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Identification of individual leopards (*Panthera pardus kotiya*) using spot pattern variation

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(With 2 figures in the text)

Twenty-one captive leopards (*Panthera pardus kotiya*) at the National Zoological Gardens in Sri Lanka were individually identified using spot pattern variation. Based on an identification method established for lions (*Panthera leo*), a code was devised examining 23 variable characters, each of which had one to three values. These characters ranged from number and spacing of muzzle spots to forehead and eye patterns. Correlation among characters to be used for identification was minimized using principal component cluster analysis. The most variable character was chosen from each of eight non-overlapping clusters, and frequencies were calculated for each character value. The probability of occurrence of a given spot pattern was calculated as the sum of the frequencies of each character value. From this probability of occurrence, the information content, in bits, was computed for each pattern. The number of bits per character was also calculated. Using the binomial theorem, the reliability of identification was estimated as the sum of the probabilities of zero or one individual having an identical combination of character values. These binomial probabilities exceeded 0·99 for 15 out of 21 animals, and 0·95 for all but two. In these two animals, the information content was low (5·99 and 5·50 bits, respectively) compared to the others, in which information content ranged from 6·87–10·86. Although the mean number of bits (8·5) was theoretically sufficient for a 99% reliable identification, it was concluded that supplementation with an additional character would be worthwhile for identification of individual leopards.

Contents

Introduction

'Then the Ethiopian put his five fingers together . . . and pressed them all over the Leopard [leaving] five little black marks all close together . . . sometimes the fingers slipped and the marks

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got a little blurred; but if you look closely at any Leopard now you will see that there are always five spots' Rudyard Kipling, 1982: 224. But are there always 'five spots'?

Many field biologists have relied on the detection of variation in natural markings for recognition of individual animals. Differences in facial structures were used by Goodall (1968) for identification of chimpanzees (*Pan troglodytes*), by MacKinnon (1974) for orang-utans (*Pongo pygmaeus*) and by Clutton-Brock & Guiness (1975) for female red deer (*Cervus elaphus*). Goddard (1966) and Mukinya (1973) used wrinkle patterns on snouts to identify black rhinoceros (*Diceros bicornis*). Schaller (1963) also used wrinkle patterns on noses in combination with the shape of nostrils to distinguish mountain gorillas (*Gorilla gorilla beringei*). In his study of African elephants (*Loxodonta africana*), Douglas-Hamilton, I. & Douglas-Hamilton, O. (1975) recognized individuals in herds by using differences in ear outlines and natural ear notches. Variation in antler shapes enabled Clutton-Brock & Guiness (1975) to identify red deer stags. Bewick's swans (*Cygnus bewickii*) have been studied extensively by Scott (1978) and Bateson, Lotwick & Scott (1980) who used differences in colour patterns on bills, combined with variation in other facial characteristics to recognize individuals.

Stripes and spots on mammals also vary discernibly amongst individuals. Peterson (1972) used a simple coding system based on the position and shape of stripes to identify zebra (*Equus burchelli*) in Nairobi National Park. Tigers (*Panthera tigris*) have variable markings on either side of the face, legs and shoulders, and these differences were used by McDougal (1977) for individual recognition in his research. Neck markings on giraffes (*Giraffa camelopardalis*) are also distinct for individuals and were the basis of identification in a field study by Foster (1966). A study of the ecology of servals (*Felis serval*) in Tanzania was made possible by recognition of 34 individuals based on stripe and spot pattern variation (Geertsema, 1985).

Pennycuick & Rudnai (1970) devised a method to identify lions (*Panthera leo*) based on variation in mystacial vibrissae spots. Their method included determination of the probability of duplication of a particular pattern and the mutual independence (both unilateral and bilateral) of spot patterns. They analysed the reliability of the method for different sample sizes and defined reliability in terms of the information content of a particular pattern. The information content, in turn, is expressed in binary units. The number of bits is dependent on the frequency of occurrence of a particular value of a particular character. Pennycuick (1978) detailed the steps necessary to use this method of identification and discussed, for different sample sizes, the number and type of characters required to obtain a sufficient number of bits to yield a low probability of duplication. In this study, we used the same method to identify individual leopards (*Panthera pardus*) based on differences in spot patterns.

