APPLICATION OF BHATTACHARYA TECHNIQUE IN SEX DETERMINATION AND SEX RATIO ESTIMATION OF TIGERS FROM PUGMARKS

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Introduction

In a recent paper (Sagar and Singh, 1991) a new criterion has been proposed to decide whether a tiger pugmark represents a male or a female. Traditionally foresters have argued that a male has a square pugmark while a female has a rectangular one. Sagar and Singh have made this notion more precise. According to them, if length of the pugmark exceeds breadth by more then 1.5 cm it suggests a female, otherwise a male. Measurement of length and breadth by fitting the pugmark tracing inside a rectangle as described by them is indeed a rather simple matter. Hence Sagar and Singh have undoubtedly provided a precise, quantitative and simple procedure. However, there are some weaknesses in the procedure too. Firstly it has not been tried and tested on pugmarks of animals of known sex. In the ultimate analysis, that is the acid test of any discriminating procedure. Secondly it is not clear whether their 1.5 cm rule can be directly used elsewhere. Perhaps each population may have to be analysed separately. In that case it is not quite clear how they arrived at the figure 1.5 cm. Further their calculations reveal an extremely strong correlation between length and breadth of a pugmark (r = 0.98 for males and 0.82 for females). This suggests that given breadth, length can be virtually treated as known. In that case discrimination could be based just on breadth. Thirdly the 1.5 cm rule leads to an estimated male to female ratio of 20:49 in 69 animals in 1989 and similarly in 1990. This ratio seems substantially different from 1 : 1. Is this expected? Finally there is no indication of errors likely to be made using this 1.5 cm rule. Would it not have been reasonable to keep a zone of ambiguity where classification is difficult? We believe such a zone can be delineated.

In this paper we shall first propose a simple intuitive method of classification similar to the 1.5 cm rule but more directly data based. We recommend it as a rough and ready reckoner. Later we describe a more elaborate graphical technique which is rather well established in statistical literature.

A simple intuitive method

Let us assume that length or breadths or their differences in case of females follow a normal distribution with a mean μ_1 and variance σ^2. The same for males also follows a normal distribution with the same variance σ^2 but a different mean μ_2. If for a measurement, the two distributions are very similar (i.e. μ_1 and μ_2 are close), that measurement is not useful for discrimination. On the other hand if the difference

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$(\mu_1 - \mu_2)/\sigma$ is large, discrimination is easier. In the former case the frequency histogram for the combined data should show essentially a single mode, while in the latter case we expect to see 2 modes clearly separated with a depression in between.

In view of these considerations, we recommend the following simple and intuitive discrimination procedure. Draw a histogram each for length, breadth and (length-breadth) for the combined data. Choose the variable which shows a clear bimodal graph. The centre of the depression between the two modes is the cut-off point.

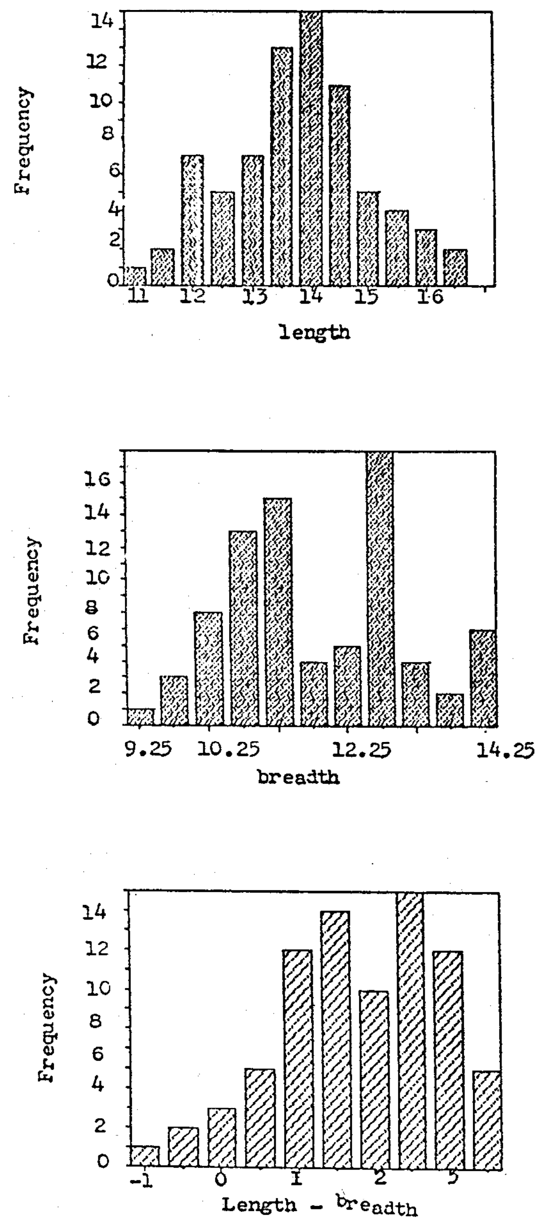
We have applied this procedure to 75 pugmark tracings from Melghat taken in 1985. The histogram (Fig. 1) suggest that breadth alone could also be used for discrimination. The rule that emerges from this histogram is "classify a pugmark as male if the breadth is 12 cm or more; otherwise classify as female". Based on this rule our estimate of ratio of males to females is 34 : 41.

