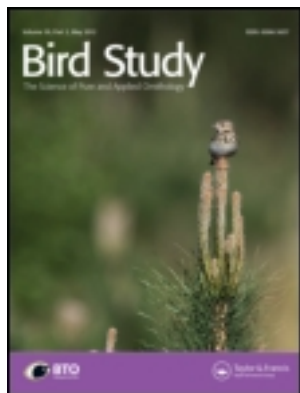


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# Field identification of individual White-headed Vultures *Trigonoceps occipitalis* using plumage patterns - an information theoretic approach

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**Capsule** Individual White-headed Vultures can be reliably identified by the pattern in their median wing coverts.

**Aims** To highlight the distinctiveness of the median wing covert pattern in White-headed Vultures and demonstrate the reliably high information content contained in this pattern.

**Methods** Photographs of 30 wild White-headed Vultures were image-processed and overlaid with an analysis grid. An information theoretic approach was used to determine the probability of a specific median wing covert pattern recurring in the population. This probability determines the information content of each pattern.

**Results** The information content of median wing covert patterns is high (median content 23.54 bits) and the probability of pattern recurrence in a population of 10 000 birds is low ( $P = 2.04 \times 10^{-3}$ ). The likelihood of the pattern changing over time is low.

**Conclusions** White-headed Vultures show variation in their median wing covert pattern that is sufficient for birds to be individually identifiable in the field. This non-invasive identification technique is reliable and is suitable for cataloguing local and regional populations of adult White-headed Vultures, thus facilitating mark–recapture studies or other studies that require identification of individuals.

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## INTRODUCTION

The ability to recognize and identify individual animals in a wild population is necessary for various types of studies. For example, mark–recapture studies and estimates of mortality and survivorship rely on animals being re-sighted. Behavioural studies need to distinguish between individuals that may exhibit variations in behaviour.

The definitive method by which animals are identified is marking or tagging, but in order to do this each animal must be captured and restrained. Catching, marking and releasing animals can sometimes be difficult and might not be cost-effective or efficient. It is also an invasive method that entails a degree of physical risk to the animals (Recher *et al.* 1985) and can alter behaviour post-release (Bustnes & Erikstad 1990, Ponjoan *et al.* 2008). In rare cases marking and tagging might increase a subject animal's susceptibility to predation (Irvine *et al.* 2007).

Where large numbers of animals are to be observed, and where capture and restraint is logistically difficult or expensive, non-invasive methods of identification can be used. These methods often utilize variation in natural markings on the animal such as skin patterns, scars and fur or plumage patterns (Pennycuick & Rudnai 1970, Bretagnolle *et al.* 1994, Arroyo & Bretagnolle 1999, Anderson *et al.* 2007, Gilkinson *et al.* 2007) as well as vocalizations (Blumstein & Munos 2005, Pollard *et al.* 2010). Natural markings are used less frequently because not all species have suitable features, or there is insufficient feature variation between individuals for the purposes of accurate identification. In addition to variation between individuals, the natural marking must be sufficiently individualistic such that a specific animal can be identified using the marking. It follows that such natural markings ought to be reasonably obvious and able to be recorded without undue difficulty. The signature characteristics must also remain constant for the duration of the observational period.

