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Population and spatial breeding dynamics of a Critically Endangered Oriental White-backed Vultures *Gyps bengalensis* colony in Sindh Province, Pakistan

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Summary

The Critically Endangered Oriental White-backed Vulture *Gyps bengalensis* has declined across most of its range by over 95% since the mid-1990s. The primary cause of the decline and an ongoing threat is the ingestion by vultures of livestock carcasses containing residues of non-steroidal anti-inflammatory drugs, principally diclofenac. Recent surveys in Pakistan during 2010 and 2011 revealed very few vultures or nests, particularly of White-backed Vultures. From 2011 in the Tharparkar District of Sindh Province we monitored a colony of Oriental White-backed Vultures. Between 2011 and 2014 the number of active nests in this colony increased from 11 to 34 while nest density decreased from 13.7 to 9.2 nests km^{-2}, suggesting that the colony is expanding. We conclude that the rate of increase is being subsidised by immigration, as the population demographics do not support the observed rate of increase in nests. We present the first analysis of spatial breeding dynamics for Oriental White-backed Vultures and describe how a clustered pattern of nest trees in colonies supports a highly clustered pattern of nests. The spatial pattern of nests relies on both the distribution of trees and the ability of trees to support more than one nest. These results highlight that the preservation of larger nest trees and the sustainable management of timber resources are essential components for the conservation management of this species. We emphasise the high importance of this colony and a nearby Long-billed Vulture *Gyps indicus* colony in this area of Pakistan. Recommended conservation management actions include the continuation of a Vulture Safe Zone established in 2012, measuring breeding success, assessing dispersal and determining the impact of mortality on these populations.

Introduction

Population declines of *Gyps* vulture species across south Asia have been well-documented since they were first reported in 1999 (Prakash 1999; Prakash *et al.* 2003; Gilbert *et al.* 2006). As a result of these declines, the Oriental White-backed Vulture *Gyps bengalensis*, Long-billed Vulture *Gyps indicus* and the Slender-billed Vulture *Gyps tenuirostris* are all listed as Critically Endangered (IUCN 2013).

The primary cause of these declines was the ingestion by vultures of livestock carcasses that had been recently treated with non-steroidal anti-inflammatory drugs (NSAIDs), principally diclofenac (Oaks *et al.* 2004; Green *et al.* 2004). Since the identification of NSAIDs as the primary cause of vulture declines in south Asia, a range of conservation efforts have focused on the recovery of vulture populations. These have included the banning of veterinary diclofenac (Pain *et al.* 2008), the establishment of conservation breeding centres (Murn *et al.* 2008; Bowden *et al.* 2012), the identification of safe alternative veterinary drugs (Swarup *et al.* 2007), efforts to remove diclofenac from the environment (Swan *et al.* 2006; Cuthbert *et al.* 2011) and the establishment of Vulture Safe Zones (Chaudhary *et al.* 2012), which provide 'safe' food for vultures in designated areas and also use advocacy and lobbying to remove diclofenac from veterinary use and subsequently livestock carcasses. There is evidence that these conservation efforts are beginning to be successful, with residues of diclofenac in livestock carcasses having fallen in some areas (Cuthbert *et al.* 2011). As a result, the rate of population decline for Oriental White-backed Vultures has slowed, and for Long-billed Vultures, reversed (Prakash *et al.* 2012; Chaudhry *et al.* 2012).

In Pakistan, the Oriental White-backed Vulture has been monitored extensively in some areas, particularly Punjab Province (Gilbert *et al.* 2006; Gilbert *et al.* 2007; Arshad *et al.* 2009). The species is known to occur in the southeast (Roberts 1991), but there is relatively little reported information about the species from Sindh Province, in southeast Pakistan. Gilbert *et al.* (2004) recorded nests in several areas of Sindh, primarily in eastern and northeastern districts, but numbers of nests were low (< 10). The range map for the species (Roberts 1991) does not extend to the far southeast of Sindh, in the Nagarparkar area of Tharparkar District, which is adjacent to the Great Runn of Kutch in the southeastern corner of the province.

Through local fieldwork starting in 2009 and during a national survey of vultures in Pakistan in 2011, a small breeding colony of Oriental White-backed Vultures was recorded in the southeast corner of Tharparkar District in Sindh Province. This paper provides the first description of this previously unreported colony of Oriental White-backed Vultures. Based on fieldwork from 2011 to 2014 we describe the population size and associated spatial dynamics of the breeding colony, and discuss the future conservation of this colony.

Study area and Methods

The study was carried out in the southeastern corner of Tharparkar District, Sindh Province, approximately 10 km northwest of the Kharoonjar Hills (E24° 20’ E70° 43’) and the town of

Nagarparkar (Figure 1). The region is arid and generally flat with areas of relief characterised by isolated granite outcrop hills. The loam soils and low rainfall provide for the main land-uses of low density perennial livestock grazing and non-irrigated crop fields. Habitat is dry open scrub with scattered trees characterised by stands of primarily Kandi *Prosopis cineraria*.

Figure 1

Annual surveys of the study area were conducted from February 2nd to April 17th 2011, April 1st to April 15th 2012, March 1st to March 15th 2013 and January 24th to February 17th 2014. Nests were located by thorough searches of the study area, by following flying birds to their roost locations in a 4x4 vehicle at the end of each day and by paying particular attention to areas with larger trees. Local residents were questioned for information about the locations of vulture nests or roosts. For roost sites that were located, numbers of birds were counted on four occasions during the annual survey visits. The number of roosting birds was counted between 15h00 and 18h00 and then again early the following morning at the same roost site. All positions were logged using a hand-held GPS. Nests were recorded as occupied if adults were in attendance or a chick was in the nest, but measures of breeding productivity were not possible because the survey was conducted only once each breeding season. Nest trees were identified with spray-painted numbers to avoid double-counting and for inter-year reference. The height of each nest tree was estimated by eye.

Nest density (nests km^{-2}) was calculated each year by dividing the number of nests by their spatial extent (km^{2}), which was determined as the area of a polygon containing all occupied nests. Oriental White-backed Vultures nest in colonies (Roberts 1991) and clusters of nests are a feature of the species (BirdLife International 2001). To assess the spatial pattern of nests and its change between years we calculated the mean nearest-neighbour distance (NND) between all nests each year. However, because more than one breeding pair of White-backed

Vultures can nest in the same tree, we calculated two nearest-neighbour metrics: (a) the distance between trees with nests (tree-NND), and (b) the distance between nests (nest-NND), using a pre-determined 3 m NND for nests in the same tree.

