Gender discrimination of tigers by using their pugmarks

Sandeep Sharma, Yadvendradev Jhala, and Vishwas B. Sawarkar

Abstract We evaluated gender discrimination of tigers (*Panthera tigris*) using the shape of their pugmarks. Discriminant Function Analysis (DFA) and logistic regression were used to discriminate gender of 13 known tigers from nine easy-to-obtain pugmark measurements. Both multivariate techniques were quite accurate in discriminating genders; the most accurate and parsimonious model was DFA with parameters of pugmark length and width. Our technique can be used to acquire sex-ratio data of tiger populations in areas where pugmarks are easy to obtain.

Key words multivariate analysis, *Panthera tigris*, sex ratio, spoor, tracks

We tested the belief that the gender of tigers (*Panthera tigris*) can be differentiated on the basis of the shape of the hind pugmark. British forester F. C. Hicks described the male tiger's pugmark as being more circular than that of a female. He added that the pugmarks of a tigress were misshapen and ugly and her forepaw resembled the hind pugmark of a male (see Sankhla 1978: 178). Sommerville (1933) suggested that the pugmarks of a male tiger were larger than the female's. He also noted the male's toes were square while the female's were more rounded and slender. Sankhla (1978) described the front pugmark of a male tiger as regular and that of a female as irregular or zygomorphic. He also observed captive tigers and found that at 3 months of age the male's pad size was double that of the female. This difference was maintained throughout life. The male tiger's pugmark was also said to be more square, less angular, and relatively wider in relation to its length (McDougal 1977, 1999). Panwar (1979*a*,*b*) suggested that the whole hind pugmark of a male tiger fit into a square frame, whereas that of a female fit into a relatively rectangular frame. He also suggested that the female's toes were slender and elongated compared to a male's toes, which were oval and more circular. This criterion is the most adopted and widely used field technique to differentiate gender of a tiger based on its pugmarks (Figure 1).

The use of the angle measure between the outermost toes (toe 1 and toe 4) of the pugmark was suggested as a gender-discriminating criterion by Gogate et al. (1989). They stated that the angle between the outermost toes, formed by joining the centers of the outermost toes and center of the pad, was about 100° in male tigers and 92.4° in female tigers. Although this indicated that male tigers have broader pugmarks, toe angles alone did not provide definitive discrimination criteria, and a group of variables associated with pugmarks might be required to discriminate tiger gender. Sagar and Singh (1993) used a 1.5-cm rule for pugmark-based gender discrimination of tigers. According to them, if length of the pugmark exceeded width by more than 1.5 cm, measurements suggested a female.

Paranjape et al. (1993) tried to statistically discriminate tiger gender by using pugmarks. They used visual inspection of histograms depicting differences among length and breadth of pugmarks to judge the cut-off value for gender discrimination. They also used the graphical technique described by Bhattacharya (1967), who assumed that a specific variable followed the normal distribution for each gender with significantly different means. The technique claims to estimate gender variation as well as the proportion of each gender in a given population, as represented by pugmark sets. Gore et al. (1993) attempted to use logistic regression for

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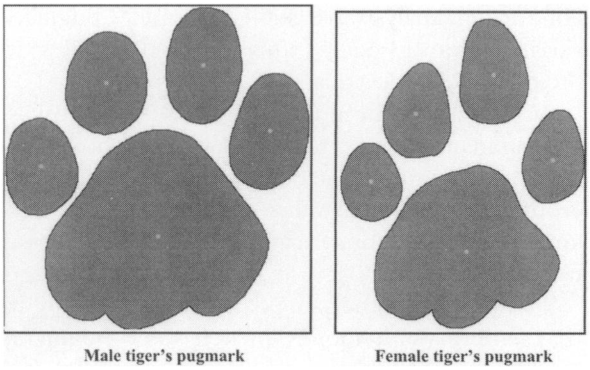

Figure 1: Hind pugmark of a male tiger and a female tiger showing the square-frame and rectangular-frame criterion for gender discrimination of tigers.

gender discrimination of 5 captive tigers (2 males and 3 females). They used the following three pugmark measurements: distance between pad center and center of first toe, distance between pad center and center of second toe, and distance between center of first toe and second toe.

