EVALUATION OF PUGMARK CENSUS TECHNIQUE

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By

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UNDER THE SUPERVISION OF

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CERTIFICATE

This is to certify that **Mr. Sandeep Sharma** of the Wildlife Institute of India has carried out original research titled " ***Evaluation of Pugmark Census Technique***" for the partial fulfillment of the Master of Science (Wildlife Science) degree from Saurashtra University, Rajkot, India. These investigations were carried out under our supervision from November 2000 to June 2001. We also certify that this research has not been submitted for any other degree to any University.

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Summary

Effective conservation strategies hinge on reliable population estimation technique. The potential of pugmark as a tool for population estimation of tigers was statistically examined. Eleven variables were selected and they were found effective in discrimination between individual tigers. These variables also discriminated between male & female in a population of 10 known tigers with 100% accuracy. This sex-discrimination modal was found 97.4% accurate during validation over three new known tigers. The above said variables were also robust for pooling left and right pugmark. The soil depth of range 0.5 cm to 2 cm was found to be ideal for PIP preparation, since the 11 predictor variables were examined to be insensitive towards shape and size change of pugmark due to substrate condition.

Classification of 17 individual tigers was achieved with 97% accuracy using stepwise discriminant function analysis. The statistical protocol developed in this study was found to be 100% accurate in predicting the correct number of tigers and correct classification of pugmarks, during validation in a blind set simulated 'census-exercise' from a known number of tigers (some of the track sets used for this analysis were not used for developing the DFA model).

Variability in pugmark tracings due to tracer's effect was found to be significant. ANOVA (p-value 0.002 with df-1, df-53) results suggest a significant difference between variables measured from tracings and those from photos. However, DFA was unable to discriminate between tracings and photographs suggesting that either could be used in the model.

Seventy five percent of the "experts" (n=8) were 100% correct in deciphering individual tigers in a blind test involving 15 tiger pugmarks from 7 individual tigers. The remaining 2 experts overestimated the tiger numbers by 1. The experts had an accuracy of 92% (sd = 7.8) in correct classification of tiger pugmarks. The other groups of respondents, ecologists (n=11) and lay persons (n=15) overestimated the tiger numbers and had an accuracy rate of 67% (sd = 24), and 64% (sd = 26) respectively in classifying pugmarks correctly.

This study suggests that pugmarks can be used as a tool for population estimation of tigers, if subjected to analytical protocol developed here in within the constraints outlined.

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Dedicated to

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INTRODUCTION

Tiger (*Panthera tigris*) is the largest obligate terrestrial carnivore in all of the mammalian assemblage in which it occurs. It once had one of the widest geographical distribution of any felid, stretching originally from almost 10^0 latitude south of equator to more than 60^0 north and through more then 100^0 longitude (Mazak 1996, Nowell & Jackson 1996). The tiger displays an immense adaptability in living in different climatic regimes, ranging from temperate forest to tropical rain forest, mangrove swamps and in semi-arid landscape amidst human dominated forests. This variation in adaptation is also applicable to prey assemblage found through out its geographical range (Pocock, 1929; Brongersma 1935; Sankhla, 1978; Sunquist 1981; Mazak 1981, 1986; Seidensticker & McDougal, 1993).

India is home for 50 % of world's wild tiger's population (Mountfort, 1981;Thapar, 1999). They are distributed across the diversity of habitat and prey in India, they attain a higher density here than anywhere else in Asia (McDougal, 1977).

The population figure of tigers shrunk to mere 1800 tigers in 1972 then exclaimed by this figures Indian government initiated '*Project Tiger*'. The birth of '*Project Tiger*' heralded the arrival of a new conservation ethos into Indian wildlife. With the tiger as its symbol, representative areas across the habitat diversity were chosen and declared as 'Tiger Reserves'.

Success of any conservation effort is supposed to be reflected back through increase in the number of the target species. Numbers are supposed to be of great importance in conservation of big cats, because next stage of conservation strategy depends on past and current status of the target species (Nowell & Jackson, 1996).

'Project Tiger' has utilised the '*Pugmark*' of tiger as a tool to assess the effectiveness of conservation efforts, because this was the only reliable and field friendly technique available at that time. But the 'Census Figure' arrived at, after pugmark census has been criticised for the technical as well as the implementation flaws (Singh, 1972,1984; S.D.Ripley, quoted in Sankhla, 1978; Karanth, 1987, Karanth & Nichols, 2000). Reliability of this technique and the veracity of the census figures by using this technique have also been contested between wildlife ecologists and field managers since the inception of this technique.

In the present study, I tried to evaluate 'Pugmark Census' technique for its reliability in an objective manner. The technique has been subjected to a quantitative and statistically rigorous method, for its endowment to judge the identity of a tiger by its pugmark and then for use of the pugmark for population estimation of tigers.

An attempt has also been made to judge the subjective accuracy of the technique by performing a simulated 'census exercise' with people of different levels of field experience. Attempts have also been made to address the possible shortcomings in the technique at field level.

Critics of pugmark census technique also argued for the validation of technique on a known population of wild tigers (Karanth, 1987). My study is based on pugmark samples collected in wild and captive conditions. Since the identity of each tiger was known with a reasonable level of certainty this study presents an ideal test data set for evaluating the pugmark census technique in an objective manner.

Review of Literature:

Importance of Reliable Population Estimation Technique:

The number of individuals of a species is a key question in the field of wildlife conservation. Conservation and management of an endangered species depends on reliable methods of monitoring population trends. Population size and trend estimation is the first step in understanding the structure and dynamics of any natural population (Seber, 1973; 1982; 1986; 1992).

Effective conservation strategies hinge on reliable knowledge of population size. Scientific literature has many examples of dubious monitoring schemes, which were found insufficient to detect even the catastrophic declines in the population over short periods. For example, an established monitoring scheme thought to be sufficient to detect declines in whale stocks was found to be inadequate to detect a 50 % change over a 10 year period (de la Mare, 1984). The long standing Coyote (*Canis latrens*) monitoring programme instituted by U.S. Fish and Wildlife Service (Roughton & Sweeney, 1979) suffered from poor planning and resulted in major changes year after the first data collection (Roughton & Sweeney, 1982).

The examples of monitoring schemes to track changes in Bear (Kendall *et al.* 1992) and Bobcat (Diefenbach *et al.* 1994) populations demonstrate the level of planning necessary before one considers population level monitoring using sign surveys. Detection of even relatively large changes in population size (e.g. 25%) may require prohibitively large sample sizes to achieve sufficient power (Diefenbach *et al.* 1994).

Role of Top-Carnivores in Ecosystem:

Carnivores are at the top of the food chain in any ecosystem. They play an important ecological role in shaping species diversity and in maintaining ecosystem stability and integrity.

Top-predators are often called as "indicator" species because the health and vitality of predators is a direct indication of well being of all other species of that eco-system. They are causative agents for trophic cascades and top-down community regulation. They even help to gauge how well the ecosystem itself is doing.

Problems in Population Estimation of Large Carnivores:

Most of the carnivores are cryptic, nocturnal or crepuscular and are often solitary. They are also sparsely distributed, which makes their population enumeration a difficult task (Seidensticker *et al.*, 1973, Beier *et al.*, 1995).

Cats, especially are notoriously difficult to count (Bertram, 1979). The traditional census techniques, such as transect count, water-hole count etc. can not be applied for density estimation of cats, because of their irregular, individualised and cryptic behaviour and movements. It tends to violate the basic assumptions of traditional density estimation method.