Mean NND (tree or nest) on its own is insufficient to describe differences between spatial point patterns because two point patterns with different characteristics might have the same mean NND. To assess the degree of clustering we calculated the ratio of the geometric mean (GMR) to the arithmetic mean of the squared NND (Brown and Rothery 1993; Murn *et al.* 2013). The maximum value for this statistic (GMR) is unity, where all NNDs are equal. Complete spatial randomness occurs at GMR = 0.5, whilst the minimum GMR value is unbounded. Therefore, increasingly smaller GMR values represent spatial patterns of nests with tighter clustering. We chose this metric because the spatial extent of the nests was discrete and as a result, there were no outlier nests that would have disproportionately affected the GMR. Similarly, the discrete spatial extent of the nests negated the need to account for edge effects – the existence of unknown nests marginally outside the study area – when measuring nearest-neighbour distances because the colony nests were the only nests in the entire study area. We expected mean values for tree-NND and nest-NND to reflect density, such that mean NND would decrease with increasing density and *vice versa*, but we held no *a priori* assumptions about the degree of nest clustering in relation to nest numbers or density.

NND data were transformed where necessary to stabilise variance and checked with Anderson-Darling tests, after which one way ANOVA was used for comparison of NNDs between years. Data that did not conform to parametric assumptions after transformation were subject to Kruskal-Wallis tests. Homogeneity of variance in sample ranks was checked with Levene's test. Tests were performed in Minitab 16.

Results

Nests were located mainly in Kandi *Prosopis cineraria* (all nests in 2011 and 2012), but Neem *Azadirachta indica* (two nests in 2013), Rohida *Tecomella undulata* and Tamarind *Tamarindus indica* (one nest each in 2014) were also used. Nest trees were larger than surrounding trees and had a mean height of 11.6 (SD ± 2) m. A maximum of seven nests in one tree was recorded, and this large tree was located within one of the villages in the study area. The distribution of the nests across the four years was dynamic and although it was not possible to identify birds individually, several nests were occupied in each of the four years, whilst new nests were made each year (Figure 2).

Figure 2

The number of recorded nests increased each year and tripled during the study period (Table 1). The marked reduction in density from 2012 to 2013, despite a 40% increase in the number of active nests, reflects the spatial expansion of the colony (Figure 2). The number of trees containing more than one nest increased rapidly from 10.5% of trees in 2011 to 23.5% of trees in 2014, but despite the tree containing seven nests, the mean number of nests per multi-nest tree remained near 2.5 each year (mean = 2.55 nests tree^{-1}, range = 2.4 - 2.75) .

Table 1

The two nearest-neighbour metrics revealed different aspects of the growth of the colony, and neither was correlated with colony area or nest density. Mean tree-NND increased each year and was significantly different between years (One-way ANOVA $F_{3,87}$ = 2.81, P = 0.04), possibly reflecting the decreasing density. Mean nest-NND decreased each year (Kruskal-Wallis $H = 11.92$, $P = 0.008$), which is most likely a function of the increasing number of trees with multiple nests. Across all years mean tree-NND was 230 m (±SE 28 m) and mean nest-NND was 110 m (±SE 20 m).

In each year, the spatial pattern of trees with nests was clustered (GMR < 0.25). But despite increasing numbers of nests, increasing mean tree-NND and decreasing density, the GMR for nest trees remained in the region of 0.20 between 2012 and 2014 (Figure 3).

Figure 3

Maximum roost counts during each survey period were 39 birds in 2011 (one site located near the active nests), 102 birds in 2013 (two sites) and 145 birds in 2014 (two sites). No roost counts were conducted in 2012. The roost sites were in the same location each day, and did not change between years. In 2014 the approximate age proportions were 60% adults, 14% sub-adults and 25% juveniles. Assuming that 1) one adult of a breeding pair (34 pairs) will remain at an active nest overnight; 2) the other breeding adult (34 birds) joins a communal roost and 3) that non-breeding adults (approximately 54 birds) and immature birds (57 birds) were also part of communal roosts, we estimate that the population of this colony during the 2014 breeding season was approximately 180 individuals. Thus, approximately 30% of the adult population are estimated to be non-breeding birds.

Nine dead vultures were found between 2011 and 2014 (Table 1), although systematic surveys to locate dead birds were not conducted. The cause of death for these birds could not be established due to advanced decomposition of the bodies.

Table 2

Discussion

The nest densities in 2011 and 2012 (Table 1) are comparable with and slightly higher than pre-decline (1980s) densities of 12.2 nests km^{-2} recorded in Keoladeo National Park, India (Prakash and Rahmani 1999), higher than pre-decline densities of 2.5 – 5 nests km^{-2} reported from coastal mangrove areas of southern Bangladesh (Sarker 1987) and approaching the higher densities of 15 nests km^{-2} reported for Changa Manga forestry plantation in Punjab Province near Lahore (Gilbert *et al.* 2002). This last population was experiencing rapid decline from diclofenac poisoning during the monitoring period (Gilbert *et al.* 2006), and so nest densities could have been lower than a potential maximum. Apart from differences in habitat (arid Nagarparkar, wetland-dominated Keoladeo, coastal mangroves Sundarbans and forest plantation Changa Manga), the manner in which spatial extent of the breeding areas was calculated and the availability of trees in each study area may provide another explanation for these variations in nest density. Regardless of the reasons for this variation, the nest densities found in our study are within the range of densities reported for a number of different locations prior to, and during, the decline of south Asian vulture populations (Prakash and Rahmani 1999, Sarker 1987, Gilbert *et al*. 2002). However, none of these densities even remotely approaches historical accounts for this species of 'up to 15 nests in one tree' and 100 nests in a 250m diameter circle (Hume and Oates 1889-1890), although Roberts (1991) describes up to six nests occurring in one tree.