The techniques described by Gogate et al. (1989), Paranjape et al. (1993), and Sagar and Singh (1993) shared one common weakness in that their pugmark data were obtained during census exercises in tiger reserves, where the gender and identity of individual tigers were uncertain. Such data are not suitable for developing predictive models. Moreover, several people traced these pugmarks, so variability associated with different tracers also might have created variation.

Gender identification of tigers using width of pads and total width of hindfeet was attempted by McDougal (1999). He found that the width of forefoot pads of males averaged >9.7 cm, while those of females averaged <9.3 cm. The hindfoot pad-width measurements averaged >8.5 cm for males and <8.5 cm for females. The total width of hindfeet of males averaged >11.0 cm and that of females averaged <11.0 cm. Similar measurements were developed for Amur (Siberian) tigers (*Panthera tigris altiaca*) based on pad-width measurement, which has been used as a means of gender and age-class discrimination of tigers (Abramov 1961, Yudakov and Nikolaev 1970, Matyushkin and Yudakov 1974, Smirnov and Miquelle 1996). Pad-width measurements also have been used to make approximate discrimination between male and female mountain lions (*Puma concolor*) (Shaw 1983, Smallwood and Fitzhugh 1995). Zalewski (1999) used discriminant function analysis for gender discrimination of pine martens (*Martes martes*) using track and gait measurements.

However, assessment of tiger gender using pugmarks has been questioned as unreliable (Karanth 1987). The method was considered crude and conservative and has not been validated with use of pugmarks from known tigers (Karanth 1987).

We evaluated the potential of using measurements of pugmarks for gender identification of tigers. We tested various multivariate methods for their potential to provide a simple, accurate, and objective gender-discrimination method for tigers.

Methods

We collected pugmark sets of tigers whose gender was known from zoos and tiger reserves (Table 1). In wild tigers, gender identity was confirmed by actual sightings. A pugmark set was defined as 10–15 replicates of tracings of different right and left hind pugmarks of the same tiger, traced from the fresh pugmark trail of a known tiger. We sampled pugmark trails that had at least 5 clear impressions of left and right hindfeet where the tiger had walked in normal gait. We examined the gait pattern for consistency in stride length and pattern of superimposition, and under- and over-shoot of front feet with reference to hindfeet (Sawarkar 1987). We then traced and photographed these pugmarks.

The first author traced pugmarks on a standardized substrate (0.5–0.8-cm soil depth, finely pulverized

Table 1. Details of the pugmark sets collected from tigers whose gender was known, from different study areas in India between November 2000 and April 2001.

Site No.	Study site	Total number of pugmark sets collected	No. of male tigers	No. of female tigers	Average number of pugmarks per pugmark set (range)
1	Keoladeo National Park, Rajasthan	1	0	1	7 (6–10)
2	Ranthabhore Tiger Reserve, Rajasthan	5	2	3	10 (8–12)
3	Kanha Tiger Reserve, Madhya Pradesh	4	0	4	11 (10–14)
4	Bandhavgarh Tiger Reserve, Madhya Pradesh	1	0	1	8 (6–10)
5	National Zoological Garden, New Delhi	2	1	1	11 (8– 15)
	Total	13	3	10	

soil) on flat terrain, following the standard pugmark-tracing technique (Choudhury 1971, 1972, Panwar 1979*a*, Sawarkar 1987). Tracing by one person eliminated observer variability. Tracings were done on acetate sheets using an indelible-ink pen. In captive situations we used Pugmark Impression Pads (PIP, a uniform layer of fine soil over a hard substrate) (Rishi 1997) to obtain pugmarks.

We scanned pugmark tracings and then measured and analyzed digital images using Arc Info 8.0.2 (Environmental Systems Research Institute, Redlands, Calif.) and Sigma Scan Pro 4 (SPSS Inc.) software. We took 9 measurements from each pugmark (Figure 2). These 9 measurements were selected from a set of 93 pugmark measurements based on their discriminatory power between tigers as indexed by an *F*-ratio criterion (Jewell et al. 2001, Sharma 2001).

We explored the potential of several multivariate approaches for the use of quantitative discrimination of tiger gender. The 9 pugmark variables of 13 tigers were first subjected to Principle Component Analysis (PCA) and a scatterplot of PC scores was plotted on PC1 and PC2 to differentiate the gender.

