Tiger census: Role of quantification

A. P. Gore, S. A. Paranjpe, Geeta Rajgopalan, A. V. Kharshikar, N. V. Joshi, M. G. Watve and M. G. Gogate

Current system of censusing tiger populations in India, based on comparisons of tiger pug mark tracings, is controversial. Our attempts to make this method more objective, quantitative and reproducible, by employing modern statistical techniques, are reported.

A key question in the field of wildlife management concerns how many individuals of a species there are in a given population. Various estimation techniques such as water-hole counts, line transect sampling, capture–recapture, etc. are practised depending on their suitability in each case. In the case of tigers, the currently practised method is based on tracings of pug marks. The method is described briefly as follows: During a predetermined period, tracings of fresh pug marks are collected from the study area after an exhaustive survey of the area. Two pug marks produced on the same day are assumed to originate from two distinct animals if their locations are far apart compared to normal distances covered by a tiger in a day. Pug marks found in close vicinity of each other are compared visually in a qualitative manner, to determine whether they could be of the same animal or not. Visual inspection of the tracing is also used to decide the sex of the animal.

Census figures resulting from this method are often contested by ecologists and wildlife experts. Arjan Sing[1] has argued that unless a pug has some deformity or abnormality, it is not generally possible to distinguish between different animals of the same sex and size. Karanth[2] criticised these census figures on the grounds that they have not been validated on a known population anywhere. It is therefore necessary to devise a procedure for discrimination which will be objective and based on sound statistical principles.

Quantifying shape and size of the pug mark

A typical pug mark tracing (see Figure 1) consists of impression of four toes and pad. Typically, foresters (e.g. Panwar[3]) take into consideration features like size, inclination of the top edge of the pad, shape of the lobes at the base, etc. in a qualitative way for discrimination. Instead we have identified a string of variables that can be measured manually or with the help of a digitiser unambiguously. These include areas of the toes and pad, distances and angles between the lines joining centres of these figures, maximum widths, maximum lengths, etc. These measurements can be easily automated using simple programs (see Gogate *et al.*[4]).

Let us assume that these measurements extract all the information about the size and shape of a given tracing.