Despite an increasing mean tree-NND each year and a moderate level of nest tree clustering (Figure 3), the decreasing mean nest-NND and the increased clustering of nests in a growing breeding population highlights the strong colonial tendencies of this species. In comparison, there are two other tree-nesting *Gyps* vultures, the Slender-billed Vulture and the African White-backed Vulture *Gyps africanus*. We are unaware of any nearest-neighbour analyses for the relatively less-studied Slender-billed Vulture, so a direct comparison is not possible. However the species is reported to nest singly (i.e. one breeding pair per tree) in relatively small colonies of 7 - 8 pairs (BirdLife International 2001) although more than one nest in a tree has been recorded occasionally (Mathews 1918).

African White-backed Vultures nest in what have been termed ‘loose colonies’ (Mundy *et al.* 1992), usually with only one breeding pair per nest tree. In savanna areas (i.e. not linear riparian nests) a mean NND distance has been reported as 697 m (±SD 913 m, n = 217) with a GMR of 0.15 (Murn *et al.* 2013). Although the mean tree-NND for African White-backed Vultures is significantly higher ($T = 6.85$, $P < 0.001$) than the Oriental White-backed Vultures in this study, the African species still shows a tendency for clustered nest trees (Figure 3). Given that a tightly-clustered pattern (GMR ~ 0.01) of Oriental White-backed Vulture nests can occur in nest trees that are moderately clustered (GMR ~ 0.20), it is likely that the colonial-nesting and clustering tendencies of this species reflect the sufficient availability of trees large enough to support multiple nests. Although not all trees in a colony will be large enough or of suitable canopy structure to accommodate more than one nest, a characteristic spatial arrangement (i.e. clustering) of nests may occur at a threshold that is related to the availability of suitable trees. For example, Satheesan (1995) reported large (pre-decline) numbers of roosting Oriental White-backed Vultures on very large trees in Agra City, India, but did not record any more than three nests in one tree in the same area. Similarly, in post-decline breeding populations, numbers of nests per tree are still in the range of 1 – 3 (Baral *et al.* 2005; Roy and Shastri 2013). It is therefore possible that the tight nest-clustering characteristics favoured by this species can be achieved with a relatively small number of nests per tree if the available trees are of a suitable size, structure and spatial pattern (GMR~ 0.2). This may suggest that an optimum level of nest tree clustering exists to support a range of colony sizes and nest densities.

Monitoring and conservation implications

Despite not being able to assess breeding productivity we do consider that, given the limitations of an annual survey, the number of nests recorded each year was representative of the breeding colony size for two reasons. Firstly, the number of inactive nests was low, suggesting that the number of breeding pairs that started a breeding attempt and failed is also low. Secondly, the survey dates of January to April each year covered the main part of the breeding season; most breeding pairs that did make an attempt would have made nests and been incubating, whilst early breeders would still be either in late stage incubation or with a chick in the nest.

Although it is encouraging that the number of recorded nests has tripled since 2011, this is tempered with a slowing of the rate at which the colony is growing (Table 1) and the fact that a number of queries and research priorities remain. Firstly, it is unknown from where the additional breeding birds have arrived. In the absence of additive mortality, Oriental White-backed Vultures are generally long-lived birds with an estimated generation time of 16 years (BirdLife International 2014). Using a conservative estimate of birds not reproducing until their fourth year, the increase in the breeding population observed in our study has almost certainly been enhanced by immigration, as the demographics of such a small population with this length of generation time do not support the observed rapid increase in the number of nests. It is also possible however, that following the 2006 ban on veterinary diclofenac, there has been an increasing rate of survival to maturity for age cohorts hatched post-2006, and that these birds are the source of the additional birds.

Secondly, the risks and effects of mortality (such as NSAID poisoning) need to be assessed. Although a number of dead birds were found without a concerted search effort, four of the nine birds were of pre-fledging or recently-fledged age, and high mortality in this age group of vultures is not unusual (Mundy *et al.* 1992). The five dead adults that were found offer more cause for concern, as adult survival is one of the most sensitive demographic parameters for vultures (Oro *et al.* 2008, Margalida *et al*. 2014) and suggests that this age-class is potentially still at risk. Even with the goal of complete removal of diclofenac and other harmful non-steroidal anti-inflammatory drugs from the environment, it is possible that residual quantities of diclofenac remain in livestock carcasses and are a threat to vultures. The establishment of a Vulture Safe Zone (VSZ) in the study area in 2012 saw the beginning of a new phase of environmental monitoring and conservation to address this. Across the approximately 8,000 km^2 VSZ, a range of activities such as livestock health camps, awareness-raising sessions in villages and consultations with veterinary dispensaries are all aimed at highlighting the risks to vultures from diclofenac and emphasising the need to maintain the ban on its use in livestock.

Thirdly, an important next step in the monitoring of this colony is to determine breeding success. Comparing breeding success with pre-decline populations (Prakash 1999) and those that were suffering acute mortality from diclofenac poisoning (Gilbert *et al.* 2002) could offer an indication of what levels of additive mortality exist for this population. Similarly, comparison of breeding productivity with the nearby colony of Long-billed Vultures (Chaudhry *et al.* 2012) will be important to see if the colonies are both (or neither) affected by similar rates of mortality.

Finally, dispersal behaviour of birds from this population must also be assessed. Oriental White-backed Vultures can range over vast distances (Gilbert *et al.* 2007), so it is not unlikely that birds may be dispersing across a wide area, in the same way that birds may have arrived to the Nagarparkar colony from adjacent areas such as Gujarat in India.

The description of breeding colony spatial dynamics outlined here has important implications for the conservation of Oriental White-backed Vultures, particularly in areas (such as our study area or other arid zone areas) where the number of suitable nest trees may be limited and a lack of suitable trees may limit clustering of nests and hence potential colony size. Large trees in particular should be preserved and protected, whilst conservation management and sustainable harvesting of timber for fuel stock and/or building materials can be focused on smaller trees. Where nest trees do not appear to be a limiting factor, Oriental White-backed Vulture colonies can reach very high numbers such as the 700-800 nests recorded at Changa Manga (Gilbert et al 2002), although the number of multi-nest trees and extent of nest clustering has not been reported for this colony.