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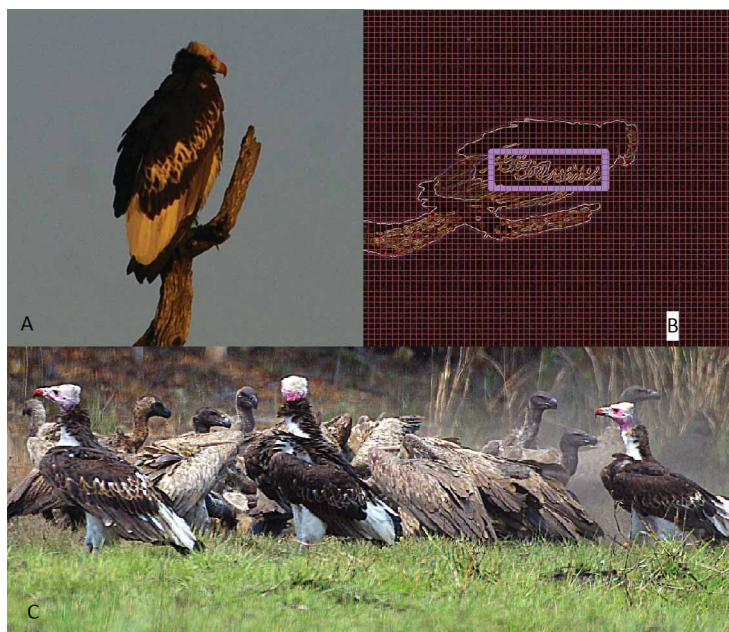
Plumage patterns have previously been used for field identification of individual birds. Bretagnolle and others (1994) identified up to 33 Ospreys *Pandion haliaetus* using plumage patterns on the head and breast in addition to iris colour. Arroyo and Bretagnolle (1999) used a combination of six plumage features to differentiate between 55 adult male Little Bustards *Tetrax tetrax*, and highlighted the low probability of feature combinations occurring more than once. Both studies utilized hand-drawn images recorded by field observers. Alternatively, Ríos-Uzeda and Wallace (2007) recorded Andean Condors *Vulture gryphus* photographically to identify age, sex and also the identity of 23 adult males. This study used distinctive marks and plumage patterns, but did not describe reliability estimates or which mark and pattern combinations were used.

The White-headed vulture *Trigonoceps occipitalis* is a large and conspicuous raptor that has a broad but patchy distribution south of the Sahara (Mundy *et al.* 1992). Adults have a distinctive appearance (Figure 1A) and are readily distinguishable from all other vulture species. The plumage exhibits a strong contrast between black and white. Unique among African vultures, White-headed Vultures are sexually dimorphic and the species exhibits a degree of reversed

sexual dimorphism, where females are slightly larger than males (Mundy 1985).

Compared with most other vulture species, the White-headed Vulture has a low population density across its range and is almost completely restricted to protected areas (Herremans & Herremans-Tonnoeyr 2000). As a solitary nesting species that is usually seen only singly or in pairs (Mundy 1997), White-headed Vultures can be difficult to observe in the wild. For these reasons, comparatively little is known about the biology of the species (Virani & Watson 1998, Monadjem 2004). Due to it being a sparsely distributed and generally uncommon bird (Borello 1987, Parker 2005), it has not been the subject of extensive behavioural studies. Few birds have been marked or ringed, and although breeding adults are assumed to be territorial (Hitchins 1980, Borello & Borello 1997, Mundy 1997), accurate individual identification of birds to confirm this behaviour is lacking.

This study examines if individual White-headed Vultures are identifiable from their plumage patterns, specifically the median wing coverts. An information theoretic approach is used (Pennycuik & Rudnai 1970), which measures the amount of information contained within a pattern and then uses the probability of pattern recurrence to determine



**Figure 1.** Lateral views of an adult female White-headed Vulture *Trigonoceps occipitalis*. (A) Original image. (B) Image prepared for analysis by GIMP ([www.gimp.org](http://www.gimp.org)) using Sobel edge enhancement and superimposed analysis grid. (C) Three adult females together showing variation in median wing covert pattern.

reliability. The aim of this study is to demonstrate that individual White-headed Vultures can be reliably distinguished by the pattern in their median wing coverts.

## METHODS

### Study area

White-headed Vultures were photographed in Kruger National Park (KNP), South Africa. The most recent population estimate for White-headed Vultures in KNP is 64 birds, based on numbers of nesting vultures seen during aerial surveys of herbivores between 1982 and 1994 (Deacon 2004). This estimate formed the basis of a confidence threshold for this study. To account for changes since 1994, and also potential inaccuracies in the estimate, the *a-priori* threshold of confidence was if at least 120 individuals could be distinguished with a level of reliability that exceeded 99%.