Methods

The leopards

The 21 leopards examined in this study were from the collection at the National Zoological Gardens of Sri Lanka. Examinations of spot patterns were made in conjunction with a study of genetic and morphological variation (Miththapala *et al.*, In press, In prep.) and reproductive physiology (Brown *et al.*, In press). Nineteen leopards were of the subspecies *P. p. kotiya* (Deraniyagala, 1949, 1956) (5 wild caught, 10 captive born and 4 of unknown status) and 2 were hybrids of *P. p. kotiya* and the Malaysian subspecies (*P. p. delacouri*). In addition to the spotted leopards, there was also a lineage of melanistic leopards (5), the founders of which are probably *P. p. delacouri*, which were obtained from Malaysia in the mid-1960s.

Spot patterns in leopards

There is noticeable variability of spot patterns in some areas of the body. On either side of the muzzle, the number of spots and their position relative to each other varies amongst individuals and, bilaterally, within individuals (Fig. 1). Markings immediately below the eyes are either definite lines or a series of spots in a row, while spots on the forehead form several detectable shapes such as circles, ovals or squares (Fig. 2). Spots on the ventral surface of the neck and chest are sometimes joined to form a 'necklace'. Though colour is not a meristic variable, it is possible to note differences in the colour of the abdomen, which is either white or buff.