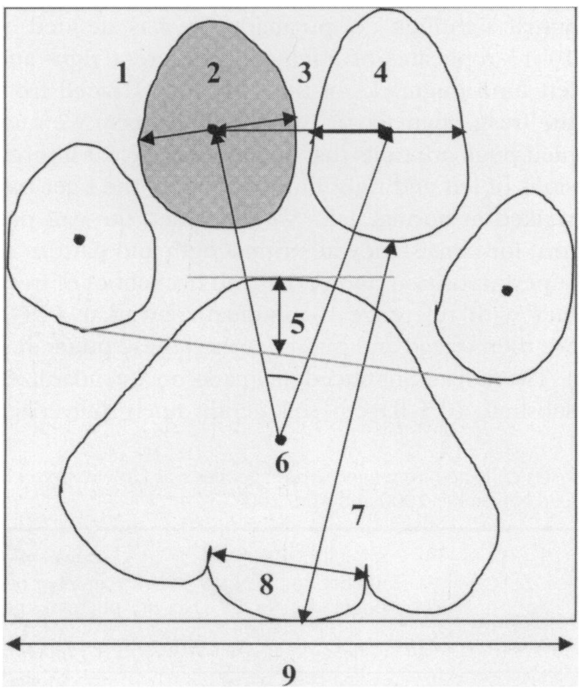

Figure 2. Nine pugmark variables measured from pugmark: (1) area of toe 3, (2) length of minor axis of toe 3, (3) distance between toe 2 and toe 3 (DT2T3), (4) length of minor axis of toe 2, (5) distance between main pad top to toe base-line (H), (6) angle between toe 2 and toe 3, (7) heel to lead toe length, (8) distance between notch 1 and notch 2 (DN1N2), (9) width of the pugmark.

For further analysis we subjected the 9 pugmark variables from 13 tigers (3 males and 10 females) to the three processes described below:

We subjected the pugmark data set to stepwise Discriminant Function Analysis (DFA) and examined the classification accuracy of original pugmark groupings. For cross-validation of results, a Jackknife method (Johnson and Wichern 1992) was used.

We then tested the same data set with predictive DFA, where we randomly picked some pugmarks from each pugmark set and assigned them a "new" identity, thus creating two equal populations of pugmark sets. One population of pugmark sets was used to develop the DFA model. We then tested this model with the other population of pugmark sets with the new identity, for its ability to correctly assign the gender of each pugmark set.

We also tested the DFA model developed using the data set from 10 tigers with a new data set from 3 known tigers (1 male and 2 females). Two of them were captive tigers (National Zoological Garden, New Delhi) and one was a wild tigress. The newly entered data set was not used to build the model on which they were tested.

Since gender identification is theoretically based on the shape of the pugmark, we separately tested only length and breadth data from pugmark sets as predictive variables for gender discrimination. We also employed logistic regression to separately examine these groups of 9 and 2 variables (Johnson and Wichern 1992).

Results

The results of PCA for gender discrimination of tigers generated two PCs, which accounted for 75.8% of the variability in the data. The scatter plot between these two PCs showed two distinct data populations (Figure 3).

Stepwise DFA selected 3 of 9 variables to discriminate between male and female tigers: 1) distance between toe 2 and toe 3 (DT2T3), 2) distance between notch 1 and notch 2 (DN1N2), and 3) distance between main pad top to toe base line (H) (Figure 2). The classification accuracy was 99.1% in the original grouping of pugmarks and 98.1% in cross-validation using the Jackknife method. For the predictive DFA, where 50% of pugmarks were used to develop a model and the remaining 50% were tested as a data set of tigers of unknown gender, the classification accuracy was 100% for