This intuitive and simple technique also has many of the weaknesses attributed earlier to the 1.5 cm rule. It should, therefore, only be used as a quick and approximate method.

Bhattacharya Technique

This technique (Bhattacharya, 1967) was developed in the context of fisheries. In fisheries, catch at any point in time represents mixture of fish recruited (born) into the stock in different breeding seasons. It is of interest to identify the number of different age (or equivalent length) classes and their means, variance and proportions in the population. The method has become so popular worldwide that it is now found in

Figure 1



Histograms for 75 pugmarks from Melghat (1985) standard manuals on statistical analysis in fisheries (Sparre *et al.*, 1989). The method is in fact more general than we need. We know that our population of pugmarks contains 2 groups with equal variances but different means. We will use this extra information to slightly modify Bhattacharya method to suit our purpose.

In its generality the Bhattacharya method involves the following steps.

(a) Prepare a frequency distribution with close mean x_i and frequencies f_i, i = 1, 2,..., k, each class with width w.

(b) Plot log $\dfrac{f_i + 1}{f_i}$ Vs X_i

In this plot, every sequence of progressively decling points is indicative of one distinct population. A straight line is drawn through this set. There are as many populations as there are straight lines. The mean (μ) and variance (σ^2) of a population can be estimated from slope (m) and intercept (c) of the corresponding line. The formulas are :

$$\mu = |c/m| - w/2$$

$$\sigma = (|m|/w) - (w^2/12)$$

(c) To estimate the proportion of individuals of a distinct population in the mixture the procedure is as follows : Suppose X_i and X_j are the midpoints of extreme classes used to fit the above straight line. Then the total observed frequency in all classes from i to j is say '0'. If

$$p = P\left[\frac{(X_i - \mu - w/2)}{\sigma} < Z < \frac{(X_j - \mu + w/2)}{\sigma}\right]$$

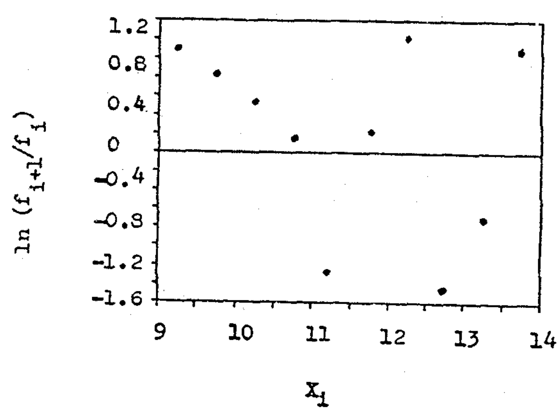
is obtained from the table of standard normal distribution, then the total number of individuals belonging to this population is given by 0/p. This number divided by the total number of observations gives the proportion in this population.

Application to Melghat (1985) Data

The Bhattacharya technique was applied to measurement of breadth of a pugmark. Here the common class width is 0.5 cm. The plot of log f_i+1/f_i Vs X_i (Fig. 2) shows that as we go down the X-axis there is a declining trend from the first point to the fifth point. A straight line fitted through these points using simple regression has the intercept 11.34 and slope -1.08. Hence the estimates of mean and variance for this population are $\hat{\mu}_1$ = 10.26 and σ^2 = 0.52.