In addition to variability in spot patterns and colour, size differences indicate the sex of an animal. Adult male leopards are larger than females (Schaller, 1972; Bertram, 1976; Wayne, Modi & O'Brien, 1986; Van Valkenburgh & Ruff, 1987) and in this collection, spotted males were 58% heavier than females and 21% larger in head-width (Miththapala *et al.*, In prep.).

FIG. 1. Diagram of mystacial spots used in the identification code (after Pennycuick & Rudnai, 1970).

These characteristics were used to devise an identification code based on methods used by Pennycuick & Rudnai (1970) and Scott (1978).

Identification code

While the animals were under anaesthesia for blood sample collection, the number and position of mystacial spots were recorded and black and white photographs were taken of (a) both sides of the muzzle, (b) the ventral surface of the neck and the chest and (c) the forehead. These photographs were supplemented with diagrams.

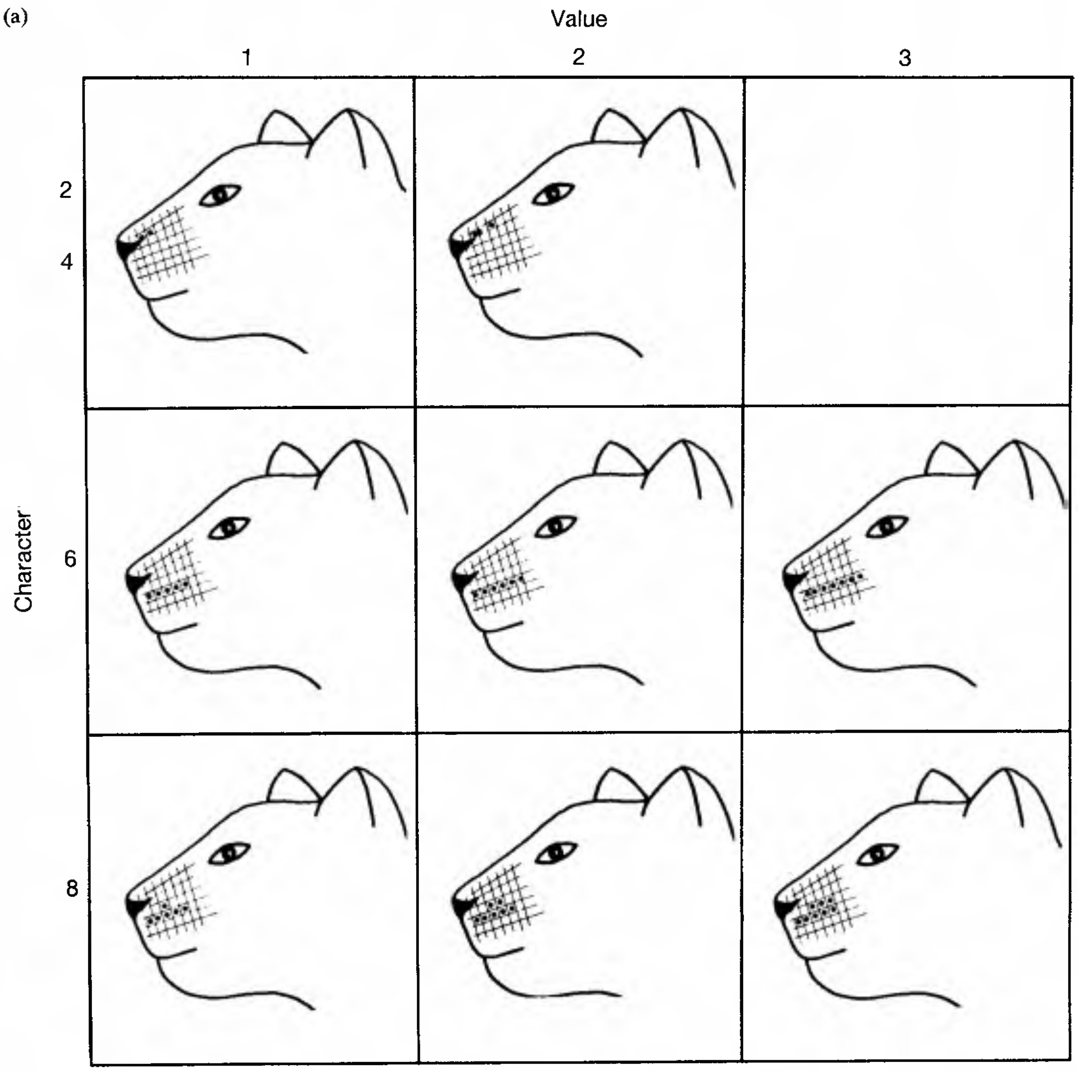
Figure 1 is an illustration of the numbering system. Rows of mystacial spots were numbered from the nose towards the lips. The first vibrissae-bearing row, Row D, had 5–7 spots and was used as the reference line for spot positions in Rows B and C. Rows B and C had 0–2 and 0–3 spots, respectively, which were either aligned or between spots on Row D. Row A had 1–4 spots that were spaced evenly or clustered together. Below Row D, there were 3–4 vibrissae-bearing rows, of which only Row E was used for description. These rows are illustrated but not numbered in Fig. 1.