Based on a recent national survey of vultures (Iqbal *et al.* 2011), this colony of Oriental White-backed Vultures is currently the only known extant breeding population in Pakistan, in addition to being previously unreported in the general literature (Roberts 1991, Gilbert *et al.* 2004, Chaudhry *et al.* 2012). Lending additional importance to our study area is the nearby colony of Long-billed Vultures breeding in the Kharoonjar Hills (Chaudhry *et al.* 2012), which is the only breeding colony of this species recorded for Pakistan (Roberts 1991). The Vulture Safe Zone in Sindh Province is thus a major step towards the long-term conservation of these two species in the south Asian region.

Diclofenac is not the only NSAID that is toxic to vultures - there are other veterinary drugs that represent a threat to vultures such as ketoprofen (Naidoo *et al.* 2010), aceclofenac (Sharma 2012) and flunixin (Zorrilla *et al.* 2014), which are all still legal and in circulation. In this regard, we support fully the continued development and maintenance of Vulture Safe Zones in south Asia as a means of ongoing progression towards the conservation objective of restoring viable populations of vultures to areas where they once occurred. However, the long-term conservation value of a Vulture Safe Zone will be reduced if there are limited opportunities for vultures to nest in the spatial patterns that optimise the dynamics of their breeding colonies. Based on the results presented here, and in addition to the removal of unsafe veterinary drugs, a key component of Vulture Safe Zone work should be the preservation of nest tree distributions that can support large colonies of clustered nests of Oriental White-backed Vultures.

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References

Arshad, M., Chaudhry, M. J. I. & Wink, M. (2009). High mortality and sex ratio imbalance in a critically declining Oriental White-backed Vulture population (*Gyps bengalensis*) in Pakistan. *J. Ornithol.* 150: 495-503.

Baral, N., Gautam, R. & Tamang, B. (2005). Population status and breeding ecology of White-rumped Vulture *Gyps bengalensis* in Rampur Valley, Nepal. *Forktail* 21: 87-91.

BirdLife International (2014). Species factsheet: *Gyps bengalensis*. Downloaded from www.birdlife.org January 2014

Bowden, C. G. R., Prakash, V., Ranade, S., Routh, A., Jakatt, R. D., Cuthbert, R., Rahmani, A. R., Green, R. E., Prakash, N. & Parry-Jones, J. (2012). Conservation breeding for the future release of the critically endangered Asian *Gyps* vultures - progress of the programme in south Asia and why it is so important. *J.Bombay Nat.Hist.Soc.* 109: 43-45.

Brown, D., Rothery, P. (1993) *Models in biology: mathematics, statistics and computing.* Chichester: John Wiley & Sons.

Chaudhary, A., Subedi, T. R., Giri, J. B., Baral, H. S., Bidari, B., Subedi, H., Chaudhary, B., Chaudhary, I., Paudel, K. & Cuthbert, R. (2012). Population trends of Critically Endangered *Gyps* vultures in the lowlands of Nepal. *Bird Cons. Int.* 22: 270-278.

Chaudhry, M. J. I., Ogada, D. L., Malik, R. N., Virani, M. Z. & Giovanni, M. D. (2012). First evidence that populations of critically endangered Long-billed Vulture *Gyps indicus* in Pakistan have increased following the ban of the toxic veterinary drug diclofenac in south Asia. *Bird Conservation International* 22: 389-397.

Cuthbert, R., Taggart, M. A., Prakash, V., Swarup, D., Suchitra, U., Mateo, R., Chakraborty, S. S., Deori, P. & Green, R. E. (2011). Effectiveness of action in India to reduce exposure of *Gyps* vultures to the toxic veterinary drug diclofenac. *PLoS ONE* 6: e19069

Gilbert, M., Virani, M. Z., Watson, R. T., Oaks, J. L., Benson, P. C., Khan, A. A., Ahmed, S., Chaudhry, J., Arshad, M., Mahmood, S. & Shah, Q. A. (2002). Breeding and mortallity of Oriental White-backed Vulture *Gyps bengalensis* in Punjab Province, Pakistan. *Bird Cons. Int.* 12: 311-326.

Gilbert, M., Virani, M. Z., Watson, R. T., Oaks, J. L., Benson, P. C., Khan, A. A., Ahmed, S., Chaudhry, M. J. I., Arshad, M., Mahmood, S. & Shah, Q. A. (2004) The status and decline of vultures in the provinces of Punjab and Sind, Pakistan: a 2003 update. pp 311-326 in R. D. Chancellor and B.-U. Meyburg, eds. *Raptors Worldwide.* Berlin: World Working Group on Birds of Prey and Owls.

Gilbert, M., Watson, R. T., Ahmed, S., Asim, M. & Johnson, J. A. (2007). Vulture restaurants and their role in reducing diclofenac exposure in Asian vultures. *Bird Cons. Int.* 17: 63-77.

Gilbert, M., Watson, R. T., Virani, M. Z., Oaks, J. L., Ahmed, S., Chaudhry, M. J. I., Arshad, M., Mahmood, S., Ali, A. & Khan, A. A. (2006). Rapid population declines and mortality clusters in three Oriental whitebacked vulture Gyps bengalensis colonies in Pakistan due to diclofenac poisoning. *Oryx* 40: 388-399.

Green, R. E., Newton, I., Shultz, S., Cunningham, A. A., Gilbert, M., Pain, D. J. & Prakash, V. (2004). Diclofenac poisoning as a cause of vulture population declines across the Indian subcontinent. *J.Appl.Ecol.* 41: 793-800.

Hume, A. O., Oates, E. W. (1889) *Nests and eggs of Indian birds*. London: R. H. Porter.

Iqbal, S., Khan, U., and Murn, C. (2011). Vulture population and status survey, Pakistan. Unpublished internal report. Lahore: WWF-Pakistan. 11 pages.

IUCN (2013). IUCN Red List of Threatened Species. Version 2012.1. Downloaded from www.iucnredlist.org January 2014

Margalidia, A., Colomer, M. A., Oro, D. (2014) Mand-induced activities modify demographic parameters in a long-lived species: effects of poisoning and phealth policies. *Ecol. App.* 24: 436-444

Mathews, W. H. (1918). Note on the Indian Long-billed Vulture. *J.Bombay Nat.Hist.Soc.* 26: 287

Mundy, P., Butchart, D., Ledger, J. & Piper, S. (1992) *The Vultures of Africa*. London: Academic Press.

