasses (37.2%), fish remains (5.9%), and human feces (0.3%). In contrast, the frequency of wild prey was much lower (6.7%) with a decreasing importance of



**Figure 4** Response of the abundance of the Egyptian vulture to variables describing human settlement density at different radii around road transects, as assessed by quasi-poisson univariate models (all models  $P < 0.05$ , except for a 5,000 m radius).

insects (5.2%), birds (1.0%), rodents (0.1%), and snails (0.1%). The total amount of solid waste produced on Socotra in 2005 was estimated at 3,250 tons, in which 1,105 tons corresponded to vegetable and putrescible organic matter (Loretz & Martin 2006). Using this information, we estimated that, at a minimum, between 16.63% and 22.41% (considering a population of either 1,900 or 2,560 vultures, respectively) of putrescible organic matter produced in Socotra each year is eliminated by vultures. It is important to note that we did not exclude the vegetable fraction of the organic waste in our calculations, so the amount of hazardous organic waste of animal origin that was disposed of by vultures should be even higher.

## Discussion

### A relict human-vulture mutualism

Our study illustrates a striking example of bird-human mutualism: humans provide food resources, which facilitates the maintenance of the densest population of the rare Egyptian vulture, whereas vultures provide a regulating service by cleaning up carrion, waste, and human feces in villages and towns. This kind of relationship between vultures and humans, although common in the past (Bannerman 1963; Mundy *et al.* 1992), has nearly disappeared recently due to the development of modern societies and the precipitous decline of many scavenger populations worldwide (Donázar *et al.* 2002; Pain *et al.*



**Figure 5** Egyptian vultures feeding tamely in a *wady* (Arabic word for a stream bed that only carries surface water intermittently) on the outskirts of Qalansiyah, where Socotran girls have just deposited waste.

2003; Koenig 2006). We disentangled and quantified for the first time this mutualistic relationship.

On the one hand, Socotran vultures benefit from human activities by obtaining food resources that, in turn, have allowed for the maintenance of the densest population of this rare species worldwide. The remarkable dependence on humans is demonstrated by the clear spatial structuring of the Socotran vulture population according to Hs and the minor influence H features have on its distribution. This pattern is particularly evident in the largest city, Hadiboh, where more than 1,000 birds were counted. The concentration of vultures in villages is likely attributable to the accumulation of waste and slaughterhouse offal, as well as the lack of wild prey in their natural Hs (Cheung & DeVantier 2006). This hypothesis is supported by the results of this study, which showed that more than 90% of the items analyzed in pellets came from human leftovers. This finding differs markedly from observations for western European populations where wild prey comprises between 50% and 75% of the diet of Egyptian vultures (Donázar *et al.* 2010, Margalida *et al.* 2012a).

On the other hand, humans benefit from the presence of Egyptian vultures, as these birds provide a key regulating service by cleaning up putrescible matter from villages and rural areas. At present, Socotra lacks a waste collection system and the dumping of carcasses and garbage in the open is the predominant form of disposal (Figure 5). The ecological importance of vultures as agents of carrion and waste disposal is well recognized, but rarely has it been quantified (Wenny *et al.* 2011, but see Markandya *et al.* 2008; Margalida *et al.* 2012b). Our data indicate that between 17% and 22% of the total putrescible waste



**Figure 6** The capital city, Hadiboh, accumulates large quantities of waste. Villagers butcher many domestic animals and the remains are deposited for vultures in the streets and in the open. Moreover, every morning two restaurants provide a barrel of kitchen waste (about 60 kg), which is consumed by vultures in a few hours time (authors' own data).

produced in Socotra each year is eliminated by vultures. Furthermore, it is important to note that this is a very conservative estimate, given that it was calculated using the minimum food requirement for an adult vulture (265 g/day), even though energy demands greatly depend on animal activity and significantly increase during the breeding period. In addition, vultures often feed on human feces, a phenomenon very well described in ancient European literature (Dewar 1906; Negro *et al.* 2002), which provides an important service in villages that usually lack a sewage system. In this way, potentially hazardous organic remains are efficiently eliminated, thus reducing the risk of infectious disease in humans and the spread of livestock diseases, such as brucellosis, tuberculosis, and anthrax (Pain *et al.* 2003; Koenig 2006; Markandya *et al.* 2008). The regulating service provided by vultures in Socotra is recognized by island inhabitants who refer to Egyptian vultures as *soeydu*, which literally means “garbage bin” (Figure 6) (Cheung & DeVantier 2006).