Tigers by nature are shy and secretive. Their largely nocturnal ranging pattern, and wide ranging behaviour make their observation difficult in wild. The tiger, being a large-carnivore, occurs at a low density, and are sparsely distributed even in high prey-biomass areas. (Karanth & Nichols, 1998, 2000).

The combinations of all the above said ecological factors i.e. extensive spatio-temporal distribution, secretive life, wide ranging behaviour, low detactability and low densities, creates a major problem in monitoring tiger populations.

Importance of Sign-Survey Technique:

Sign surveys of various species have been tested over a whole array of signs i.e. scrapes, scats, tracks etc. to check the relationship between population density and sign frequency (Stephenson, 1986; Van Dyke *et al.*,1986;Van Sickle & Lindzey, 1992; Ahlborn & Jackson 1988).

Sign-survey methods have been used to estimate the indices of animal activities (Van Dyke, Brocke & Shaw 1986; Smallwood & Fitzhugh, 1995; Zielinski & Kucera, 1995; Zielinski & Stauffer, 1996) habitat use (Petrak, 1990; Putman, 1990) and population density (Kostar & Hart, 1988; Smallwood & Fitzhugh, 1993; Komers & Brotherton, 1997; Karanth & Nichols, 1998; 2000; Carbone *et al.* 2001).

Though the data gained by sign survey techniques was found to be not as rigorous as from the more direct methods, like radio tracking (Servin, Rau & Delibes, 1987). But the sign survey techniques have their own advantages. They are relatively inexpensive, logistically easy to implement and non-invasive. They do not require direct contact with the animal and they do not affect the natural behaviour of the animal (Alibhai *et al.*, 2001; Jewell *et al.*, 2001).

It was found that though there is a direct relationship between population density and sign frequency, practically the sign frequency is unlikely to yield more then an indication of relative abundance and probably can not be translated to a numerical estimate of population size.

Recent studies by Smallwood (1997) and Smallwood & Schonewald (1998) showed that Mountain Lion density indices derived from track surveys tend to overestimate actual densities, because of survey biases towards areas of high animal density. The randomization of sampling is one solution, but it requires substantial time and survey staff (Lewison *et al.,* in press). It was also suggested that if individual lions could be determined based on tracks then survey precision would improve.

Use of Track as an Individual Identity:

Attempts have been made to identify individuals of a species based on its tracks. Researchers and field managers could distinguish between Mountain lion (*Felis concolor*) individuals by using deformations and gross differences in size and shapes (Currier *et al.*, 1977; Kutilek *et al.*, 1983; Fitzhugh & Gorenzel, 1985; Van Dyke *et al.*, 1986), by one or more track measurements (Koford, 1976; Currier *et al.*, 1977; Fitzhugh & Gorenzel, 1985, Smallwood & Fitzhugh, 1993; Grigione *et al.*, 1999;Lewison *et al.*, 2001; Fitzhugh *et al.*, 2000), by associations with radio-telemetry locations (Fitzhugh & Gorenzel, 1985, Van Dyke *et al.*, 1986; Neal *et al.*, 1987), by distances between track sets (Currier *et al.*, 1977; Shaw, 1983) and by morphometric analysis of pad shape (Grigione & Burman, 2000).

Attempts have also been made on other animal species, to identify individuals of that species by using their tracks e.g. Asian Rhinos (Strickland, 1967; Schenkel & Schenkel-Hullinger, 1969;Kurt, 1970; Borner, 1970;Flynn & Abdullah, 1983; Van Strien, 1985) Black Rhino (Jewell *et al.*, 2001), Pine marten (Zalewski, 1999) Snow leopards (Riordan, 1998) and Jaguars (Marcelo Aranda, *Pers comm.* & Carolyn Miller, *Pers comm.*).

Tracking tigers for hunting was a tradition among Indian hunters which often flourished under royal patronage (Sankhla 1978), this is one of the ethnic methods used by tribals and *Shikaris* all over the India (Singh, 1999). During the British time the skill of tracking tigers developed new dimensions and a few systematic observations on tiger tracks were published (Champion, 1929; Brander 1930). It was claimed that not only the individuals but the sex, age and even the physical conditions of a tiger could be determined from its track (Corbett, 1944; Choudhury, 1970, 1971, 1972; Sankhla, 1978; Panwar, 1979; Jayarajan, 1983; Sawarkar, 1987; Basappanavar 1988; Gogate *et al.*, 1989; Rishi, 1997; Singh, 1999).

Use of Pugmark as a 'Census Tool':

The first attempt to enumerate tigers by their pugmarks was supposed to be done by W.J. Nicholson of Imperial Forest Service in Palamau district, Bihar in 1934, which gave him a figure of 32 animals for an area of 299 sq. kms. (Jayarajan, 1983). Dharma Kumar Singhji (1959) advocated the use of pugmarks followed by baiting and driving census for Tiger, Leopard and Asiatic Lion.

Abramov (1961) gave an idea for census of Siberian tigers. He also described the methods to determine the age, sex composition and nutritional status of tigers by examining pugmarks. He classified four age groups of tigers based on the pad width of pugmark.

The technique of identifying individual tiger was conceptualised by late Saroj Raj Choudhury (Choudhury 1970, 1971b). He introduced the 'tiger tracer' and refined the methodology of census. This method was again fine-tuned by his successors (Panwar, 1979; Sawarkar 1987; Singh 1999). It has been claimed that experienced persons can segregate the tracings and can identify each individual tiger precisely (Panwar 1979, Sale & Berkmuller, 1988).

The tools deployed in counting tigers vary from tracing of footprints to radio-tracking gears and the sophisticated camera traps. Each method has its own pros and cons. Pugmark technique is simple but its reliability is questioned many times because of the subjectivity involved in the technique (Schaller, 1967; Singh, 1972, 1984; S.D. Ripley quoted in Sankhla, 1978; Karanth, 1987,1993,1999; Karanth & Nichols, 2000).

It is believed that an individual tiger's pugmark changes in shape and size over different substratum, soil texture, soil moisture and soil depth. Another source of variability is the variation between individual tracer's ability to trace the features of the pugmark over the tracing sheet (Karanth, 1987).

Camera trap based mark-recapture technique is an expensive method and has its own limitations in precise population estimation in low-density populations (Karanth 1987, 1999). Some experienced field personnel believe that an individual tiger could be incorrectly identified by photographic capture records due to apparent changes in stripe patterns associated with the gait of the tiger and angle of the camera (Goyal & Johnsingh, 1996; Rajesh Gopal *pers. comm.*). Singh (1998) said that the stripe pattern in tiger changes with growth and age.

Karanth (1995, 1998) Karanth & Nichols (2000) advocated the use of camera-traps as a mean for individual identification and density estimation for a particular area. The stripe patterns over the body of a tiger and its facial patterns are claimed as to be unique identity of an individual. It is true for many species of felids. Tigers can be identified on the basis of stripe pattern above the eye (Schaller 1967) or on the cheek (McDougal, 1977). Leopards (Bertram, 1978; Miththapala *et al.,* 1989), Jaguars (Carolyn Miller *pers comm.*) Snow leopards (Hillard 1989) and Cheetahs (Eaton, 1974; Frame, 1981; Caro & Collins, 1989; Bowland 1993) have been identified on the basis of the facial spot patterns and tail tip band patterns, which can also be used as an index of individual relatedness (Caro & Durant 1991). Lions can also be identified individually by unique patterns of whisker vibrissae spots (Pennycuick and Rudnai, 1970; Bertram, 1978; Jhala *et al.*, 1999).