### Pattern selection and permanence of pattern

Most large raptors generally have moult and feather replacement cycles that are of long duration (del Hoyo *et al.* 1994). Large Aegyptine vultures such as the White-headed Vulture are no exception, and may take up to 3 years for a complete moult and replacement cycle of the primary and secondary flight feathers (Mundy *et al.* 1992). Observations of a captive Cinereous Vulture *Aegypius monachus*, another large Aegyptine vulture, resident at the Hawk Conservancy Trust (UK), suggested that the replacement of non-flight feathers such as wing coverts takes much longer. This bird had had a number of its median wing coverts bleached for identification purposes, and after 4 years of observation, these distinctive feathers had not been moulted and replaced (author unpublished data). Additionally, White-headed Vultures resident at the Hawk Conservancy Trust showed no apparent change in median wing covert pattern over a period of more than 12 months. Such feathers and the pattern they create may actually persist for many years, perhaps most of the life of a large vulture.

It was thus assumed that, intra-seasonally at least, the wing covert pattern on White-headed Vultures observed during this study would not change. The wing covert pattern on White-headed Vultures is distinctive and from field observations it is obvious that variation exists between birds (Figure 1A,C). The distinctive

appearance is due to the size of each covert feather and, importantly, variation in the extent of white edging, or 'piping', on each feather. Individual patterns vary in two ways: (1) spatial extent of the pattern; (2) the within-pattern size, shape, presence or absence of covert feather edges. Due to the distinctiveness of the pattern and the slow replacement rate, this plumage feature was selected for testing for individuality and reliability.

### Collection and processing of photographs

Photographs were taken mainly by the author with some images contributed by volunteers between May 2009 and December 2011. Equipment consisted of a digital SLR camera with 170–500 mm lens or a digiscope arrangement with a Swarovski telescope. Digiscoping consists of attaching a digital camera directly to a telescope via a specialist adaptor, in this instance a Swarovski KA TLS 800 mm converter, which enabled subjects as distant as 200 m to be photographed. The number of photographs taken of each bird encountered varied considerably (3 to > 20), and wherever possible both lateral aspects were captured. Approximately 1500 photographs were taken of White-headed Vultures, and a large number of images revealed that the outer median coverts were either in shadow or difficult to see because they were not perpendicular to the line of sight. Prior to analysis, potential images were screened to check that light levels were good, that the median coverts were clearly visible and the bird was close to perpendicular to the camera. Once a total of 30 birds had been identified as meeting these criteria, for each bird the clearest image was retained for analysis.

Images were processed for analysis using GIMP (GNU Image Manipulation Program, [www.gimp.org](http://www.gimp.org)), an open-source graphics manipulation package. Each photograph was rotated, flipped and re-sized so that the lateral view of each bird was the same. An analysis grid was superimposed on the images and adjusted so that each photograph had an 18 × 6 grid pattern (A1 to F18) beginning at the inner median covert and ending at the last outer median covert. Grid height to width ratio was locked, with the 18 cell lateral extent determining the height of the grid (i.e. the height was determined by the width). The size and extent of the analysis grid was determined by the requirement to represent sufficient detail within a pattern while avoiding a grid that consisted of hundreds of character

positions (cells). Given that the outer median coverts are often more difficult to see than the inner median coverts, only the first 9 columns (i.e. inner median coverts, cells A1 to F9) of the analysis grid were used for analysis, a total of 54 character cells.

Using GIMP, each image was enhanced and subjected to a Sobel edge detection process. The Sobel operator is a detection algorithm that measures separately two-dimensional (vertical and horizontal) changes in image intensity at any given point in the image. The resultant gradient provides a measure of how quickly the image intensity changes at each point and in what direction, thus indicating the likelihood of an edge. Figure 1 shows an original photograph (A) and the same image after processing and ready for analysis (B).