To be useful in discrimination they must have two

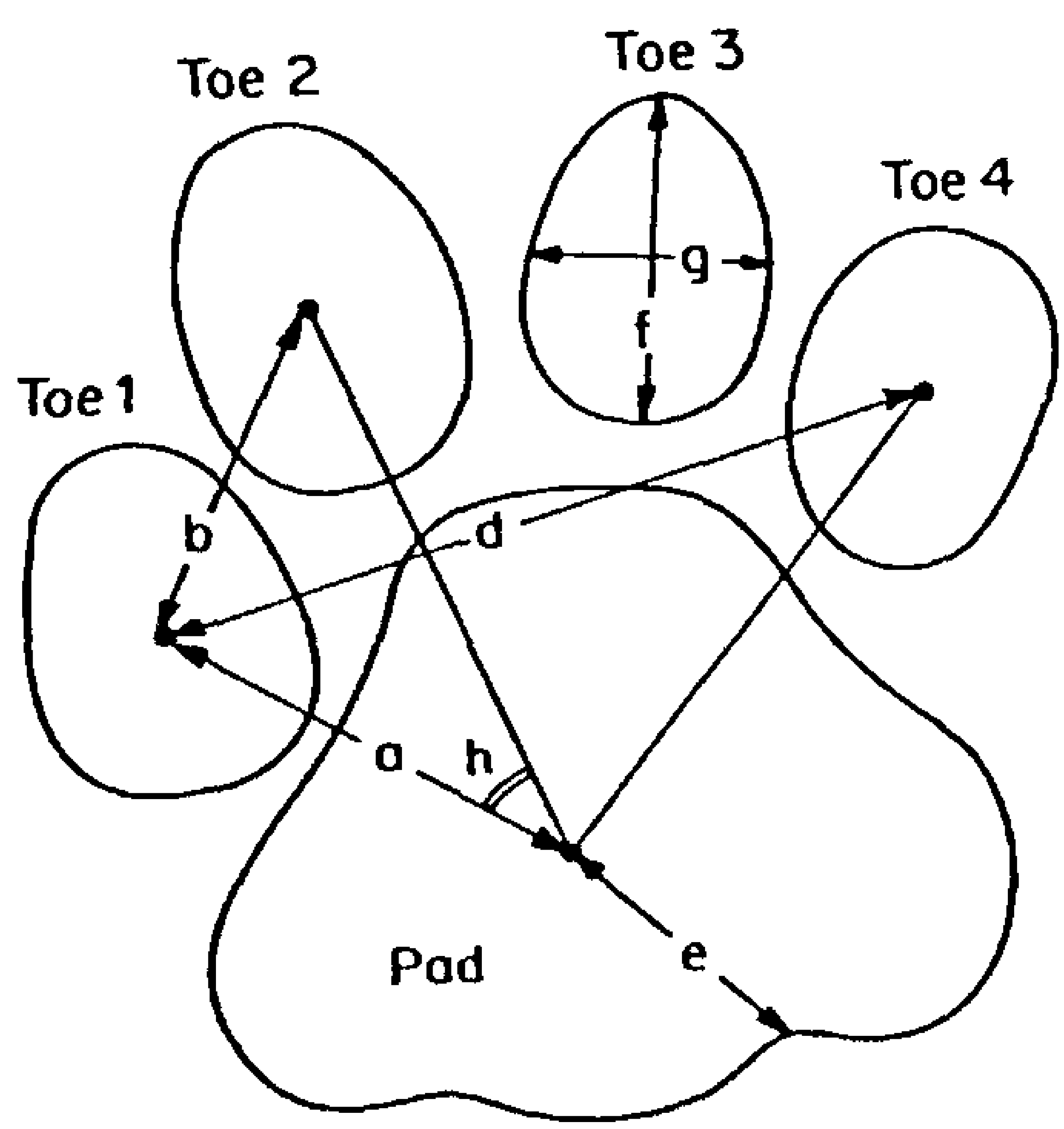

Figure 1. A typical tiger pug mark tracing indicating possible measurements. a, Distance between pad centre and centre of toe 1; b, distance between centres of toe 1 and toe 2; d, distance between centres of toe 1 and toe 4; f, maximum toe length; g, maximum toe width; h, angle; g, distance between pad centre and indent 1.

A. P. Gore, S. A. Paranjpe, Geeta Rajgopalan and A. V. Kharshikar are in the Department of Statistics, University of Poona, Pune 411 005, India; N. V. Joshi and M. G. Watve are in the Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India; and M. G. Gogate is with the Project Tiger, Melghat 444 805, India.

more properties. They must be sensitive to variation between animals and must be insensitive to other extraneous factors like substrate, operator, etc. Specifically we must ask the following series of questions.

1. To what extent do the measurements vary if (a) the same pug mark is traced by different individuals, (b) the same person traces different pug marks of the same animal in a trail, (c) the same animal produces pug marks in different substrates?

2. Do the pug marks of males differ systematically from those of females?

3. To what extent do the pug marks of animals in one reserve differ from those in another?

Partial answers to these questions based on pilot experiments are now available.

Variation due to operators, substrates and replication

In one experiment six foresters were asked to trace the same three pug marks from a trail (i.e. the same animal), in Project Tiger, Melghat, Maharashtra. Measurements of these tracings were subjected to analysis of variance for each variable separately. In 28 out of 36 variables examined, neither the operator-to-operator variation nor the pug mark-to-pug mark variation was statistically significant. These variables therefore can be judged provisionally to be stable. Of the eight remaining variables, six showed significant operator effect while two showed significant replication effect. These latter variables therefore should either not be used for discrimination between individual animals or if used, suitable extra allowance should be made to account for this sensitivity.

A similar pilot experiment conducted also at Melghat involved three substrates (fine soil, sand, wet mud) and two animals. These prints were also subjected to analysis of variance. In this analysis 32 variables turned out to be unaffected by the substrate while four showed a significant effect.

The combined list contains 10 variables that exhibit some effect of the factors considered. Thus it appears that 26 out of 36 variables considered are insensitive to extraneous factors and hence potentially useful in discrimination.

Sex discrimination

Foresters generally believe that sex of a tiger can be guessed from the pug mark. Sommerville[5] suggested that pug marks of a male tiger are larger and toes are square while in the female prints these are more rounded and slender. Sankhla[6] claimed that at three months of age, the area of the male's pad is double that of a female, a difference that is maintained throughout life. Panwar[3] suggested that hind paws (not just toes) of the male fit in a prominently squarish frame whereas those of a female fit in a relatively rectangular frame. These ideas need to be made precise and validated with known cases.