### Confronting the conservation dilemma: ideas for policy choices

Policy makers in Socotra currently face an important development versus conservation dilemma that involves the complex relationship between biodiversity preservation needs and the demands of poverty alleviation (Adams *et al.* 2004). Globalization is beginning to impact the archipelago, entailing drastic changes in traditional land uses and economic activities, as well as the modernization of infrastructure and sanitary conditions in urban areas (Van Damme & Banfield 2011). From both

social and economic perspectives, development is desirable in Socotra, but it is not cost-free from an environmental perspective and the question arises as to what extent this imminent growth is compatible with the maintenance of a healthy (i.e., not constrained by human-related limiting factors) vulture population and its associated functions.

Unfortunately, there are precedents showing failures in the attempt to reconcile these two positions. The situation on the Canary Islands provides an instructive example. This archipelago has many biogeographical similarities with Socotra, but the contemporary history of insular development is radically different. Until the second half of the last century, the islands were virtually undeveloped, but the clear prioritizing of economic development over biodiversity conservation gave rise to several negative impacts on the ecosystem, most of them irreversible, which notably included the disappearance of numerous endemic taxa such as the Egyptian vulture (presently at risk of extinction, Donázar *et al.* 2002). Notwithstanding, national and regional governments are obliged to take active measure in favor of these endangered species. Consequently, recent European conservation plans have invested a substantial amount of economic resources to protect and promote their welfare. Considering only the LIFE projects public funds, a total of 19.14 million Euros has been devoted to the recovery of Egyptian vulture populations in the last two decades (European Commission-Environment-LIFE Programme 2011).

However, jointly achieving both conservational and developmental goals is challenging. Here, we propose a possible solution that would guarantee the conservation of the Egyptian vulture population by simultaneously promoting the sustainable development of the island and relies on the restructuring of the mutualistic human-vulture relationship by shifting from the regulating service toward a cultural service on a general scale, while partially maintaining the regulating service to (1) guarantee the disposal of carcasses in the open and rural areas, according to human demand and (2) assure food resources to maintain a dense vulture population.

The Socotra's outstanding biodiversity and landscapes and particularly, the unique ecological and behavioral traits of Socotran Egyptian vultures (especially its amazing tameness) may act as a driving force of a nature-based tourism. The promotion of an environmentally responsible and socially sensitive bird-related ecotourism would drive a natural change in the way people value the species and, consequently, a shift from a waste disposer toward a natural treasure and an income-generating asset, which will, in turn, offer local inhabitants new livelihood opportunities. In this sense, the Egyptian vulture would be

considered as a cultural service provider and hence converted into a 'flagship-species,' that is, "a species used as the focus of a broader conservation marketing campaign based on its possession of one or more traits that appeal to the target audience" (Verissimo *et al.* 2011).

The feasibility of obtaining both conservational and developmental goals has often been questioned and branded as unrealistic, due to incompatibilities and the intrinsic cost of one goal or the other that may hinder the final outcome (Adams *et al.* 2004). Our approach constitutes, however, a remarkable exception since no direct losses are expected regarding both biodiversity and the environment, and conservation would not increase poverty in any way.

At the local scale, the policy need is to reconcile the interests of different stakeholders in the management of the natural resources. It is worth noting that when operating in ecologically sensitive areas, such as this insular ecosystem, all actions should be based on sound planning. To accomplish this proposal, it would be advisable to take into account the following conservational and developmental considerations:

1. Maintenance of traditional extensive grazing practices that guarantee available food resources for the subject species, which also includes management plans aimed at controlling potential future negative impacts associated with these practices, for example, overgrazing and trampling (Gangoso *et al.* 2006; Platcher & Hampicke 2010).
2. Sustainable economic development, based on background knowledge (e.g., Donázar *et al.* 2002; Hille & Collar 2011), that avoids potential future limiting factors for biodiversity, and in particular for the vulture population, such as H loss and nonnatural mortality due to poisoning, pollution, or direct and indirect persecution.
3. Avoidance of unsustainable tourist industries that imply massive H destruction, proliferation of inadequate infrastructures, and promotion of irresponsible activities (e.g., off-road rallies) such as those already occurring in other archipelagoes, including Cape Verde and the Canary Islands.
4. Enhancement of the proposed strategy by instilling new values in the local inhabitants through environmental education and soliciting popular participation in H management.