A complete list of the characters that were initially described for identification is presented in Table I and the values for each of these characters are illustrated in Fig. 2.

Results

In order to minimize correlation amongst characters selected for identification, the computer program SAS (PC Version 5, 1985) was used to perform oblique principal component cluster analysis. Based on a correlation matrix, the characters were grouped into eight non-overlapping clusters, which were essentially not similar to each other. From each cluster, the most variable character (i.e. with the highest standard deviation) was chosen for further analysis. This procedure necessarily reduced the character set described initially, and the characters actually used in the analysis are marked with an asterisk in Table I. The frequencies of each of these character values, as well as the probability of occurrence of a given spot pattern, were computed (Table II and III).

(a)



See Fig. 2 legend.

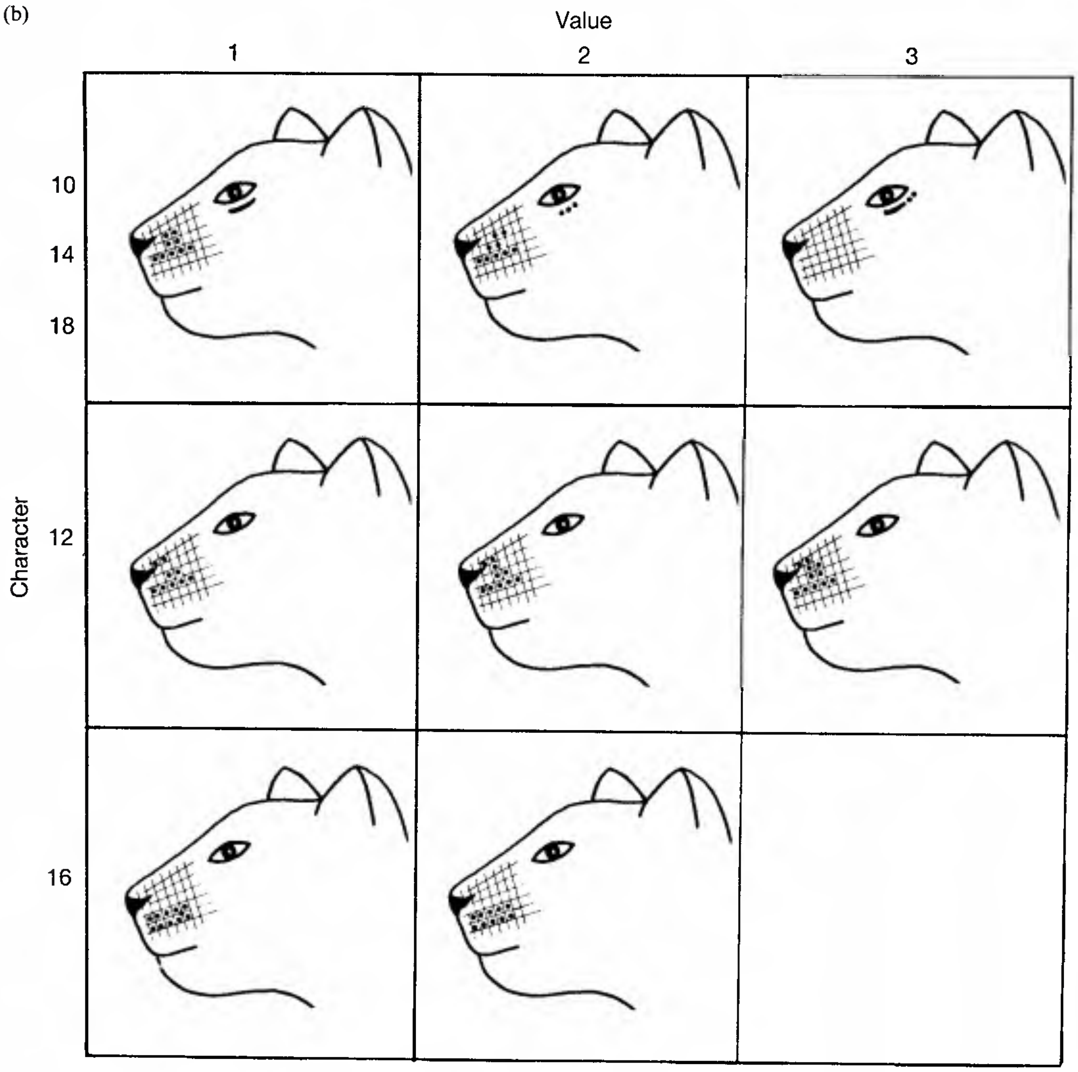
The probability of occurrence of a given spot pattern (i.e. a specific combination of character values) is the aggregate frequency of each character value for that pattern (Pennycuick & Rudnai, 1970).

The reliability of identification is defined in terms of the information content in binary units (bits) as:

$$I = -\log_2 p \tag{1}$$

where I is the information content in bits and p is the probability of occurrence (Pennycuick & Rudnai, 1970). The information content of each pattern and each character value used in the analysis are presented in Tables II and III.

(b)



See Fig. 2 legend.

(c)