Sagar and Singh[7] have recently attempted this. They have come up with what may be called the '1.5 cm rule'. They fit a pug mark within a rectangle and use the difference between length and breadth to decide the sex. If the difference is smaller than 1.5 cm, the animal is classified as male otherwise as female. Paranjpe *et al.*[8] have offered two alternatives to this. The intuitive alternative involves visual inspection of histograms of lengths, breadths and differences. The histogram which exhibits the most prominent pair of modes with a sharp depression in between is used for classification. The x value corresponding to the depression is used as cut-off. The other alternative offered by them is based on the graphical technique due to Bhattacharya[9]. In this approach it is assumed that a suitably chosen variate, say breadth, follows a normal distribution for one sex, say male. It follows a normal distribution in case of females also, but with different parameters. The technique leads to estimation of parameters of both the populations as well as the proportion of each sex in the given set of prints. A rule for classification of individual pug marks can easily be based on these estimates. Stride, the distance from the top end of a left hind pug to the top end of the next impression of the same pug, has been proposed[10] as a measure to distinguish tracks of a leopard and a tiger cub. The above methods can be applied to measurements on stride as well.

These techniques have one common weakness, viz. they are not based on known cases. Hence a small pilot experiment was conducted on two males and three females. These animals were induced to walk on specially prepared ground and around 100 prints were traced. The technique of logistic regression analysis (see Shanubhogue and Gore[11]) was used to develop a sex identification rule. Most of the variables measured on the pug mark tracing turned out to be of marginal use in sex identification. Three variables selected for use were (a) distances between pad centre and centres of first toe (X_1) and second toe (X_2), (b) distance between centres of first and fourth toe (X_3). Intuitively, the first two variables indicate the length of the print and the third indicates the breadth.

If p is the probability that a given pug mark represents a female, then the logistic regression analysis of these three variables yields the formula.

$$\ln\frac{p}{1-p} = 56.06 - 2.76X_1 - 3.56X_2 - 1.1X_3.$$

Given the values of X_1, X_2 and X_3 for a pug mark, this formula yields the value of p. The sex identification rule, proposed here is as follows. If p is below 0.25

classify as male, if p is above 0.75 classify as female, if p is between 0.25 and 0.75 the case is left unclassified. This rule applied to the 97 prints (known sex) yielded the results given in Table 1.

Variations between two reserves

Ninety pug mark tracings from Project Tiger, Kanha, MP and the same number of pug mark tracings from Melghat, Maharashtra were taken for this analysis. Half of each set was used for calibration and the remaining half was used for testing. The two calibrating sets were used to construct a discriminant function based on 10 variables measuring distances between various centres (see Anderson[12]). We denote by $\bar{X}_k$ the set of means of all variables for Kanha and by $\bar{X}_m$ the same for Melghat. Let S_k and S_m be the corresponding sample variance–covariance matrices. The classification rules are slightly different if covariance matrices are unequal.

Take the vector of measurements X of a print to be classified. Compute likelihood assuming X belongs to Kanha. Let it be L_k. Compute likelihood assuming X belongs to Melghat denoted by L_m. Compute $T=L_k/L_m$. If T is >1 the print is classified as belonging to Kanha and to Melghat otherwise. The extent of misclassification is indicated in Table 2.

It seems reasonable to conclude that reserve-to-reserve variation in pug marks is substantial enough to allow correct classification to the extent of about 90%.

An algorithm for counting tigers from pug marks

We now propose in outline an algorithm for determining the number of tigers on the basis of the pug marks collected by foresters from a specified area.

To state the problem formally, we have n independent vectors, $X_1, X_2, \ldots, X_n$, each with p co-ordinates. X_i follows a p-variate normal distribution with mean vector $\vec{\mu}_i$ and variance–covariance matrix Σ (assumed to be known), which is the same for every i. The aim is to find k, the number of *distinct* mean vectors $\vec{\mu}_i$ among the n mean vectors.

At one extreme we may have $\vec{\mu}_1=\vec{\mu}_2=\ldots=\vec{\mu}_n$ in which case $k=1$ and all the pug marks are attributable to one tiger. At the other extreme, $\vec{\mu}_i\neq\vec{\mu}_j$ whenever $i\neq j$ and the collection of pug marks represents n distinct individual tigers.

The algorithm involves first testing the hypothesis $H_0: k=n-1$; if that is accepted, then testing $H_0: k=n-2$ etc. We continue testing until $H_0: k=g$ is rejected. Then we conclude that there are $g+1$ tigers.

How do we test the hypothesis $H_0: k=g$? To fix ideas consider the case $g=1$. If all pug marks belong to the same tiger then an overall measure of variation among n pug marks must be small. In particular

$$\sum_{i=1}^{n} (X_i-\bar{X})'\Sigma^{-1}(X_i-\bar{X}),$$

where $\bar{X}$ is the mean of n vectors, has to be less than the upper, say, 95% value of the chi-square distribution with $(n-1)p$ d.f. If not, the notion that all vectors are from the same distribution is deemed untenable.

For a general value of g, the test is conducted as follows: Divide the n vectors into g groups such that every group has at least one member. For each group, compute a measure of variation between vectors in that group. Pool these measures for all g groups and compare with upper 95% value of the chi-square distribution with $(n-g)p$ degrees of freedom. If the pooled measure of within groups variation is too large reject the hypothesis.