Estimating the population size of the tiger in a given natural habitat relies heavily upon indirect evidence because of the difficulty in the actual sightings of the individuals inhabiting the area. Recently three field methods based on pugmarks are being used for population monitoring of tiger; the snow track counts of the Russian Far East (Miquelle *et al.,* 1996), pugmark counts in Nepal (McDougal, 1977) and the pugmark census of India (Panwar, 1979; Choudhary, 1970; 1972). McDougal (1977, 1999) suggested that it is possible to identify a few resident individuals by using pugmark, with constant experience and skill.

The pugmark census technique is based on five major postulates (Singh, 1999).

- *A tiger has a definite pugmark signature.*
- *During its daily activity, every tiger records its presence while walking on soil amenable to receiving its foot impressions.*
- *In good habitats adult male and female tigers have well defined territories.*
- *In medium level habitats there are overlapping territorial pattern.*
- *In poor habitats and low populations territorial patterns may be absent.*

Karanth (1987,1999) and Karanth & Nichols (2000) has criticised that the pugmark census has not been validated up till now on population of known tigers. He suggests that pugmark can be used as an index to conduct track counts and then to assess the density index for a particular area for a fixed season. Then this exercise can be repeated round the year for all the season and then it is possible to get a trend of population. One can even compare the indices of two areas. He suggests that this is a better way of monitoring the population trends of tigers. He raised the strong need for clear identification of breeding residents in a population to understand their long-term dynamics. He claimed that current pattern of tiger census in India has failed in maintaining the records for breeding residents and then segregation between transient and resident tigers could create confusion during census exercise. He adds that a few cases of known breeding residents and their individual identity on the basis of pugmark is known (Panwar, 1979; Rathore, 1983) but these are exceptional cases and limited to a few tiger reserves where the sightings are not very rare (Karanth 1987).

The pugmark census, at present is more of a qualitative and subjective approach. It needs to be converted into a more precise, objective and quantitative method.

Attempts have been made to quantitatively assess the pugmark based individual identification of tigers (Gogate *et al.,* 1989; Watve, 1989; Gore *et al.*, 1993; Das & Sanyal, 1995; Riordan, 1998). These studies suggest that the pugmarks do possess quantifiable information that could permit individual identification, however, due to limitation of an experimental design and sample sizes from wild tigers, these studies were not conclusive. Recent more definitive studies on tracks of Mountain lion (Smallwood & Fitzhugh, 1993; Zalewaski, 1999; Riordan, 1998; Lewison, *et al.,* In press; Jewel *et al.,* 2001; Carolyn Miller *Pers comm.*) used a quantitative approach for discriminating the individuals on the basis of a given group of track sets. They have also tried to standardise the variables, which gave maximum discrimination between individual of the study species.

Grigione *et al.* (1999) refined and validated the technique on known radio tagged Individuals. But they have warned that grouping of tracks is sensitive to the type of substrate, time of the day and the number of tracks in a set. If the above said conditions are controlled then the technique has a potential for application in population monitoring of mountain lions.

So ultimately it leads to the need for either the development & standardization of more reliable techniques or modifications and fine-tuning of pre-existing techniques (Pugmark-Census), which should be in standardized form so that the results obtained by different observers from different areas are comparable.

In the present study I attempt to test quantitative methods for discrimination of individuals on the basis of pugmark.

Sex-Discrimination of Tigers:

It is believed that the gender of the tiger can be differentiated on the basis of shape of its hind pugmark. British forester F.C. Hicks distinguished the male tiger's pugmark as being much circular then that of a female, he added that the pugmark of tigress are misshapen and ugly, and her forepaw resembles the hind pugmark of a male tiger (Hicks, 1910). Sommerville (1933) suggested that pugmarks of a male tiger are larger and toes are square while in the female, these are more rounded and slender. Sankhla (1978) described the front pugmark of tiger as *regular* and that of a tigress as *irregular* or *zygomorphic*. He also made observation on captive tigers and found that at three months of age, the area of male's pad is double of that of a female. This difference is maintained throughout the life. Panwar (1979) gave the idea of *Square* and *rectangular* frame. He found that the whole hind pugmark of a male tiger fits into a prominently square frame, whereas that of female fits into a relatively rectangular frame. This criterion is the most adopted and widely used field technique to differentiate the sex of tiger on the basis of its pugmark.

Gogate *et al.* (1989) suggested the use of angle between toe number two and three in pugmark as the sex discriminating criterion. Sagar & Singh (1993) gave the '1.5 cm rule'. They used the difference between length and breadth to decide the sex of the tiger. Paranjape *et al.* (1993) tried the statistical discrimination of tiger pugmark. They used the visual inspection of histograms of length, breadth and their differences of pugmark for judging the 'cut-off value' for sex-discrimination. They also used the graphical technique given by Bhattacharya (1967), where they assumed that a suitably chosen variate follows the normal distribution for each of the sex, but with peak at different values of mean. The technique claims to estimate the variables of both the populations as well as the proportion of each sex in the given population, represented by pugmark sets.

Objectives of the Study:

The present study has following objectives:

1. *To evaluate the potential of using quantitative data from pugmarks for individual identification of tiger and their gender identification.*
2. *If pugmarks were found to have sufficient information for individual identification then, to develop analytical protocol for identifying individual tigers from their pugmarks and its use for population estimation of tigers.*
3. *To determine the effect of substrate and variations due to multiple tracer on quantitative identification of tigers from their pugmarks.*
4. *To determine the variability between pugmark trace and the photograph of the pugmark.*
5. *To evaluate the currently used "Expert Knowledge" based individual identification of tigers from their pugmarks.*

STUDY AREA

Study Design:

To achieve the objective of this study I needed to have a population of tiger pugmarks with sufficient replicates from definitively known different individual tigers.

This was achieved by sampling tiger pugmark-sets from different zoos and from different tiger reserves in India (Table 1, Figure 1). Based on direct sightings of tigers and geographical and temporal separation, I ensured that individual pugmark-sets that I traced and photographed within a tiger reserve were from different tigers. When there was any ambiguity regarding a track-set belonging to a tiger whose track set was already traced, then one of the two track sets was omitted from the analysis.