Murn, C., Combrink, L., Ronaldson, G. S., Thompson, C. & Botha, A. (2013). Population estimates of three vulture species in Kruger National Park, South Africa. *Ostrich* 84: 1-9.

Murn, C., Khan, U. & Farid, F. (2008). Vulture populations in Pakistan and the *Gyps* Vulture Restoration Project. *Vulture News* 58: 35-43.

Naidoo, V., Wolter, K., Cromarty, D., Diekmann, M., Duncan, N., Meharg, A., Taggart, M. A., Venter, L. & Cuthbert, R. (2010). Toxicity of non-steroidal anti-inflammatory drugs to *Gyps* vultures: a new threat from ketoprofen. *Biol.Lett.* 6: 339-341.

Oaks, J. L., Gilbert, M., Virani, M. Z., Watson, R. T., Meteyer, C. U., Rideout, B. A., Shivaprasad, H. L., Ahmed, S., Chaudhry, M. J. I., Arshad, M., Mahmood, S., Ali, A. & Khan, A. A. (2004). Diclofenac residues as the cause of vulture population decline in Pakistan. *Nature* 427: 630-633.

Oro, D., Margalida, A., Carrete, M., Heredia, R. & Donázar, J. A. (2008). Testing the goodness of supplementary feeding to enhance population viability in an endangered vulture. *PLoS ONE* 3(12): e4084

Pain, D. J., Bowden, C. G. R., Cunningham, A. A., Cuthbert, R., Das, D., Gilbert, M., Jakati, R., Jhala, Y., Khan, A. A., Naidoo, V., Oaks, J. L., Parry-Jones, J., Prakash, V., Rahmani, A., Ranade, S., Baral, H. S., Senacha, K. R., Saravanan, S., Shah, N., Swan, G., Swarup, D., Taggart, M. A., Watson, R. T., Virani, M. Z., Wolter, K. & Green, R. E. (2008). The race to prevent the extinction of South Asian vultures. *Bird Cons. Int.* 18: S30-S48.

Prakash, V. (1999). Status of vultures in Keoladeo National Park, Bharatpur, Rajasthan, with special reference to population crash in Gyps species. *J.Bombay Nat.Hist.Soc.* 96: 365-378.

Prakash, V., Bishwakarma, M. C., Chaudhary, A., Cuthbert, R., Dave, R., Kulkarni, M., Kumar, S., Paudel, K., Ranade, S., Shringarpure, R. & Green, R. E. (2012). The population decline of *Gyps* vultures in India and Nepal has slowed since the veterinary use of diclofenac was banned. *PLoS ONE* 7: e49118

Prakash, V., Pain, D. J., Cunningham, A. A., Donald, P. F., Prakash, N., Verma, A., Gargi, R., Sivakumar, S. & Rahmani, A. R. (2003). Catastrophic collapse of Indian white-backed Gyps bengalensis and long-billed Gyps indicus vulture populations. *Biol.Conserv.* 109: 381-390.

Prakash, V., Rahmani, A. R. (1999). Notes about the decline of Indian vultures, with particular reference to Keoladeo National Park. *Vulture News* 41: 6-13.

Roberts, T. J. (1991) *The birds of Pakistan: Volume 1: Regional Studies and Non-Passeriformes*. Karachi: Oxford University Press.

Roy, A., Shastri, K. (2013). Nesting of the White-rumped Vulture *Gyps bengalensis* in Orchha Wildlife Sanctuary, Madhya Pradesh, India. *J.Bombay Nat.Hist.Soc.* 110: 6

Sarker, S. U. (1987). The Indian Whitebacked Vulture in the Sundarbans, Bangladesh. *Vulture News* 18: 8-14.

Satheesan, S. M. (1995). Roost and nest trees preferred by Indian Whitebacked Vultures *Pseudogyps bengalensis* in Agra city and environs. *Vulture News* 32: 3-9.

Sharma, P. (2012). Aceclofenac as a potential threat to critically endangered vultures in India: a review. *J.Raptor Res.* 46: 314-318.

Swan, G., Naidoo, V., Cuthbert, R., Green, R. E., Pain, D. J., Swarup, D., Prakash, V., Taggart, M., Bekker, L., Das, D., Diekmann, J., Diekmann, M., Killian, E., Meharg, A., Patra, R. C., Saini, M. & Wolter, K. (2006). Removing the threat of diclofenac to critically endangered Asian vultures. *PLoS Biol.* 4: 395-402.

Swarup, D., Patra, R. C., Prakash, V., Cuthbert, R., Das, D., Avari, P., Pain, D. J., Green, R. E., Sharma, A. K., Saini, M., Das, D. & Taggart, M. (2007). Safety of meloxicam to critically endangered *Gyps* vultures and other scavenging birds in India. *Anim.Conserv.* 10: 192-198.

Zorrillia, I., Martinez, R., Taggart, M. A. & Richards, N. (2014) Suspected flunixin poisoning of a wild Eurasian Griffon Vulture in Spain. *Cons. Biol*. doi: 10.1111/cobi.12417