In conclusion, the challenge for Socotra is to find an ecologically, socially, and economically sustainable path for future insular growth that reconciles trade-offs between conservation and development. The recognition of the species' roles within the ecosystem and the a priori identification of the underlying trade-offs will assist in

the design of future management plans. This is crucially relevant in the Socotra archipelago, one of only four UNESCO Natural World Heritage Sites in the Arab world, at a time when Yemen and a number of other Middle Eastern countries are undergoing political reforms as a result of the current uprisings and the rapidly changing political landscape (Van Damme 2011).

## Acknowledgments

We thank Mauro Fasola, Francesca Pella, and Fabio Atorre for logistical support in Socotra and for the data provided. Javier Juste and Fernando Hiraldo made useful comments on earlier versions of the manuscript. The research was funded by the projects CGL2004-00270 and CGL2009-12753-C02-02. During the writing of this manuscript, LG was supported by the FP7-REGPOT 2010-1 EcoGenes Project (Grant No. 264125). The Regional Socotran and National Yemeni Governments approved the research protocols.

## Supporting Information

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

### Methods

Please note: Wiley-Blackwell is not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

## References

- Adams, W.M., Aveling, R., Brockington, D. *et al.* (2004). Biodiversity conservation and the eradication of poverty. *Science*, **306**, 1146–1149.
- Bannerman, D.A. (1963) *Birds of the Atlantic Islands. Vol. I. A history of the birds of the Canary Islands and of the salvages*. Oliver & Boyd, Edinburgh and London, UK.
- Battersby, S.A., Pearsons, R. & Webster, J.P. (2002). Urban rat infestations and the risk to public health. *J. Environ. Health Res.*, **1**, 4–12.
- BirdLife International. (2011). Species factsheet: *Neophron percnopterus*. Available from: <http://www.birdlife.org> (visited Dec. 19, 2011).
- Cerny, V., Pereira, L., Kujanova, M. *et al.* (2009) Out of Arabia—the settlement of island Soqotra as revealed by mitochondrial and Y chromosome genetic diversity. *Am. J. Phys. Anthropol.*, **138**, 439–447.
- Cheung, C. & DeVantier, L. (2006). *Socotra —a natural history of the islands and their people*. Odyssey Books and Guides, Airphoto International Ltd., Hong Kong.
- Cortés-Avizanda, A., Ceballos, O. & Donázar, J.A. (2009). Long-term trends in population size and breeding success in the Egyptian vulture (*Neophron percnopterus*) in Northern Spain. *J. Raptor Res.*, **43**, 43–49.
- del Hoyo, J., Elliott, A. & Sargatal, J. (1994). *Handbook of the birds of the World, Vol II: New World vultures to Guinea Fowls*. Lynx Editions, Barcelona, Spain.
- Dewar, D. (1906). *Bombay Ducks*. John Lane, London, 277 pp.
- Donázar, J.A., Palacios, C.J., Gangoso, L., Ceballos, O., González, M.J. & Hiraldo, F. (2002). Conservation status and limiting factors in the endangered population of Egyptian vulture (*Neophron percnopterus*) in the Canary Islands. *Biol. Conserv.*, **107**, 89–97.
- Donázar, J.A., Cortés-Avizanda, A. & Carrete, M. (2010). Dietary shifts in two vultures after the demise of supplementary feeding station: consequences of the EU sanitary legislation. *Eur. J. Wildl. Res.*, **56**, 613–621.
- European Commission-Environment-LIFE Programme. (2011). Available from: <http://ec.europa.eu/environment/life/> (visited Dec. 1, 2011).
- Gangoso, L., Donázar, J.A., Scholz, S., Palacios, C.J. & Hiraldo, F. (2006). Contradictions in conservation of island ecosystems: plants, introduced herbivores and avian scavengers in the Canary Islands. *Biodivers. Conserv.*, **15**, 2231–2248.
- Grimm, N.B., Faeth, S.H., Golubiewski, N.E. *et al.* (2008). Global change and the ecology of cities. *Science*, **319**, 756–760.
- Hille, S.M. & Collar, N.J. (2011). Status assessment of raptors in Cape Verde confirms a major crisis for scavengers. *Oryx*, **45**, 217–224.
- Koenig, R. (2006). Vulture research soars as the scavengers' numbers decline. *Science*, **312**, 1591–1592.
- Lavine, A. (2011). The urban wildlife we don't want: Coyote Management Planning and Regulatory Control Measures. Available from: <http://dx.doi.org/10.2139/ssrn.1862801> (visited Apr. 30, 2012).
- Loretz, R. & Martin, F. (2006). SWM Masterplan for Socotra, Yemen. NDS-U Thesis, University of Applied Sciences, Northwestern Switzerland.
- Luck, G.W., Daily, G.C. & Ehrlich, P.R. (2003). Population diversity and ecosystem services. *Trends Ecol. Evol.*, **18**, 331–336.
- Margalida, A., Carrete, M. & Sánchez-Zapata, J.A. (2012a). Good news for European vultures. *Science*, **335**, 284.
- Margalida, A., Benítez, J.R., Sánchez-Zapata, J.A., Ávila, E., Arenas, R. & Donázar, J.A. (2012b). Long-term relationship between diet breadth and breeding success in a declining population of Egyptian Vultures. *Neophron percnopterus*. *Ibis*, **154**, 184–188.
- Markandya, A., Taylor, T., Longo, A., Murty, M.N., Murty, S. & Dhavala, K. (2008). Counting the cost of vulture decline—an appraisal of the human health and other benefits of vultures in India. *Ecol. Econ.*, **67**, 194–204.