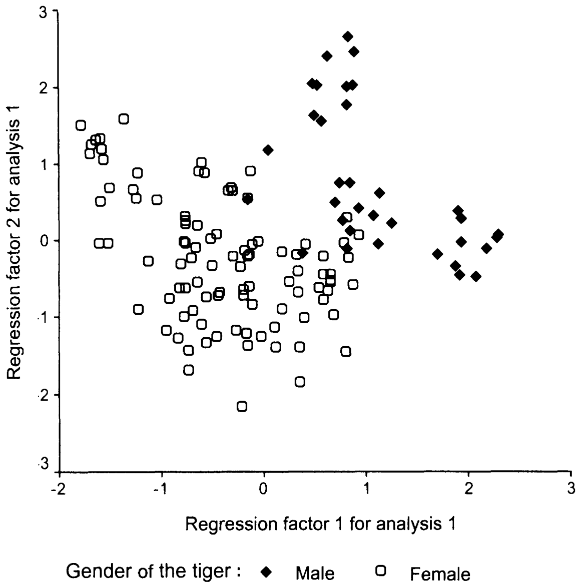

Figure 3. Scatterplot between PC1 and PC2 for 13 tigers of known gender, showing two distinct data populations of males and females, based on pugmark measurements.

pugmark sets (tigers) and 99.1% for individual pugmarks. When the data set of 3 new tigers was tested over the model built using the data set of 10 tigers, the classification accuracy was 100% for pugmark sets (tigers) and 99.1% for individual pugmarks. The Jackknife results for individual pugmarks gave 98.1% accuracy.

The DFA model developed for gender discrimination by using 9 variables was as follows:

For female tigers:

$$F = -0.345\,(DT2T3) - 0.524\,(DN1N2) - 0.822\,(H) - 0.619 \quad (1)$$

and for male tigers:

$$M = 1.775\,(DT2T3) + 1.432\,(DN1N2) + 2.338\,(H) - 6.176, \quad (2)$$

where,

DT2T3 = distance between toe 2 and toe 3,
DN1N2 = distance between notch 1 and notch 2,

and

H = distance between main pad top to toe base line.

Discriminant Function Analysis using only 2 variables (i.e., length of pugmark and width of pugmark) for 10 tigers resulted in 100% correct classification of pugmarks in the original as well as the Jackknife test. Predictive DFA resulted in gender classification accuracy of 100% for pugmark sets as well as for the original grouping of individual pugmarks. The accuracy of the Jackknife test for classification of individual pugmarks was also 100%.

When we used this DFA model and logistic regression model (Table 2) to predict the gender of 3 newly entered tigers, all tigers were correctly assigned by both models. However, one pugmark of a male tiger was misclassified as belonging to a female tiger. The classification accuracy was 97.9% for a group of 97 pugmarks in females and 94.1% for a group of 34 pugmarks in male tigers. The overall accuracy of correct classification was 97.0% for individual pugmarks.

The final DFA model developed by using length and width of the pugmark as predictor variable was as follows:

For female tigers:

$$F = -0.0795\,(L) - 1.092\,(W) - 0.5 \quad (3)$$

and for male tigers:

$$M = 1.887\,(L) + 2.646\,(W) - 4.899, \quad (4)$$

where

L = Length of the pugmark,
W = Width of the pugmark.

Discussion

Principal Component Analysis (PCA) using 9 morphometric pugmark measurements separated the distinct clusters of pugmarks obtained from 3 male and 10 female tigers.

Discriminant Function Analysis using 9 predictor variables resulted in very accurate results. But since one gender-discrimination method (visual examination of pugmark shape) suggested the concept of square and rectangular frames (Panwar 1979*a*), we tried to cross-check this concept by examining the discriminating power of two variables (i.e., length and width of the pugmarks) that were presumed to provide sufficient information to examine the square and rectangular frame concept.

Use of DFA followed by the Jackknife test and use of logistic regression again resulted in very accurate discrimination between gender of tigers on the basis of these two variables. The models developed using pugmark sets collected from known tigers

Table 2. Logistic regression model for gender discrimination of tigers, where length and width measurments of pugmark are used as variables. Model generated using data collected from sites in India between November 2000 and April 2001.

	B	S.E.	Wald	df	Sig.	R	Exp(B)
L (Length of pugmark)	2.1729	0.8189	7.0402	1	0.0080	0.1833	8.7834
W (Width of pugmark)	5.4964	1.5178	13.1139	1	0.0003	0.2722	243.8065
Constant	– 4.7226	1.3308	12.5929	1	0.0004		

were then successfully validated over a pugmark sample set of 3 newly entered tigers.