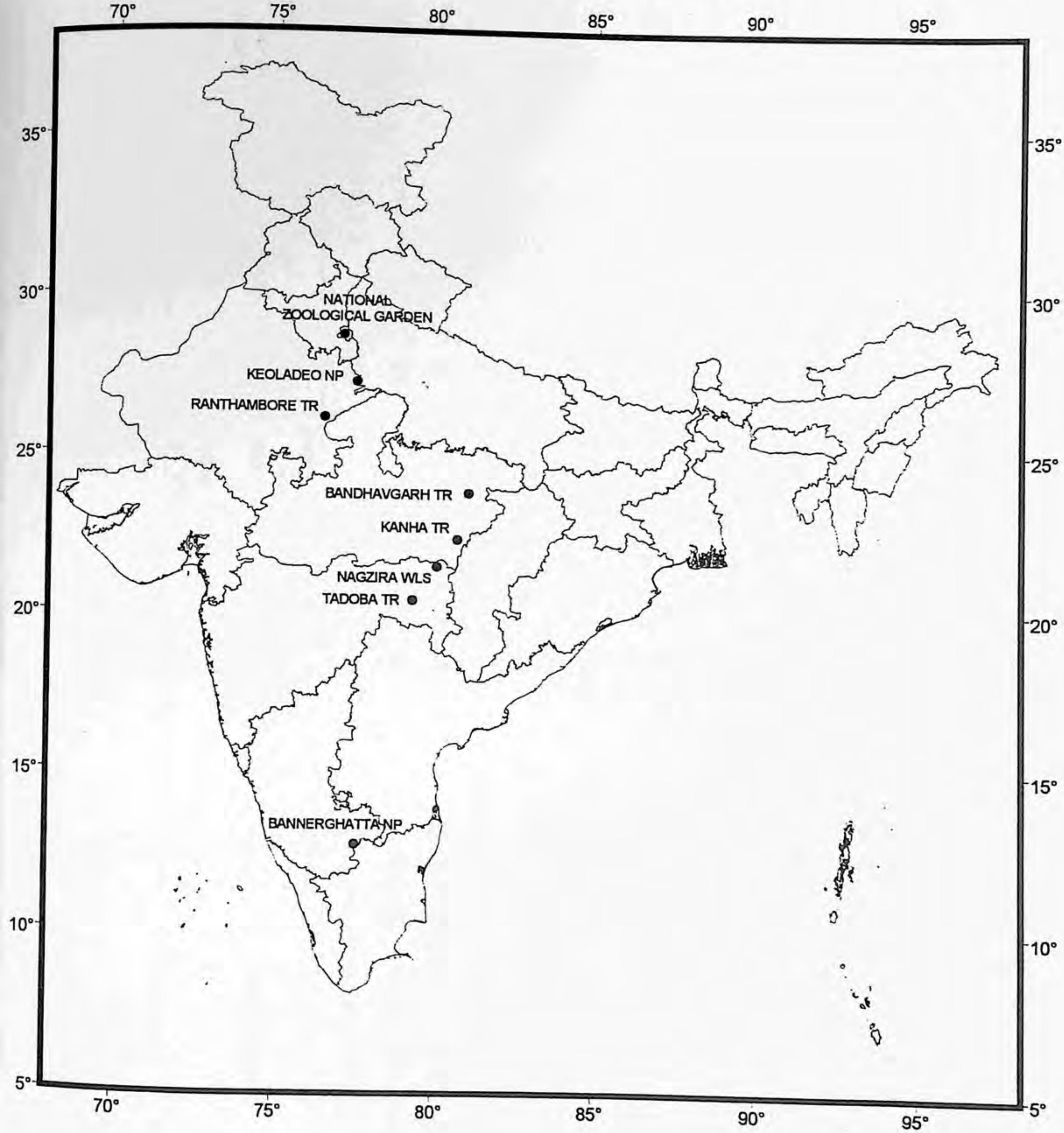
Study area:

Based on the abundance of tigers, the sighting frequency and conduciveness of substrate for registration of pugmark sets, and thus to maximize the probability to get a required sample size, following protected areas and zoological gardens were chosen for the present study.

1. Ranthambhore Tiger Reserve, Rajasthan.
2. Kanha Tiger Reserve, Madhya Pradesh.
3. Bandhavgarh Tiger Reserve, Madhya Pradesh.
4. Tadoba Tiger Reserve, Maharashtra.
5. Nagzira Wildlife Sanctuary, Maharashtra.
6. Keoladeo Ghana National Park, Bharatpur, Rajasthan. *
7. National Zoological Garden, New Delhi. **
8. Bannerghatta National Park, Karnataka. **

- *Keoladev Ghana National Park was chosen for collection of track-sets and for calibration of sampling procedure, because of the presence of a single tigress in the park.*
- *Captive tigers*

Map showing locations of study sites



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GIS Cell, June 2001

	Study site	Number of pugmark-sets collected	Number of individual tigers represented by the pugmark-set	Number of pugmarks collected	Average number of pugmark per pugmark-set (range of pugmarks)	Number of pugmark-sets photographed for individual tigers
1	**Keoladeo National Park**, Rajasthan	3	1	22	7 (6-10)	1
2	**Ranthabhore Tiger Reserve**, Rajasthan	8	8	80	10 (8-12)	5
3	**Kanha Tiger Reserve**, Madhya Pradesh	7*	6*	78	11 (10-14)	3
4	**Bandhavgarh Tiger Reserve**, Madhya Pradesh	2	2	16	8 (6-10)	1
5	**Tadoba Tiger Reserve,** Maharashtra	0	0	0	0	0
6	**Nagzira Wildlife Sanctuary**, Maharashtra	0	0	0	0	0
7	**National Zoological Garden,** New Delhi	5	5	59	11 (8- 36)	3
8	**Bannerghatta National Park**, Karnataka	1	01	10	10 (10)	0
	Total	**26**	**23***	**265**	**10 (6-36)**	**13**

Table 1. Details of study sites visited and samples of pugmark-sets collected between Nov. 2000 to April 2001for this study .

* The identity of tiger for 1 pugmark set was not known with certainty. This pugmark set was believed to be from a different individual, but was dropped from the initial analysis of DFA, but later included as test case.

STUDY METHODS

The study methods are broadly classified into two parts.

(a) The field data collection and data preparation i.e. tracings and photography of the pugmark and generating morphometric measurements from them.

(b) Quantitative analysis based on these measurements.

Field methods:

The field methods include the search of tiger pugmarks and collection of tiger pugmarks by means of tracing and photographing them in the field.

The study sites were thoroughly searched in the early morning hours for fresh pugmarks. To control for substrate variation, I collected pugmark sets from the well-beaten earth roads and dirt tracks, having fine soil of thickness between 0.5 to 0.8 cm. Only those pugmark-trails, which were not more than 12 hours old and had at least five clear pugmark impression of left-hind and right hind foot, were chosen for tracings and photography. Most of the pugmark-sets were collected from long series of pugmarks, where the tiger had apparently walked in normal gait (Figure 2). The gait pattern was judged as normal after examining the pugmark trail for consistency in stride length and pattern of superimposition & under / over shoot of front foot with reference of hind foot.

Two different methods were used for acquisition and preservation of the pugmarks.

(a) The tracing method

(b) Photography of the pugmark.

Tracing method:

Pugmarks were traced out using "tiger tracer"(Choudhary, 1971;Panwar, 1979; Singh 1999). The "Tiger-tracer" is an extremely simple and helpful device to pick up accurate tracings of pugmarks at 1:1 scale. It is a transparent flawless rectangular glass plate of size, 20 cm width and 25 cm length. The thickness of glass plate is 3 mm. It carries four screws with fly-nut at the four corners to hold it in balance over the pugmark.

After search and examination of pugmark-series, the pugmarks with clear relief edges and sharp features were selected for tracings. Partially superimposed or pugmarks with fuzzy boundaries were discarded.

In the conventional method given by Choudhary (1971) and later modified by Panwar (1979), a well-edged left-hind pugmark is selected for tracing. The glass plate supported by screws is placed over the pugmark. The distance between the lower bottom of the glass plate and ground will be about 5 to 7 mm providing sufficient space not to distort the relief edge of the pugmark. The tracer should kneel over the tracer in such a way, that he can bend over the plate and his eyes come vertically above the tracer and pugmark (Figure 4). Then the tracing of the pugmark outline is done by using a free-flowing felt tip pen. Extreme care should be taken to avoid the parallax error, this can be minimized by moving the eyes with the pen so as to keep the line of sight vertically above the segment under tracing.

Figure. 2 Tiger trail over fine substrate showing a series of good quality pugmarks

Figure 4. Tracing of a tiger pugmark using tiger-tracer.

Then this tracing is transferred to tracing paper, by placing it over the tracing paper over the tracer, and redrawing the outlines of pugmark on the tracing paper, by keeping the tracer against the light source.