To estimate parameters of the second population we will have to use strictly speaking only two points namely seventh and eighth, which is rather inadequate. Instead, we shall use the same estimate for variance as in the first population and for the mean we shall use the second modal value in the histogram, namely $\hat{\mu}_2$ = 12.75.

Figure 2



Bhattacharya Plot for breadth of 75 pugmarks from Melghat (1985)

Now let us estimate the proportion of females i.e. pugmark with lower values of breadth. Here 0, the observed frequency of all classes used to estimate μ_1 and σ^2 (i.e. class 1 to class 5) is 37. Midpoint of the first class interval is 9.25 and that of the fifth class interval is 11.25. Hence

$$p = P\left[\frac{9.25-10.26-0.25}{\sqrt{0.52}} < Z < \frac{11.25-10.26+0.25}{\sqrt{0.52}}\right]$$

which comes out to be 0.92. Thus 37/0.92 or about 40 is the number of females in the whole set which gives the estimate of λ is 40/75 i.e. 0.53. Hence estimated male to *female ratio is 35 : 40 which is in agreement* with the rough estimate obtained earlier.

Classification of individual pugmarks

The Bhattacharya technique does not attack the problem of classifying individual observations into one of the two populations of interest. However it is done routinely using other statistical methods.

Suppose f_1 and f_2 are probability density functions of two normal distributions with known means and variances and observations from these are mixed in the ratio $\lambda : (1-\lambda)$ where the fraction λ is know. Now suppose we consider one observation from this mixture. Then the standard statistical rule for classification (Anderson, 1972) is as follows:

If $\lambda f_1(x) - (1-\lambda) f_2(x) > 0$, the observation x is declared to have come from population 1, *otherwise from population* 2.

In our case we only have estimate of means, common variance and λ which introduces in the above rule a degree of approximation. Substituting the estimated *values we get the above differences as*

$$0.53\ e^{-(x-10.20)^2/1.04} - 0.47\ e^{-(x-12.75)^2/1.04}$$

which is calculated for every pugmark. If the difference is positive the pugmark is classified as that of a female, otherwise a male. Thus a pugmark with width 13 leads to the above differences being 0.00039 - 0.44 which is negative. Hence it represent a male. It is very easy to verify that pugmarks with width below 11.5 will be treated as females and other as males. Thus about 37 pugmarks are classified as females out of 75.

It may be argued that this rule does not allow for any ambiguity either. But that does not mean it is error free. Notice that mean breadth for males is 12.75 cm with s.d. 0.72. Thus it is impossible to have a male with pugmark breadth 11.31 (mean - 2 s.d.). Also the mean breadth for females is 10.25 with the same s.d. Hence an upper limit for breadth in females is 11.70 (mean + 2 s.d.). Thus breadth value between 11.30 and 11.70 cm can be treated as an ambiguity zone. About 5 individuals fall in this group. In any case extraneous information on individuals should never be ignored in such classification. There is always a possibility, however rare, of a female having a very broad pugmark. In Melghat there was indeed a print with breadth of 13 cm and accompanied by a print of a cub.

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SUMMARY

Various methods and rules of tiger pugmarks have been used by foresters to represent male or female tiger. Some of the methods have not been tried and tested on pugmarks of animals of known sex. The present paper indicated a simple intuitive method and Bhattacharya method of classification of male and female tiger pugmarks in a more elaborate graphical technique and their application in forests.

पगचिन्हों से बाघों में लिंग विनिश्चयन तथा लिंग अनुपात का अनुमान लगाने में भट्टाचार्य विधि प्रयोग

एस० ए० परांजपे, ए० पी० गोरे व एम० जी० गोगटे

सारांश

नर और मादा बाघ अलग-अलग पहचानने के लिए वानिकों ने बाघों के पगचिन्हों की कई रीतियाँ और नियमावलियाँ बनाई हैं। इनमें से कुछ रीतियों को ज्ञात लिंग वाले पशुओं के पगचिन्हों पर उपयोग का परीक्षित नहीं किया गया है। प्रस्तुत अभिपत्र में एक सरल और सहज रीति, अधिक विस्तृत एवं सचित्र प्रविधि में नर और मादा बाघ पगचिन्हों के वर्गीकरण की भट्टाचार्य रीति और वनों में उनकी उपयोज्यता बताई गई है।

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