- Marzluff, J.M. (2001). Worldwide urbanization and its effects on birds. Pages 19–48 in J.M. Marzluff, R. Bowman, R. Donnelly, editors. *Avian ecology in an urbanizing world*. Norwell, MA, Kluwer.
- McKinney, M.L. & Lockwood, J.L. (1999). Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends Ecol. Evol.*, **14**, 450–453.
- Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: synthesis*. Island Press, Washington.
- Mundy, P., Butchart, D., Ledger, J. & Piper, S. (1992). *The vultures of Africa*. Academic Press, London.
- Negro, J.J., Grande, J.M., Tella, J.L. *et al.* (2002) Coprophagy: an unusual source of essential carotenoids. *Nature*, **416**, 807–808.
- Pain, D., Cunningham, A.A., Donald, P.F. *et al.* (2003). Causes and effects of temporospatial declines of Gyps vultures in Asia. *Cons. Biol.*, **17**, 661–671.
- Plachter, H. & Hampicke, U. (2010). *Large-scale livestock grazing. A management tool for nature conservation*. Springer-Verlag, Berlin, Germany.
- Porter, R. & Stone, F. (1996) An introduction to Socotra and its birds. *Sandgrouse*, **17**, 73–80.
- Porter, R. & Suleyman, A.S. (2012). The Egyptian vulture *Neophron percnopterus* on Socotra, Yemen: population, ecology, conservation and ethno-ornithology. *Sandgrouse*, **34**.
- Sará, M., Greci, S. & Di Vittorio, M. (2009). Status of Egyptian vulture (*Neophron percnopterus*) in Sicily. *J. Raptor Res.*, **43**, 66–69.
- UNEP/WCMC. (2008). Socotra Archipelago, Yemen. UNESCO Fact Sheet. World Heritage Sites – Protected Areas and World Heritage. United Nations Environment Programme & World Conservation Monitoring Centre, 11pp. Available from: <http://whc.unesco.org/en/list/1263> (visited Nov. 20, 2011).
- Van Damme, K. (2011). Insular biodiversity in a changing world. *Nature Middle East*, doi: 10.1038/nmiddleeast.21011.61.
- Van Damme, K. & Banfield, L. (2011). Past and present human impacts on the biodiversity of Socotra Island (Yemen): implications for future conservation. Biodiversity Conservation in the Arabian Peninsula. *Zool. Middle East*, **3**, 31–88.
- Verissimo, D., MacMillan, D.C. & Smith, R.J. (2011). Toward a systematic approach for identifying conservation flagships. *Conserv. Lett.*, **4**, 1–8.
- Wenny, D.G., Devault, T.L., Johnson, M.D. *et al.* (2011). The need to quantify ecosystem services provided by birds. *The Auk*, **128**, 1–14.
- Whelan, C.J., Wenny D.G. & Marquis, R.J. (2008). Ecosystem services provided by birds. *Ann. NY Acad. Sci.*, **1134**, 25–60.