Slight modifications were done in the "Tiger Tracer" conventionally used for tracing pugmarks. I used acetate sheets instead of tracing paper, and the transparent acetate sheet was directly fixed over the "Tiger tracer" by means of clips, so as to avoid any movement between the Tiger tracer and acetate sheet. Use of acetate sheet also eliminates out the step of retracing the pugmark and thus eliminates out the chances of tracing error, during retracing the same pugmark.

In captive situation i.e. in National Zoological Garden, Delhi, PIP's (Print impression Pads) (Rishi, 1997; Singh, 1991) were prepared on the routes frequently used by tigers inside the moats.

Different variables related to gait of tiger and field conditions were noted down on the tracing along with the date, time and place. Each of the tracing were given a pre-decided code-number, so as to identify it later during the image-processing and measurement phase.

Variables associated with the gait of the tiger were also measured in the field. These were Stride, Straddle and Step (Figure 5).(Singh, 1999; Zielinski & Kucera, 1995)

Stride: a stride is one cycle of locomotion and is measured as the distance from where a point on a foot touches the surface to the next spot where the same point on the same foot touches the surface. It is the distance between two consecutive impressions made by the same foot.

The stride of a walking mammal approximates the distance from the hip to the shoulder and provides an estimate of the length of the animal.

Straddle: it is the distance from the left edge of the left footprint to the right edge of the right footprint of the same pair (front or hind). In the present study, straddle between the hind pugmarks, i.e. pelvic straddle was recorded.

Step: it is the distance between the front and back foot, either left or right. Step is usually half the distance of stride.

Stride and step is measured parallel to line of travel, and straddle is measured perpendicular to the line of travel.

All the gait variables given above were measured in the field, for every pugmark-set collected. Three to ten measurements were recorded for each gait-associated variable.

Assessing Tracer's variability and substratum effect:

The pugmark census technique was questioned because of flaws at the implementation level. The most criticised flaws at field level are:

(a) The variability in pugmark shape and size due to substratum condition viz. Soil composition, soil depth and soil moisture.

(b) Variability associated with the different tracer's and the tracing skills.

I have tried to address both problems in my study. To examine the variability due to substratum, sampling was done at Keoladeo national park, Bharatpur, Rajasthan. A solitary tigress was reported in Keoladeo National Park, Its presence was confirmed in August 2000. (Bholu Khan *Pers comm.*). The presence of a solitary animal in wild conditions was

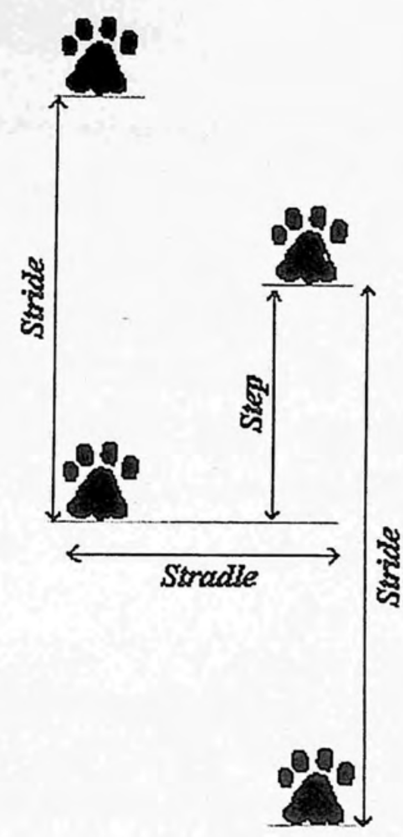


Figure 5. Gait associated measurements.

found to be ideal control situation to do experiment for effect of soil depth along with calibration and field trial of study design.

(a) Effect of Substratum:

Sampling was done three times, at the interval of three and one days respectively at different locations at three different soil depths of < 0.5 cm 0.5 cm and 2 cm respectively.

(b) Assessment of Tracer's Variability:

To address the issue of tracer's variability, sampling was done at National Zoological garden, New Delhi.

Myself and five other persons with various levels of field experience about pugmark tracing; Shri V.B.Sawarkar, Dr.Y.V.Jhala, Shri H.S.Panwar (Ex-Director, Project Tiger & Wildlife Institute of India), Shri. Jagmohan Sharma (Joint Director, National Zoological garden, New Delhi) and Shri A.K.Malhotra (Curator, National Zoological garden, New Delhi) participated in this exercise. Among these first three tracers traced the same 7 pugmark, four from a male tiger and three from female tiger. Rest of the three tracers traced one pugmark of the each of the above said tiger.

Photographing the Pugmarks:

Photographs provide records of animal tracks and the trail for little time and effort compared to any other method of track-preservation, e.g. plaster casts and tracings. Photographs ensure a good record of the tracks of rare carnivores.

The purpose of photographing the pugmarks was to compare the photographs with the tracing of the same pugmark, and if found effective then to suggest the use of pugmark-photographs in place of tracings.

Photographs for track identification have been used for the study of Mountain lions (Grigione *et al.*, 1999) Jaguar (Marcelo Aranda *pers. comm.*, Carolyn Miller *pers. comm.*,) Black rhino (Jewell *et al.*, 2001) Tigers and Snow Leopards (Riordan, 1998). Each of them used a standardized protocol to photograph the tracks of study species.

Present study also followed a fixed protocol for photography of pugmarks. I designed a camera stand for photography of pugmarks, it contains a rectangular steel frame (dimensions 28 cm length, 20 cm width, 1 cm high) with a small rectangle (dimensions 20 cm length and 16 cm width) cut inside the outer frame (Figure 6). The aluminium scale was fixed on all the four edges of this frame for calibration of image during the variable measurement phase, back into laboratory. On one of the long edge a cylindrical rod (70 cm long) is fixed with nut & bolt arrangement so as to capture the long axis of pugmark on the long axis of photograph. A clamp is fixed over this rod, which has arrangement for holding the camera vertically over the pugmark. The camera fixed over this clamp has the lens directed vertically over the pugmark in a manner that, if a plumb line is dropped from the centre of the lens then it will pass through the centre of pugmark. This clamp can be slid up and down, as per the user requirement. Four levelling screws were also fixed on all the four corners of the camera-stand. The whole assembly can be dissembled and reassembled in a few minutes in the field and can be carried to long distances without any problem.

The need for such sophistication is to reduce the aberration in manual photography, so as to standardise the photography for pugmarks, from a fixed height and fixed specifications.