We found that the models demonstrated high levels of accuracy in discriminating and predicting gender. In particular, we found that length and width of pugmarks were robust variables in prediction of gender.

We acknowledge that our sample of pugmark sets was low, but it was collected in the field from individually known tigers. It was difficult to obtain good pugmark sets with enough replicates in the field because tigers are elusive, primarily nocturnal, have large home ranges, and are sparsely distributed. Moreover, we wanted to collect pugmark sets of individually known tigers, which made sampling difficult. Also, it was more difficult to obtain male pugmarks than female pugmarks in the wild because the sex-ratio is biased toward females and males have larger home ranges.

Management and conservation implications

Tigers are shy and secretive by nature. Their largely nocturnal, wide-ranging movements and low detectability make observations difficult in the wild. In such conditions one has to rely on signs left by tigers to determine their presence. Pugmark collection and analysis could serve as a cost-effective, reliable, and accurate tool for monitoring tiger sex ratios and gender-specific movement patterns.

The non-invasive gender-discrimination technique we propose could be used successfully to gather important demographic data about tiger populations. Together with the algorithm developed for individual identification of tigers (Sharma 2001), it could be used to obtain important information about population structure and density of tigers. The combined algorithms also could hold promise for continuous monitoring of tiger populations.

Since pugmark morphology of many big cat species is similar, the algorithm we described in this paper might facilitate development of monitoring protocols for other species.

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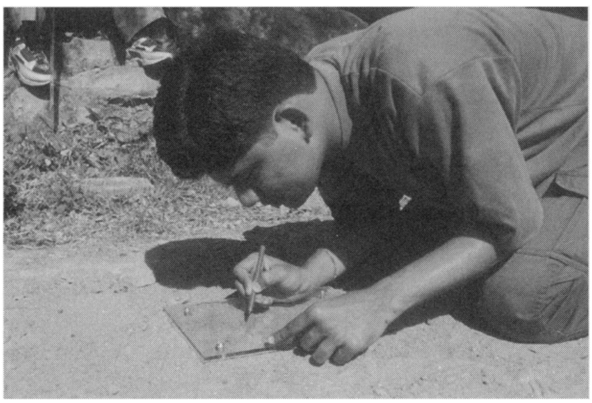

Using pugmark tracer. Photo by Y. V. Jhala.

Collection of pugmark samples using standardized technique of pugmark photography. Photo by Y. V. Jhala.

One of our study tigers moving on a PIP (pugmark impression pad). Photo by Sandeep Sharma.

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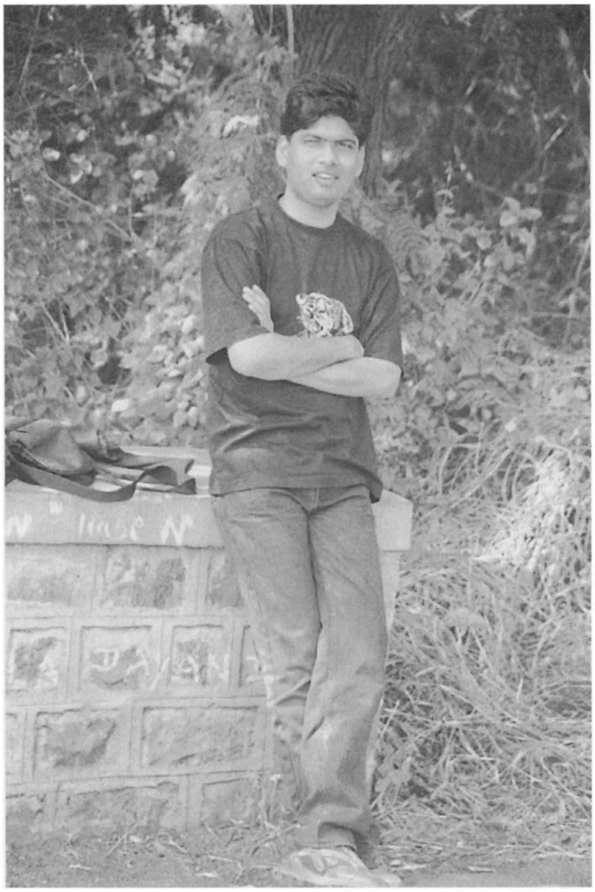

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