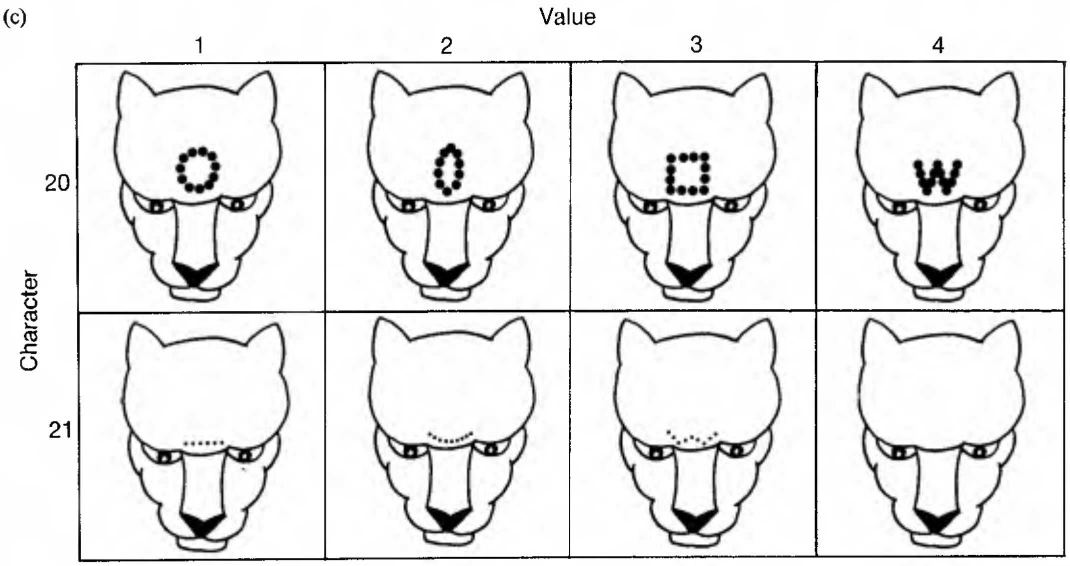


FIG. 2. Diagrams for character values described in Table I: (a) mystacial spot pattern values; (b) spot patterns below the eye and mystacial spot pattern values; and (c) forehead spot patterns.

The reliability of identification is estimated by calculating the probability of x individuals from a given population having a specific spot pattern, which is described by the binomial formula:

$$Q_x = p^x . (1-p)^{m-x} . \frac{m!}{x!\,(m-x)!} \qquad (2)$$

where p is the probability of occurrence for a given spot pattern, and x is the number of individuals having that pattern in a population m (Pennycuick & Rudnai, 1970). It follows that the sum of the probabilities of 0 or 1 individuals having the identical pattern, Q_0 and Q_1 equals:

$$(1-p)^m + mp(1-p)^{m-1} \qquad (3)$$

and that the sum should exceed 0·95 at a 0·05 significance level and 0·99 at 0·01 (Pennycuick & Rudnai, 1970). These probabilities are also presented in Table III.

Discussion

It was apparent from the analysis that some characters yielded more information than others. Characters 7 (Row D, right, number), 8 (Row C, left, number), 9 (Row C, right, number) and 13 (Row B, right, number) contributed more information (25·1%, 18·8%, 16·2% and 14·6% of the total information, respectively) than characters 1 (sex), 2 (Row A, left, number), 5 (Row A, right, spacing) and 10 (Row C, left, spacing) (6·3%, 6·8%, 6·1% and 6·1% of the total) (Table II). Using Scott's (1978) data on Bewick's swans, Pennycuick (1978) demonstrated that if one value of a character is very rare, then its occurrence increases the information content and therefore the total number of bits becomes high based solely on one value. He recommended that, on average, characters should yield about one bit of information. All the characters used in this analysis

TABLE I

Description of characters and their values

Character	Value	Definition
*1. Sex	1	Male
	2	Female
Mystacial vibrissae spots:		
*2. Row A, number, left	1	2 or fewer spots
3. Row A, number, right	2	3 or fewer spots
4. Row A, spacing, left	1	Spots separated from each other
*5. Row A, spacing, right	2	At least 1 spot touches another
6. Row D, number, left	1	5 or fewer spots
*7. Row, D, number, right	2	6 spots
	3	7 or more spots
*8. Row C, number, left	1	1 spot
*9. Row C, number, right	2	2 spots
	3	3 spots
*10. Row C, spacing, left	1	All spots in line with spot/spots on Row D
11. Row C, spacing, right	2	At least one spot between spots on Row D
12. Row B, number, left	1	0 spots
	2	1 spot
*13. Row B, number, right	3	2 or more spots
14. Row B, spacing, left	1	All spots in line with spots on Row D
15. Row B, spacing, right	2	At least one spot between spots on Row D
16. Row Di, left	1	Presence of spot between Row D & E
17. Row Di, right	2	Absence of spot between Row D & E
Patterns below the eyes:		
18. Eye, left	1	Presence of line only beneath eye
19. Eye, right	2	Presence of spots only beneath eye
	3	Presence of both line and spot beneath eye
Forehead patterns:		
20. Forehead, major	1	Spots in a circle
	2	Spots in an oval
	3	Spots in a square
	4	Spots in a 'W'
21. Forehead, minor	1	Line below major pattern
	2	Semicircle below major pattern
	3	'W' below major pattern
Other variables:		
22. 'Necklace'	1	Presence of connected spots on ventral surface of chest
	2	Absence of connected spots on ventral surface of chest
23. Abdomen	1	White
	2	Buff