Notice that the number of ways of dividing n individually identifiable vectors into g groups can be astronomically large. If we encounter one of these ways for which the pooled measure of within-groups variation is small, the null hypothesis can be accepted without having to examine all other ways. However, for terminating the algorithm we need to assure ourselves that even for the best way of grouping, the within-groups variation is unacceptably large. If enumeration of all ways is not feasible due to an excessive volume of computations, a large enough sample of these ways can be used instead.

Mathematical justification for the various aspects of the algorithm will be given in detail elsewhere.

Table 1. Sex identification using logistic regression

Decision based on P	Known sex M	F	Total
M ($p<0.25$)	23	7	30
F ($p>0.75$)	1	59	60
Ambiguous ($0.25\leq p\leq 0.75$)	6	1	7
Total	30	67	97

Table 2. Reserve identification using discriminant function true classification

Decision based on T	Kanha	Melghat	Total
Kanha	40	4	44
Melghat	5	41	46
Total	45	45	90

Conclusions

1. Size and shape of a tiger pug mark can be quantified and measured objectively.

2. These measurements have some potential use in deciding the sex of an animal. The variables that seem to play a major role in sex discrimination are (a)

distances between pad centre and centres of first two toes and (b) distance between first toe centre and fourth toe centre.

3. Most of these measurements are robust in the sense that effect of extraneous factors on these measurements may not be significant.

4. There appear to be significant variations between prints from two reserves namely Kanha and Melghat. This may be a new dimension revealed by the present analysis.

5. The findings presented in this article seem sufficiently promising to warrant a study on a much larger scale to arrive at definitive recommendations for use in the field. In particular, it is imperative to generate a substantial data base of prints of known animals (see Watve *et al.*[13]) to set up numerical decision rules and to test their validity.

6. The possibility of using these and similar techniques for identification of individual animals needs to be explored.

1. Arjan Sing, *Tiger*, Jonathan Cape, 1984.
2. Karanth, U., *J. Bombay Nat. Hist. Soc.*, 1988, **85**, 1–8.
3. Panwar, H. S., *Indian For.*, (special issue on International Symposium on Tiger) 1979, 70–77.
4. Gogate, M. G., Joshi, P. A., Gore, A. P. and Paranjpe, S. A., Technical Bulletin No. 2, Directorate, Project Tiger Melghat, Paratwada 444805.
5. Sommerville, A., *At Midnight Comes the Killer*, Thacker, Spink and Co., 1933.
6. Sankhla, K., *Tiger*, William Collins Sons & Co. Ltd. Glasgow, 1978.
7. Sagar, S. R. and Singh, L. A. K., *Indian For.*, 1991, **117**, 24–28.
8. Paranjpe, S. A., Gore, A. P. and Gogate, M. G., *Indian For.*, (to appear).
9. Bhattacharya, C. G., *Biometrics*, 1967, **23**, 115–135.
10. Sagar, S. R. and Singh, L. A. K., *Indian For.*, 1990, **116**, 214–219.
11. Shanubhogue, A. and Gore, A. P., *Curr. Sci.*, 1987, **56**, 933–936.
12. Anderson, T. W., *An Introduction to Multivariate Statistical Analysis*, John Wiley and Sons, 1984.
13. Watve, M., Paranjpe, S. A. and Gore, A. P., *Tiger Census by Pugmark Analysis: The role of Zoos*, Zoo's Print, October 1989, pp. 5–7.

Received 25 March 1992; revised accepted 16 January 1993

Institution of Chemists (India): Associateship Examination, 1994

The 44th Associateship Examination of the Institution of Chemists (India) will be held in November, 1994. The last date for Registration is 30 November 1993. The Examination in Applied Analytical Chemistry is divided into the following eleven sections and each candidate will be examined in two of them according to his choice as approved by the Council, in addition to General Chemistry including Organic, Inorganic, Physical and Applied Analytical Chemistry: Analysis of minerals, silicates, ores and alloys; Analysis of drugs and pharmaceuticals; Analysis of foods; Analysis of water and sewage; Biochemical analysis; Analysis of oils, fats and soaps; Fuel and gas analysis; Analysis of soils and fertilizers; Analysis connected with forensic chemistry; Analysis connected with leather chemistry; Analysis connected with textile chemistry. The examination is recognized by the Government of India as equivalent to M Sc in Chemistry for purposes of recruitment of Chemists. Further enquiries regarding this and for Membership may be made to the Honorary Secretary, Institution of Chemists (India), 11/4, Dr Biresh Guha Road, Calcutta 700 017, India.