### Determining the probability of pattern occurrence and information content

Following the assumption that the median wing covert pattern of White-headed Vultures does not change, it is necessary to determine the probability that any particular wing covert pattern will occur more than once in the population. For each sample, the 54 characters (cells) across the analysis grid were checked for the presence (1) or absence (0) of white edging on the median wing covert feathers. For each bird that had both sides photographed, variation between the two sides was assessed by comparing the number of characters that differed.

Assuming that the presence of an edge in a character is unrelated to the presence of an edge anywhere else in the pattern, the probability of occurrence for a characteristic of interest reflects the frequency at which it occurs in the population, and if the characteristic (i.e. an edge) occurs in cell  $i$  of  $n_i$  patterns, then the frequency of occurrence  $f_i$  of that edge is defined as

$$f_i = n_i/N$$

where  $N$  is the number of patterns (i.e. wing covert patterns) in the sample (Pennycuick & Rudnai 1970). Conversely, the probability of an edge not occurring at position  $i$  is  $(1 - f_i)$ . Thus, if an observed wing covert pattern has edges in cells  $a$ ,  $b$  and  $c$  of the grid but no edges in cells  $x$ ,  $y$  and  $z$  of the grid, then the probability of occurrence  $P$  of that particular combination is

$$P = f_a \times f_b \times f_c \times \dots \times (1 - f_x) \times (1 - f_y) \times (1 - f_z) \dots$$

(Pennycuick & Rudnai 1970).

This probability can be expressed in terms of information (bits), whereby the amount of information

contained in a pattern is related to its probability of occurrence  $P$  by the relationship

$$I = -\log_2 P$$

where  $I$  is the information content in bits (Pennycuick & Rudnai 1970).

*Comparing observed pattern frequencies with randomised patterns.* Any character positions that occurred much more frequently than expected by chance were considered over-represented and thus contributed less information to patterns. Similarly, character positions that occurred very infrequently compared to chance would inflate the information content of a pattern. These marginal character positions could be excluded from the probability of occurrence calculations. To test for the presence of such character positions, the observed character frequencies were compared with the mean character frequencies of 5000 randomly generated character patterns. Observed character positions that occurred in more than 90% or less than 10% of the randomized patterns were considered marginal values and were excluded from the probability of pattern calculations. This was done by setting their value at one.

*Assumption of unrelated character positions.* To examine the assumption that the presence of an edge in a character is unrelated to an edge anywhere else in the pattern, two procedures were used. First, to reveal any spatial autocorrelation, the presence of an edge in each cell was tested for pair-wise independence with its adjacent cells. This was done by comparing the joint probability of an edge occurring in two cells in a pair (e.g. cells A4 and B5) with the combined probability of an edge occurring in both cells and measuring if these probabilities were equal (Anderson *et al.* 2007), such that for cells A4 and B5 in the analysis grid:

$$P(A4 \cap B5) = P(A4)P(B5).$$

The differences between the joint and combined probabilities of adjacent cells in the sample of 30 birds were compared to probabilities from the 5000 randomly generated patterns. If the difference between the observed and expected probabilities exceeded more than 99% of the bootstrapped values, the difference was considered to be too large to have occurred by chance. These pairs of characters were considered not to be pair-wise independent, and the character cell with the lowest amount of information content was removed from further analysis.

Secondly, once the non-independent cells were removed, cell counts in the nine analysis columns were compared to each other using a Kruskal–Wallis test. Pattern variation in the wing coverts occurs in the

horizontal rather than vertical plane (i.e. covert feathers and their edges are seen vertically or near vertically in the lateral view), and each column was treated as a group of samples. The Kruskal–Wallis test is a non-parametric method that tests whether there is a tendency for counts from groups of samples (in this case columns) to be higher or lower than the aggregate of the other groups. An assumption of the Kruskal–Wallis test is homogeneity of variance in the sample ranks, which was checked using Levene’s test. To investigate if cell counts were related at a different scale (e.g. among groups of feathers) the test procedure for the nine columns was repeated at a larger scale using aggregated groups of three columns (i.e. columns 1 to 3, 4 to 6 and 7 to 9).