* Characters used in analysis

TABLE II

Frequencies of character values and their information content

Character	Value	Frequency	Information bits	Percentage of total information
1	1	0·640	0·644	6·3
	2	0·360	1·474	
2	1	0·280	1·836	6·8
	2	0·780	0·474	
5	1	0·420	1·263	6·1
	2	0·580	0·778	
7	1	0·040	4·644	25·1
	2	0·880	0·184	
	3	0·080	3·644	
8	1	0·208	2·263	18·8
	2	0·708	0·497	
	3	0·083	3·585	
9	1	0·333	1·585	16·2
	2	0·542	0·885	
	3	0·125	3·000	
10	1	0·417	1·263	6·1
	2	0·583	0·778	
13	1	0·417	1·263	14·6
	2	0·375	1·415	
	3	0·208	2·263	

TABLE III

Probability of occurrence and information content of individual spot patterns

Animal ID number	Aggregate probability of occurrence	Information in bits	Binomial probability
01	0·0021	8·88	0·998
02	0·0024	8·69	0·998
03	0·0061	7·35	0·985
04	0·0086	6·87	0·973
06	0·0006	10·60	0·999
07	0·0032	8·30	0·996
09	0·0027	8·54	0·996
14	0·0048	7·69	0·991
16	0·0005	10·86	0·999
18	0·0033	8·26	0·996
19	0·0013	9·57	0·999
21	0·0087	6·84	0·972
22	0·0158	5·99	0·919
24	0·0062	7·33	0·986
26	0·0006	10·80	0·999
27	0·0011	9·88	0·999
29	0·0221	5·50	0·859
30	0·0049	7·67	0·990
31	0·0007	10·43	0·999
32	0·0029	8·45	0·997
33	0·0010	10·02	0·996

yielded more than one bit (Table II) and therefore the unevenness of bits across characters should not affect the analysis.

The analysis also indicated that the identification system is reliable at a 0·05 significance level. In all but two individuals, the probability of zero or one animal having the same combination of character values is less than 0·05 (Table III). Although probabilities were higher for individuals No. 22 and 29, 15 out of 21 animals showed levels less than 0·01. In animals No. 22 and 29, the information content was low (5·99 and 5·50 bits, respectively), compared to others which ranged from 6·87–10·86, with a mean of 8·5 bits (Table III). In his review of this system, Pennycuick (1978) plotted the probability of duplication against information (bits) for several population sizes. According to his graph, 8·5 bits would be 99% reliable for a population of 50 and the probability of duplication would decrease to almost 0·001 for a population of 25.

There were 1296 possible combinations of each value of each of the eight characters used. The 20 most probable combinations were rank ordered and binomial probabilities calculated as before. The most common and third most common combination had probabilities of occurrence of 0·0158 and 0·0221 and binomial probabilities of 0·9192 and 0·8587. These are the same probabilities yielded by spot patterns for leopards No. 22 and 29.

Therefore, even though there is sufficient information according to Pennycuick's model, it may be worthwhile to augment the system with one or more characters, though the number of possible combinations would then necessarily increase, at a minimum, to 2592 (for two values) and 3888 (for three values).

Further, choosing additional characters from Table I may not be as simple as it appears, because of the insidious problem of correlation among characters. It may be necessary to obtain complete data sets on forehead and eye patterns (Table I, characters 18, 19, 20 and 21), which appeared extremely variable but could not be included in the present analysis because of some missing values.

To conclude, the identification system used in this study was for the most part reliable at 0·05 to 0·01 significance level, although supplementation with additional characters would be worthwhile.

Summary

Variation in natural markings has been valuable to field biologists for identification of individual animals. In this study, individual leopards at the National Zoological Gardens in Sri Lanka were identified using spot pattern variation, based on a method used successfully by Pennycuick & Rudnai (1970) for lions. A total of 23 variable characters, ranging from number and spacing of muzzle spots to forehead and eye patterns, were initially described. Principal component cluster analysis was used to minimize correlation among characters included in identification, and the most variable character was chosen from each non-overlapping cluster. Frequencies of character values were summed to obtain probabilities of occurrence of a given spot pattern and then, the information content (in binary units) calculated for each individual. The reliability of identification was estimated using the binomial theorem. These binomial probabilities exceeded 0·99 for 15 out of 21 animals, and 0·95 for all but two. In these two animals, the information content was low (5·99 and 5·50 bits, respectively) compared to others which ranged from 6·87–10·86. Although the mean number of bits per animal (8·5) was theoretically sufficient for a 99% reliable identification, it was concluded that supplementation with an additional character would be worthwhile for individual leopard identification in field projects.

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