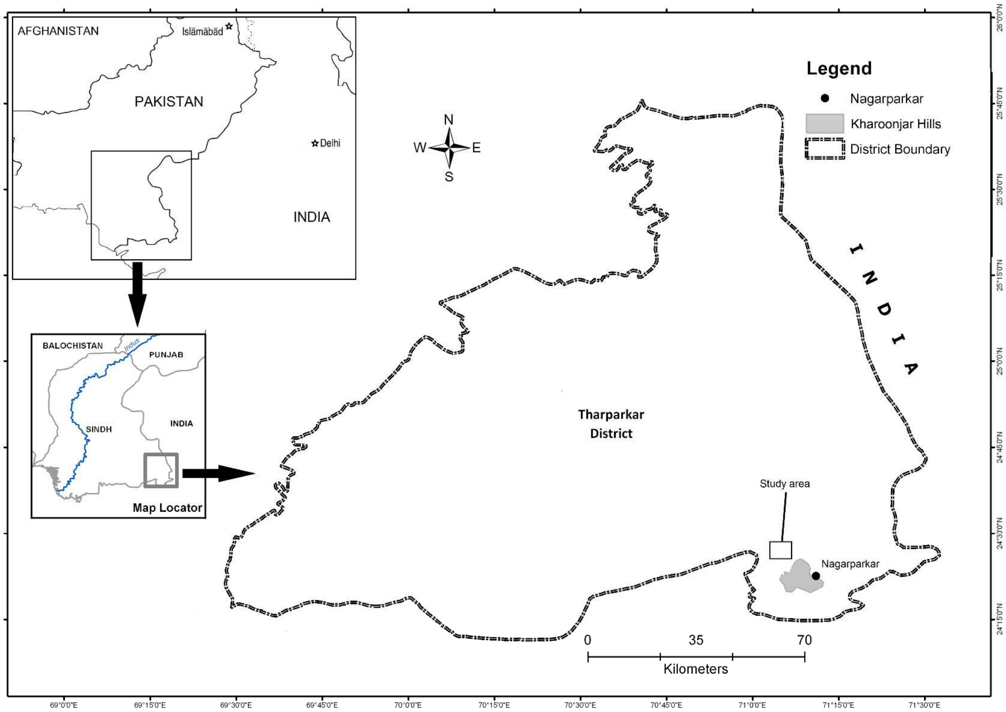


Figure 1: Location of the study area near Nagarparkar town in southeast Sindh Province, Pakistan.

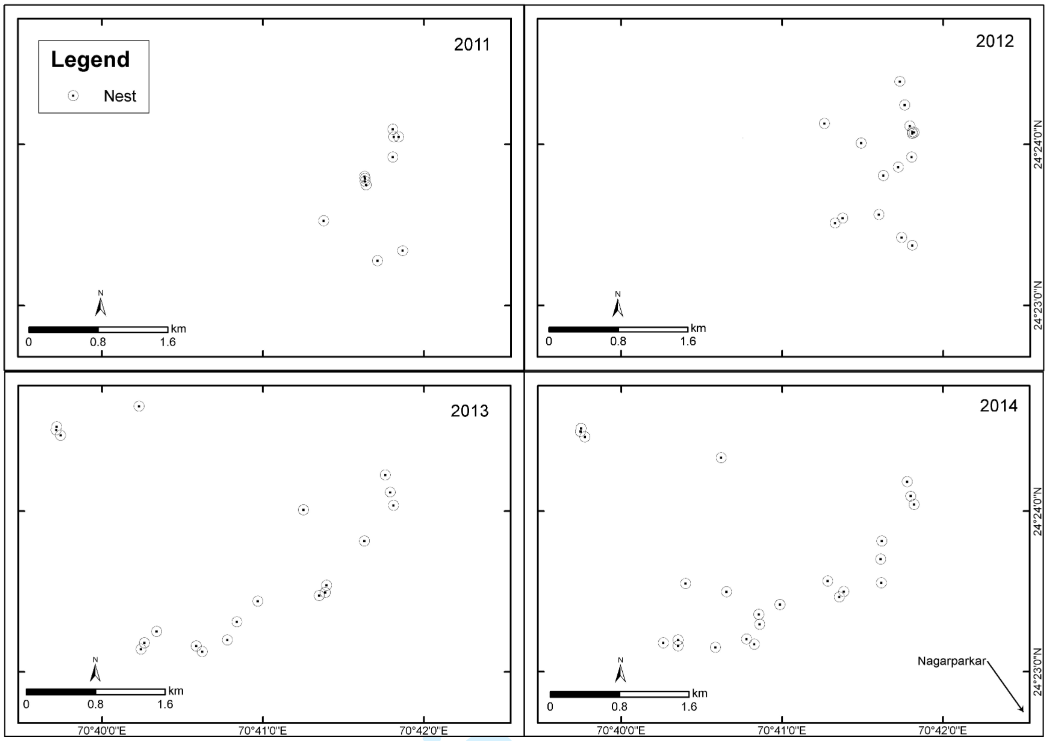


Figure 2: The spatial pattern of nest trees in an Oriental White-backed Vulture colony, 2011 to 2014, Sindh Province, Pakistan.

Table 1: Number of nests and some spatial characteristics of an Oriental White-backed Vulture *Gyps bengalensis* colony in Tharparkar District, Sindh, Pakistan.

Year	Number of nests	Colony area (km^2)	Density (nests km^{-2})	Mean NND* (±SD) – Tree (meters)	Mean NND* (±SD) – Nest (meters)	Number of multi-nest trees (max nests per tree)
2011	11	0.8	13.75	157 (± 182)	157 (± 182)	0
2012	19	1.4	13.6	159 (± 137)	147 (± 146)	2 (3)
2013	27	8.0	3.4	256 (± 278)	136 (± 278)	5 (4)
2014	34	3.7	9.2	271 (± 329)	56 (± 94)	8 (7)

*Nearest-neighbour distance

Table 2: Details of dead vultures found during breeding colony surveys of Oriental White-backed Vultures *Gyps bengalensis* in Tharparkar District, Sindh, Pakistan.

Date	Remains	Age	Found
5/2/11	Desiccated carcass	Adult	Hanging from tree
19/2/11	Feather remains	Adult	On the ground
16/3/13	Desiccated carcass	Pre-fledged nestling	Ground below nest tree
16/3/13	Desiccated carcass	Pre-fledged nestling	Ground below nest tree
15/3/13	Partial remains	Pre-fledged nestling	In nest
15/3/13	Desiccated carcass	Juvenile	On the ground
16/3/13	Desiccated carcass	Adult	In nest
16/3/13	Partial remains	Adult	In nest
7/2/14	Desiccated carcass	Adult	Ground below nest tree