A 35 mm SLR camera with 50 mm lens was used for photography of pugmark. 200 ASA & 400 ASA fast speed film were used for photography of pugmark. Use of flash and combination of flashes

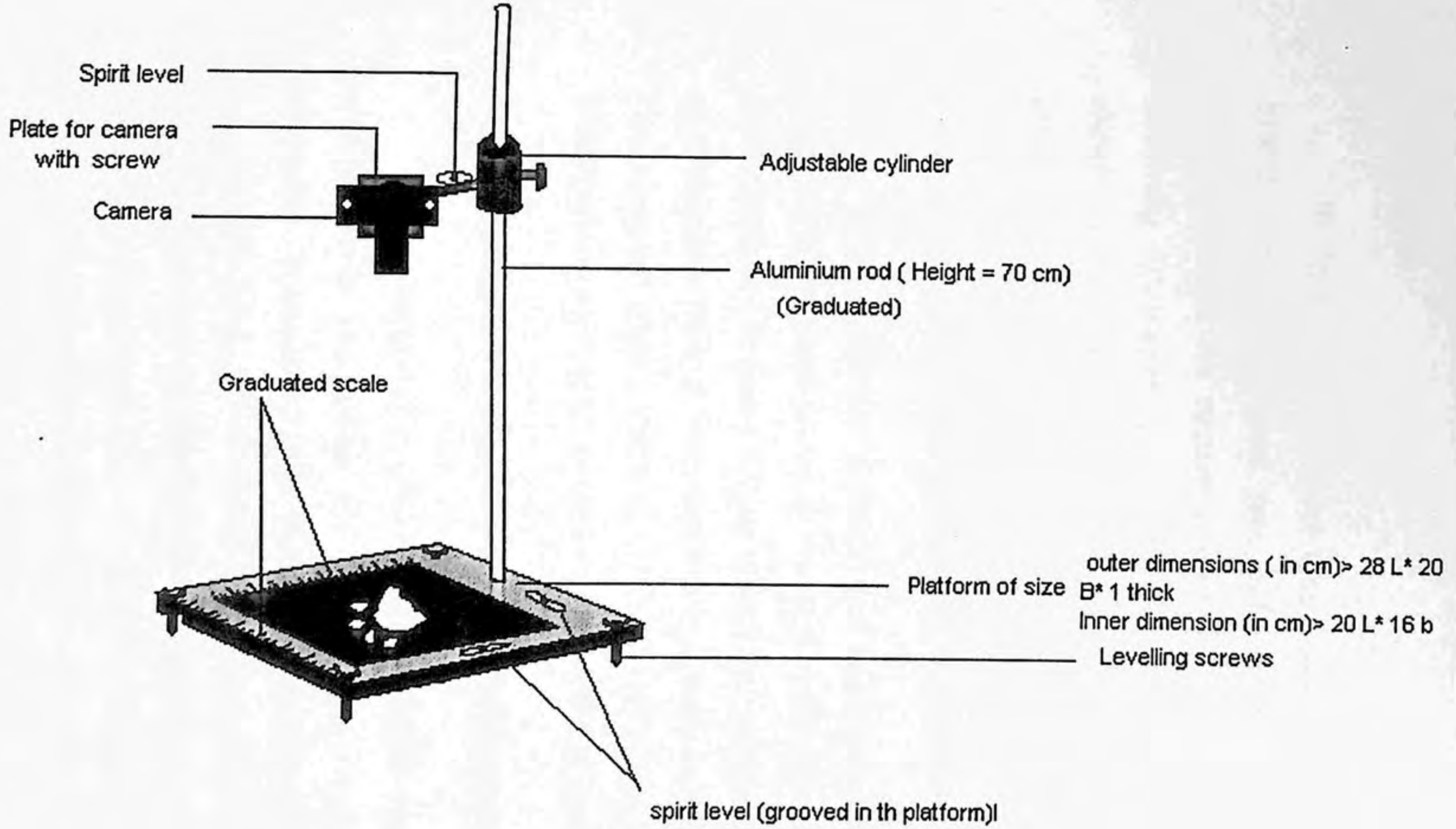


Figure 6. Camera stand devised to photograph tiger pugmark.

Positioned at a fixed low angle were tried out to enhance edges and to give depth to the photographs. But this attempt was unmatched with the quality of photograph taken in the early morning hours, in low angled natural light of sun. Flash tends to flood the whole pugmark with excess-light and thus was not found to give required edge and depth enhancement to the pugmark. Compared to this photographs taken in natural slanted sunlight were found to have enough edges and a proportionate combination of light a shaded area along the relief edge of pugmark.

In the field, the camera was fixed over the assembled camera-stand, name of the place, date and pugmark code were written on the place left over the rectangular frame. Camera was aligned pointing vertically downward over the pugmark at a fixed height, and then clicked by using 10 second timer, so as to avoid shake during photography.

Scanning of Pugmark Tracings and Pugmark-Photographs:

All the pugmark tracings and photographs were scanned, by following a fixed well-tested protocol. A calibration line of five cm length was introduced in every tracing during the scanning, so as for the ease of calibration during morphometric measurement phase of pugmark. The scanned tracing then saved in TIF (Tagged Image File) format. The scanned photographs were saved in JPEG format.

Assigning the Centroid to the Pugmark Polygons:

The pugmark of a felid has one trilobiate pad, with two notches and four oval toes (Figure 7). This makes in-all five polygons in a pugmark. Scanned tracings had a lot of speckles, so before bringing the pugmark into GIS (Geographical Information System) domain, the scanned tracings were despeckled by redrawing the edges of pugmark polygons, using Sigma Scan-Pro 4 (SPSS Inc.). The resulting image is a clear despeckled image with sharp outlines of the same scale as was

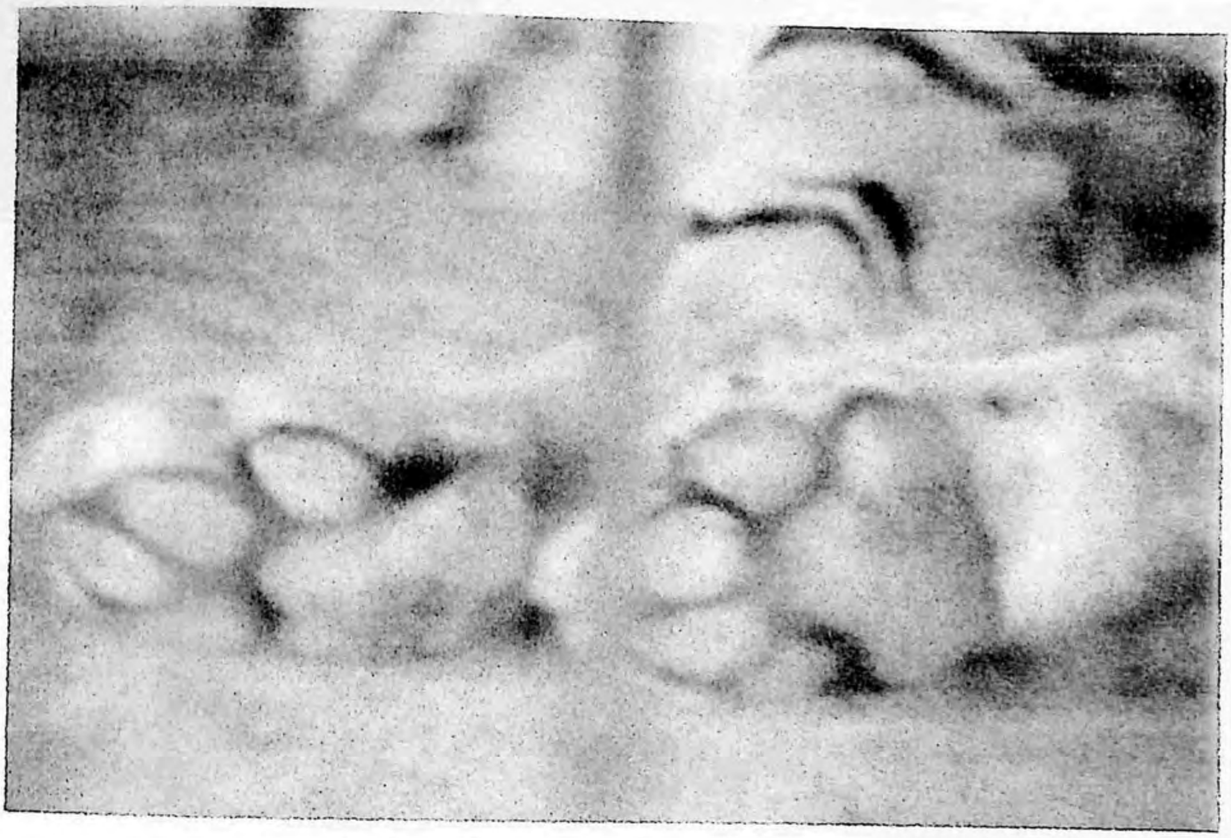


Figure 7. Morphology of hind foot of tiger showing trilobiate pad and four toes.

the original field tracing (Figure 8). There is no image distortion while doing the above said image processing. This despeckled image was then imported into GIS domain and converted into vector form from Raster format by the use of Arc Info 8.0.2 (Environmental Systems Research Institute, Inc., Redlands, CA, USA). This process digitized the pugmark. After that centroids were assigned to each of the pugmark polygons, by Arc Info.