*Reliability of information.* As described by Pennycuik and Rudnai (1970) the reliability of a specific pattern can be determined by establishing that the probability of it recurring in two or more individuals in a population is less than an arbitrary value  $\beta$ . Therefore, the probability that there will be zero or one individual in a population with the pattern must exceed  $1 - \beta$ , and this relationship can be expressed as

$$(1 - p)^M + Mp(1 - p)^{M-1} > 1 - \beta$$

where  $M$  is the population size and  $p$  the probability that at most one individual has the specific pattern of interest (Pennycuik & Rudnai 1970).

By applying this equation to the *a-priori* threshold determined for this study, it can be seen that for a population size of 120 the maximum probability for

any given pattern cannot exceed  $1.2423 \times 10^{-3}$  if reliability above 99% is to be maintained. In terms of information content, this means that for an individual bird to be identified reliably in the population, its wing covert pattern must contain more than 9.65 bits of information.

## RESULTS

Mean frequencies of occurrence for all 30 character patterns are shown in Figure 2. Of the 54 original cells, 17 were removed from further analysis due to their frequencies of occurrence being marginal ( $\leq 10\%$  or  $\geq 90\%$ ) compared to the bootstrapped patterns (Figure 2). The pair-wise independence test revealed that in eight pairs of cells (A5/B6, B5/B6, B6/C5, B7/C6, C6/D5, F6/F7, F7/F8 and F8/F9) the difference between the joint and combined probabilities exceeded 99% of the bootstrapped values. Subsequently cells A5, B6, C6, B7, F7 and F8 were removed from further analysis (Figure 2). After the remaining data were ranked, Levene’s test indicated that variances did not differ significantly between the ranked columns for both the nine-column ( $P = 0.35$ ) and the aggregated three-column ( $P = 0.73$ ) samples. The Kruskal–Wallis tests at both the nine-column and three-column scales were not significant (nine-column:  $K = 5.41$ ,  $df = 8$ ,  $p > 0.05$ ; three-column:  $K = 1.90$ ,  $df = 2$ ,  $p > 0.05$ ), indicating there is no evidence to suggest that counts of feather edges in any of the

	1	2	3	4	5	6	7	8	9
A	0.27	0.67	0.87	0.63	0.43	0.23	0.13	0.83	0.87
B	0.63	0.93	0.90	0.90	0.67	0.63	0.47	0.33	0.20
C	0.83	0.90	0.97	1.00	0.87	0.83	0.77	0.63	0.67
D	0.77	0.93	0.90	0.87	0.87	0.97	0.87	0.90	0.90
E	0.37	0.67	0.70	0.80	0.87	0.87	1.00	0.90	1.00
F	0.87	0.17	0.20	0.33	0.50	0.63	0.50	0.53	0.63

**Figure 2.** Mean frequencies of occurrence for median wing covert patterns in a sample of 30 White-headed Vultures. Each cell represents a position on the wing and the cell value is the frequency at which the pattern occurred in the 30 vultures. Darker and lighter shading correspond to lower and higher frequencies of occurrence, respectively. Cells with frequencies that occurred in  $\geq 90\%$  or  $\leq 10\%$  of 5000 bootstrapped samples were excluded from analysis (crossed cells). Additionally, cells A5, B6, B7, C6, F7 and F8 were excluded due to lack of pair-wise independence.

columns is more or less than the other columns, and that this is maintained across scales of pattern.

All of the 30 birds in the analysis had wing covert patterns containing an information content of more than 17.22 bits (median 23.54 bits, range 17.22–40.06 bits). This is a high level of information content and indicates the probability of recurrence for the pattern containing the least amount of information is approximately  $2.04 \times 10^{-3}$  in a population of 10 000 individuals. This greatly exceeded the *a-priori* confidence threshold of 1 in 120.