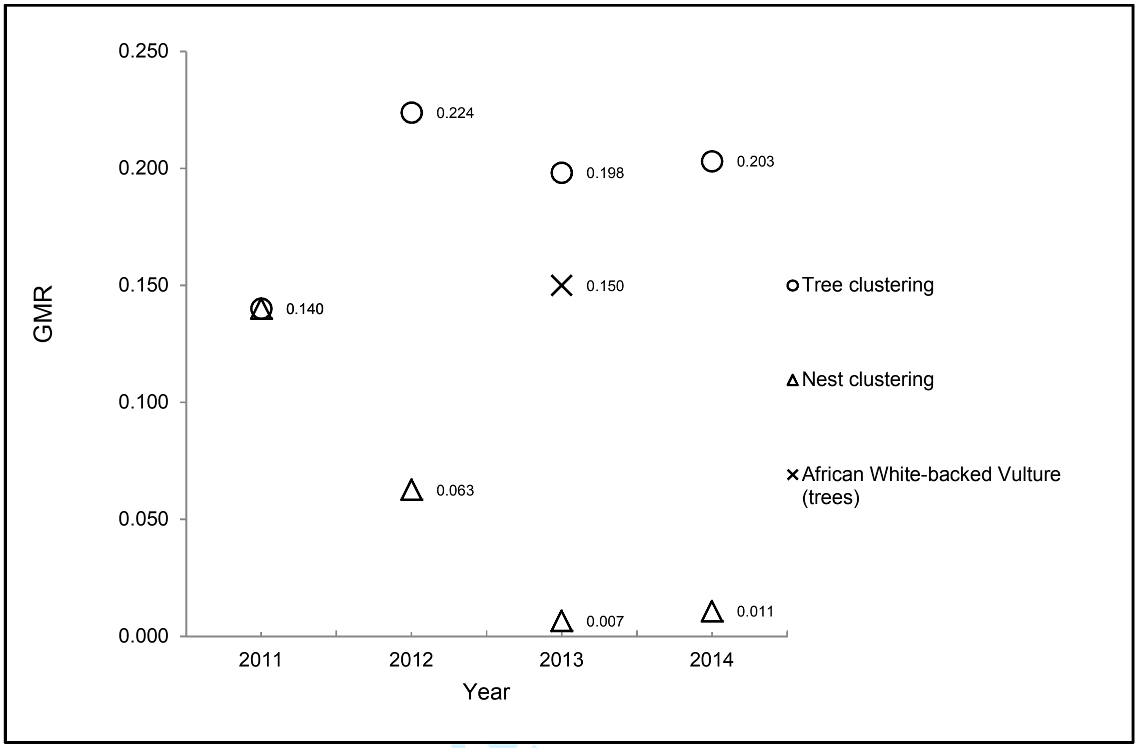
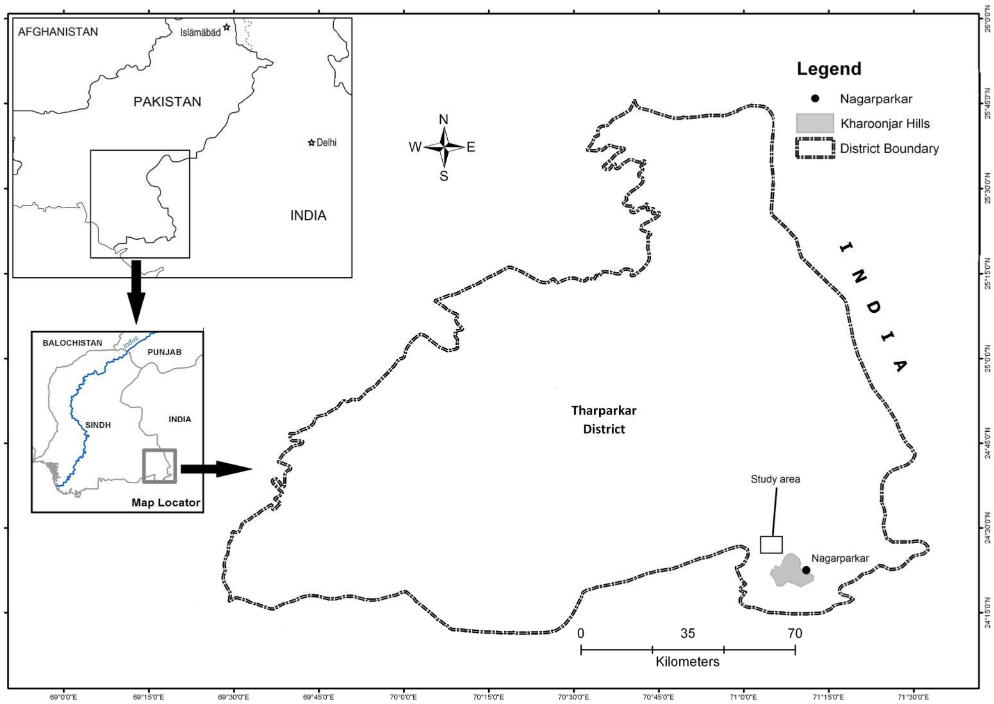


Figure 3: Spatial dynamics of an Oriental White-backed Vulture breeding colony over four years. The clustering characteristics of nest trees and nests are analysed as spatial point patterns. GMR is the extent of clustering; lower values occur with tighter clustering of a spatial point pattern. A similar tree-nesting vulture species, the African White-backed Vulture *Gyps africanus,* is provided for comparison.



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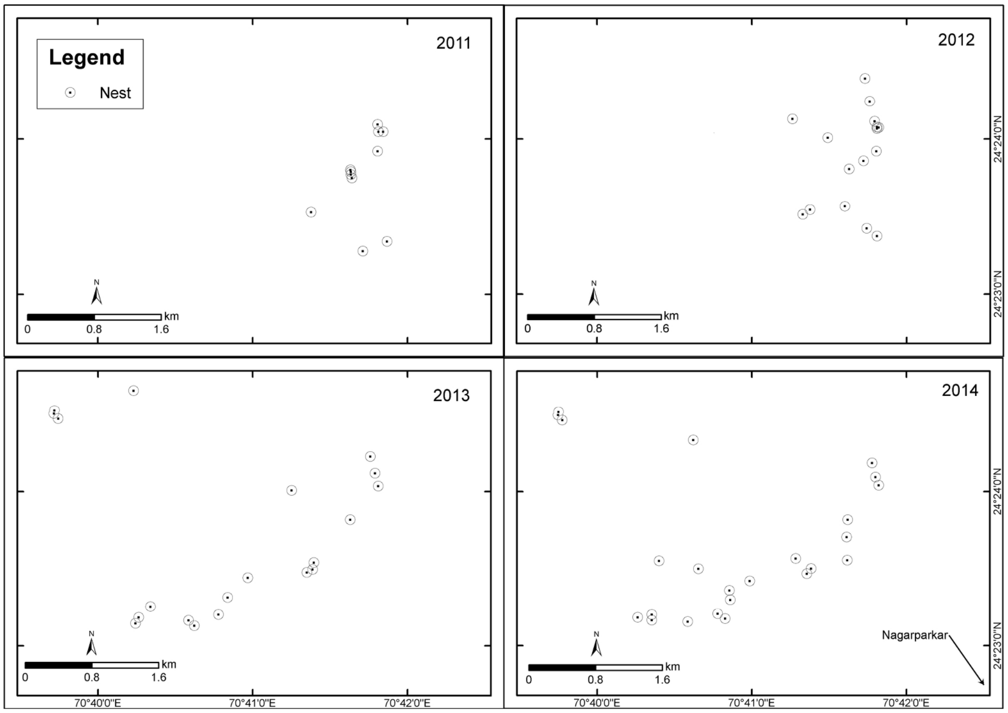