The pugmark cover images with centroids were then exported to Arc View 3 (Environmental Systems Research Institute, Inc., Redlands, CA, USA), for re-conversion into raster image. There the format of the image file was again changed into JPG and exported to Image measurement software.

Morphometric Measurement of Pugmark Profile:

A total of 93 Morphometric measurements (Appendix 1) were decided upon to measure from left as well as the right pugmark. The reason to select a plethora of variables was to extract out maximum possible information from the pugmark and to determine which measurement has maximum discriminating power. Though there were earlier studies (Gogate *et al.* 1989, Das & Sanyal 1995) on the selection of robust variables from the pugmarks, but those studies were limited to very few individuals, pugmarks from only two tigers in case of Das & Sanyal (1995). So the selected 93 variables were supposed to provide a fairly good idea about the geometry of pugmark. Out of the chosen 93 variables, 47 were linear, 7 were area, 11 were angle, 18 are ratio and 10 were shape variables (Table 2).

The morphometric variables were measured by using Sigma Scan Software. The calibration line of 5 cm length introduced during scanning, was used here to calibrate the software to the given scale. The CGS (Centimetre-Gram-Second) scale was followed for measurement. The precision for linear and area measurement is 0.1

mm and .01 square mm. Precision for angular measurement is 0.1° (i.e.6').

A protocol was developed for morphometric data acquisition from scanned & centroid assigned tracings as well from Pugmark photographs. The matrix of the measured variables was then subjected to statistical analysis.

Table 2. Percent contribution of each variable group in maximum CV-ratio and maximum F-ratio criteria of parameter selection, and in final variables.

Parameter Groups	All parameters	Maximum F-ratio	Maximum CV-ratio	Final parameters used in analysis
Area	**7** (7 %)	**7** (21%)	**7** (21%)	**1** (9%)
Linear	**47** (49%)	**22** (67%)	**22** (67%)	**7** (64%)
Angle	**11** (11%)	**1** (3%)	**0** (0%)	**1** (9%)
Ratio	**18** (19%)	**0** (0%)	**1** (33%)	**0** (0%)
Shape	**10** (10%)	**0** (0%)	**0** (0%)	**0** (0%)
Gait	**3** (3%)	**3** (9%)	**3** (9%)	**2** (18%)
Total	**96**	**33**	**33**	**11**

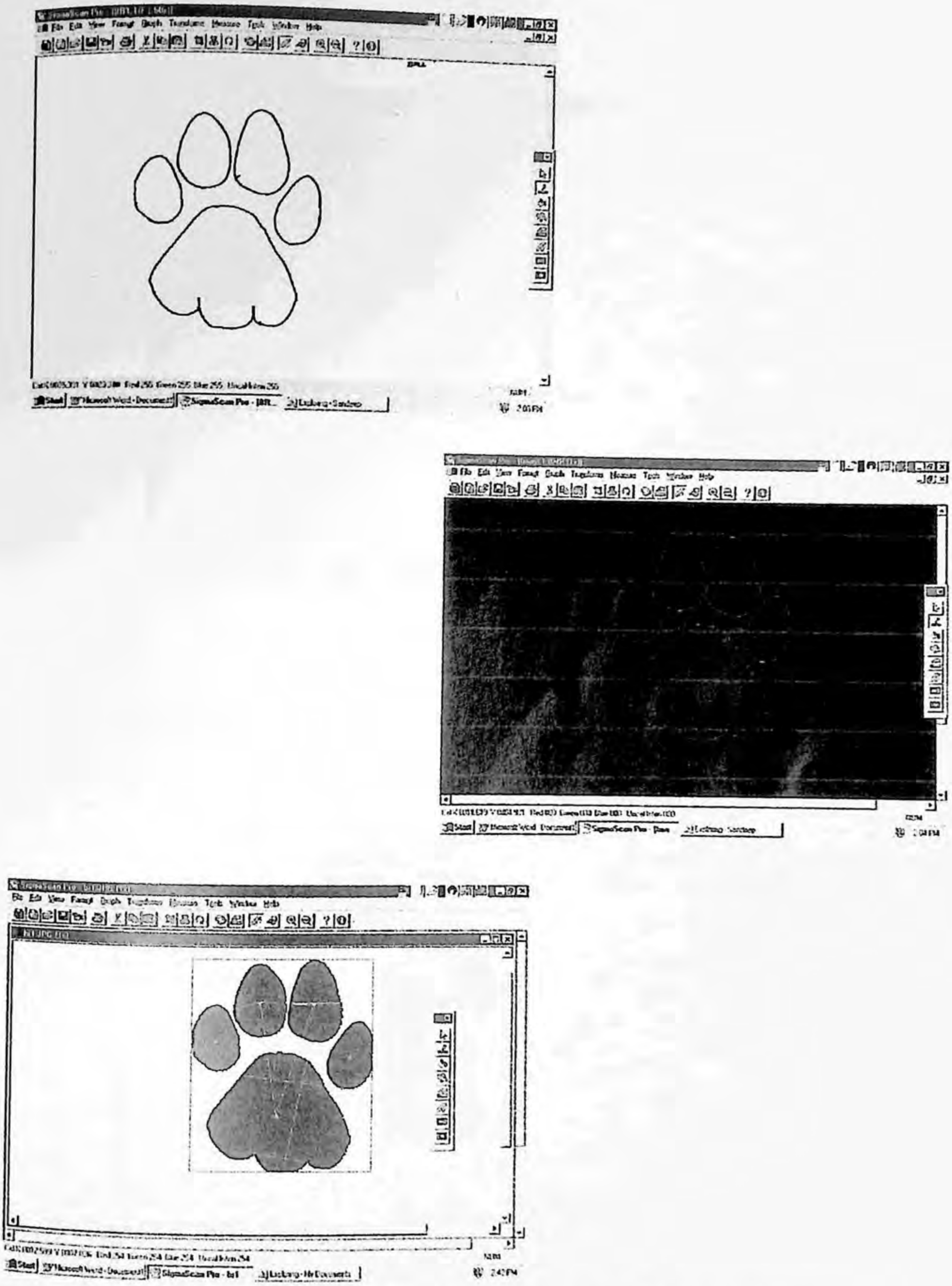


Figure 8. Image processing of pugmark from the stage of field tracing till measurement by using Sigma Scan Pro 4. Software.