The sample size of birds having both lateral views available for analysis was small ( $n = 4$ ) but was sufficient to confirm that differences in pattern exist between each side of a bird (average character difference  $17.00 \pm 4.41\%$ ). In addition to different patterns (that may have similar information content), the average difference in information content between sides was  $3.14 \pm 2.25$  bits (range 0.39–5.14). Therefore, the left and right lateral views of a bird are not interchangeable as a means of identifying individual birds.

## DISCUSSION

Individual White-headed Vultures exhibit clear differences in the pattern of their median wing coverts. The pattern is obvious and easily photographed when a bird is perched. The information content of these patterns is high on both sides of a bird and the probability of recurrence for a pattern is low enough for individual birds to be identified reliably from one side only. Based on the mean information content from half the visible pattern (inner median coverts) and the existing global population estimate of 7000–12 000 birds (Mundy *et al.* 1992), there is a reasonable suspicion that adult White-headed Vultures each possess a unique pattern. This means that a fieldworker armed with a reasonably powerful camera lens can identify, re-sight and potentially follow individual White-headed Vultures, without the need for trapping and tagging. The most recent population estimate of White-headed Vultures in Kruger National Park is approximately 64 birds (Deacon 2004), so it is clear that using this method all the adult White-headed Vultures in the Kruger should be identifiable. The largest challenge posed to achieving this, in common with other protected areas, is actually encountering and photographing the birds under suitable conditions. Apart from varying light conditions that can affect the clarity of photographs, White-headed Vultures are

encountered only infrequently and are often observed from the ventral side, usually when they are at high flying altitudes.

Apart from the benefits associated with a non-invasive form of monitoring, being able to identify individuals is important for a number of research areas and provides a potentially revealing method by which a number of studies can proceed. These include demographic studies, mark–recapture studies, home range estimates and behavioural studies.

An information theoretic approach has been used to identify individual mammals successfully (Pennycuik & Rudnai 1970, Anderson *et al.* 2007), but this study appears to be the first time the method has been used for individual identification from plumage analysis. It may be that other large avian species with distinctive plumage are suitable for this method of identification. Apart from the theoretical approach another key feature of this study is the addition of a reliability estimate when identifying individuals. With regard to White-headed Vultures specifically, and possibly other Aegyptine vultures or other large birds, a final important point is that these wing covert patterns are very slow to change. They may actually persist for many years, perhaps for a significant proportion of the lifetime of each bird.

The use of the analysis grid was effective for determining the information content and standardizing the way in which the sample of White-headed Vultures could be analysed. However, it is a cumbersome, time-consuming process and unnecessary to identify individual birds. The information theoretic analysis used here was done to highlight the low probability of pattern recurrence, rather than distinguishing between White-headed Vultures. Indeed, specific comparisons between birds and building a catalogue of White-headed Vultures were not aims of this study. In other words, fieldworkers can photograph White-headed Vultures and compare them by eye; there is no need to flip and rotate photographs or employ time-consuming image-processing and information theoretic analyses. With sufficient attention to detail, the human eye can process images and compare them quickly, and is able to do so without requiring familiarity with computer coding and image identification software.

Particularly for a species such as the White-headed Vulture where adults are low in number, distinguishable by their plumage patterns and encountered infrequently, computer image analysis is not necessary. Indeed, prior to the development of modern computing power, fieldworkers were capable of

identifying literally hundreds of individuals in study populations, using only photographic catalogues and the attention to detail of observant people (Goddard 1966, Moss 1988, Caro 1994).

Using photographic identification it is quite possible that a researcher can feasibly catalogue the entire population of adult White-headed Vultures resident in an area. This can facilitate analyses that rely on mark–recapture information. Given the wide variation in plumage of adult White-headed Vultures, it may also be possible to catalogue a regional or supra-regional population of this species.

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