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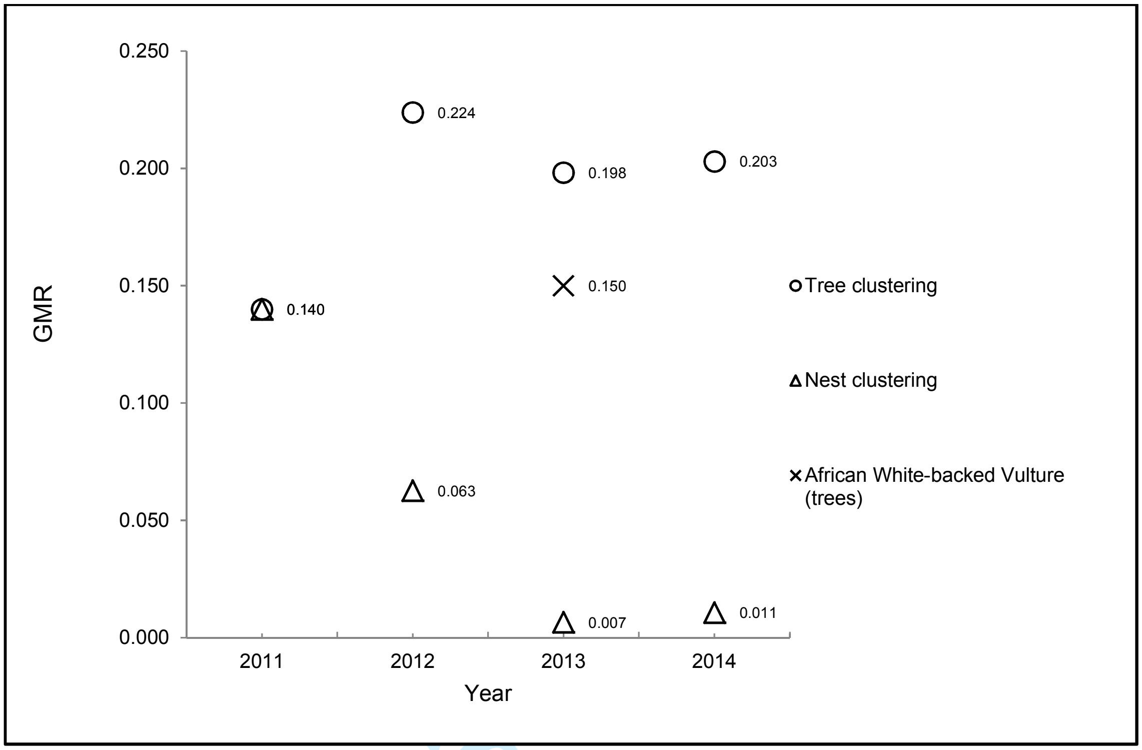
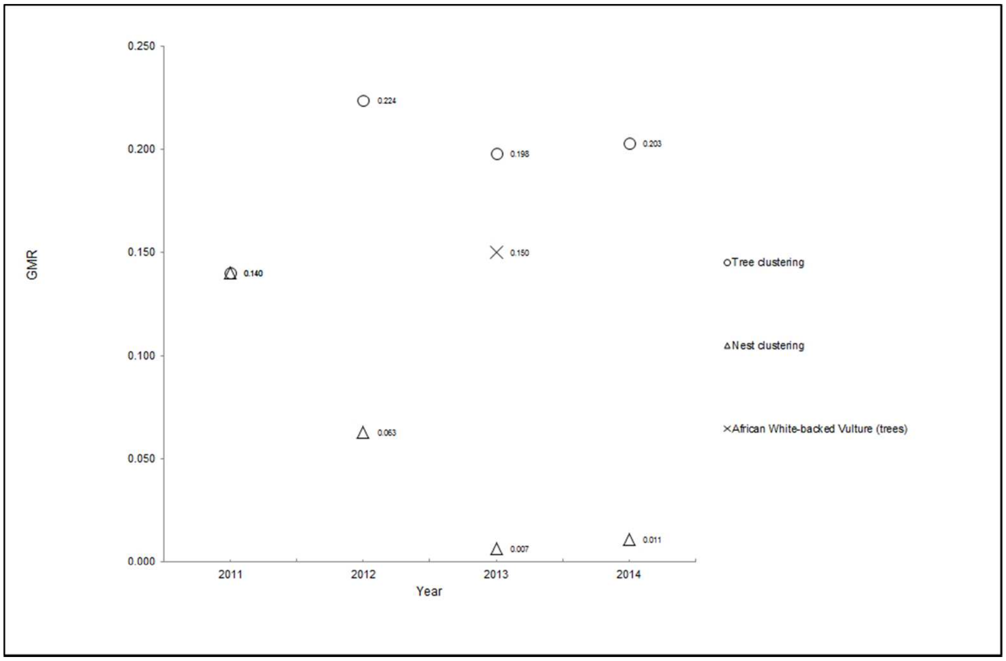

0.250
0.200
0.150
0.100
0.050
0.000
GMR
0.224
0.198
0.203
0.150
0.140
0.063
0.007
0.011
2011
2012
2013
2014
Year
Tree clustering
Nest clustering
African White-backed Vulture (trees)



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