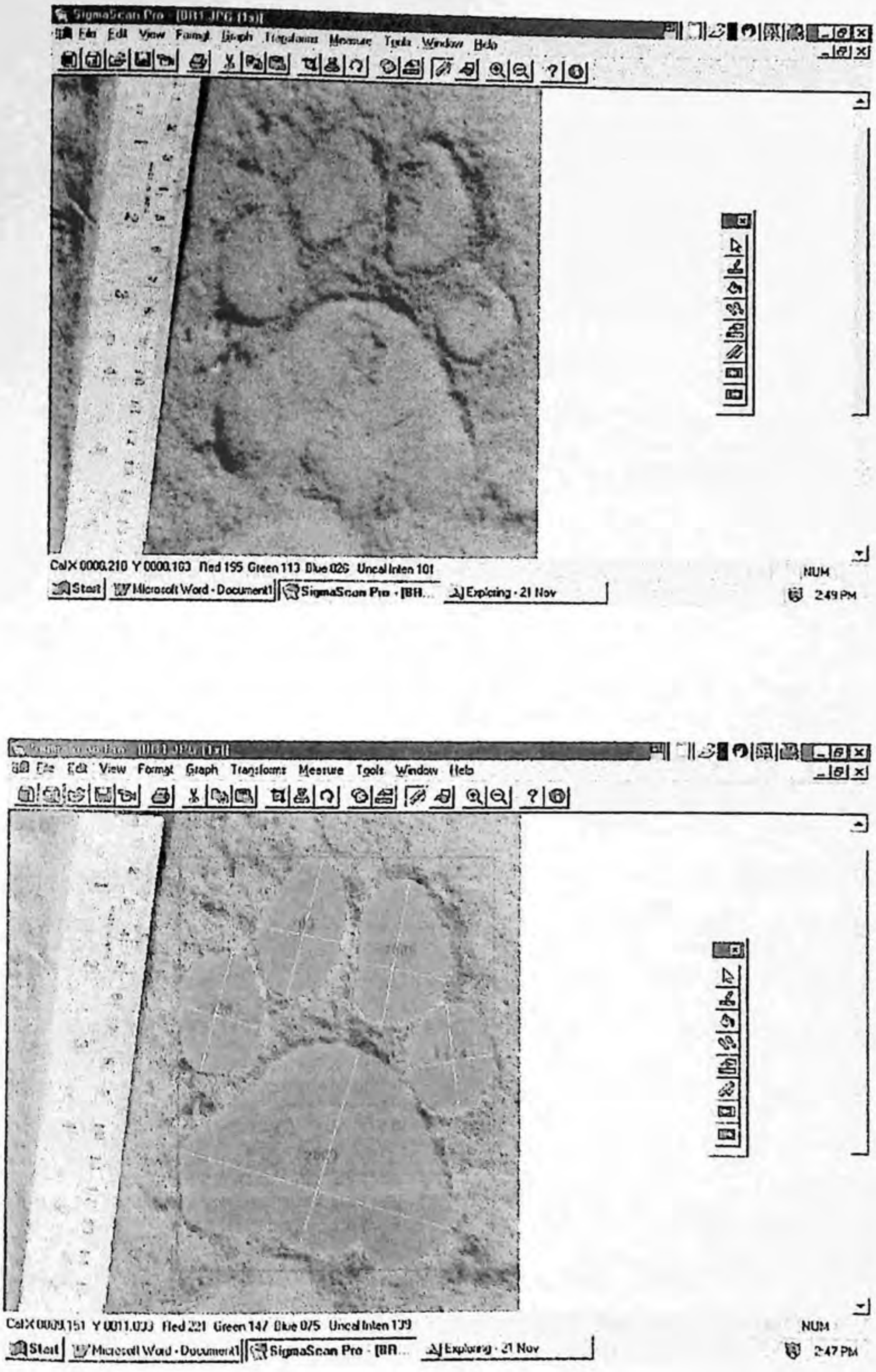


Figure 9. Pugmark photograph subjected for variable measurement.

Statistical methods:

SPSS 8.0 and SPSS 10 (SPSS Inc.) were used for all statistical analysis. The variables were of different scales so all of the variables were converted into Z-scores before subjecting them to any statistical analysis.

Variable selection:

The objective of this process was to reduce the data dimensionality, so as to achieve maximum discrimination with a few robust variables. To find out a small group of predictor variables, which should give maximum discrimination between the pugmark-set, but should not vary much between the set, two methods were tested:

(a) Maximum CV ratio method

(b) Maximum F-ratio method

In maximum CV ratio method, the Coefficient of Variation (CV) for each of the measured variable of a pugmark was computed for individual tigers (CV_t). A grand coefficient of variation (C) was computed for the same variables across all tigers using all pugmark sets collected from the field. CV_g was then divided by the individual CV's (CV_{t1} to CV_{t18}) of each of the tiger for each variable. The objective was to get maximum CV ratio (CV_r) which denotes minimum variation within the pugmark set and maximum variation between the pugmark-set/ tigers ($CV_r = CV_g$ / CV_{t1} to CV_{t18}).

Variable with the large value of CV_r would have a large CV between tigers but small CV within each tiger i.e. it would have a greater capability to discriminate between individual tiger.

The maximum F-ratio method uses the ratio of largest variance to the smallest variance from the data set, it determines whether the variances in two independent samples are equal. In pugmark data set I computed variance within the each pugmark set for each variable (S_w^2)

as well as variance between the pugmark sets (S_b^2), the F-ratio is S_w^2 / S_b^2. The large value of F-ratio for a particular variable suggests that it is fairly consistent between the same pugmark set but differs to an extent between the pugmark sets of different tigers so as to give discrimination between the tigers. The gait variables viz. stride, step and straddle were also tested for the maximum CV method and maximum F-ratio method.

DFA was done by using all the 93 variables, for left as well as right pugmark, and by adding gait variables, so as to select the variables used by DFA model to give the maximum discrimination. Those variables, which were found to give maximum discrimination in DFA model but are not present in the other two methods of variable selection, were added in the group of predictor variables.

Then this set of predictor variables was subjected to DFA to get a set of more robust variables. I also checked for the correlation among the variables. Since all measured variables were from the same pugmark and were morphometric measurement, they were presumed to be auto-correlated.

Pearson's bivariate correlation coefficients were calculated for each group of variables and between those groups. Similar exercise was done to check the correlation between each variable. The objective was to reduce the geometrical redundancy of variables. Highly correlated variables, but which were appearing in predictor variable set, because of maximum F-ratio and maximum CV ratio were replaced by variables which were next in queue of list of maximum F-ratio and maximum CV-ratio. I tried to keep the variables for analysis in such a way so that there was nearly equal representation of area, angle, linear & shape variables.

It was found that a few variables were having significant difference between left and right pugmark. The model was likely to suffer due to lack of sufficient samples of pugmarks per pugmark set.

The sample size could be increased if left and right pugmarks from the same tiger are pooled for analysis. The variables were tested by paired t-test and pooled after looking at p values. By this test, those variables, which were different between left and right pugmarks, were eliminated and at the same time the left and right pugmarks are pooled. It doubled the sample size of pugmarks from the same tiger, without much loss of morphometric information from the pugmark for analysis. The selected variables were robust for the left and right pugmark.

Discriminating Individual Tigers:

To reduce the dimensionality of the variables and to extract maximum information from the measured pugmark, Principal Component Analysis (PCA) (Johnson & Wichern, 1992) was done for 93 pugmark variables for left and right pugmark and 3 gait parameters. For discrimination between different tigers, Stepwise Multiple Group Discriminant Function Analysis (DFA) (Johnson & Wichern, 1992) was used for analysis of individuality of tigers based on pugmark.

The main purpose of a discriminant function analysis is to predict group membership based on a linear combination of the interval variables. The procedure begins with a set of observations where both group membership and the values of the interval variables are known. The end result of the procedure is a model that allows prediction of group membership when only the interval variables are known. A second purpose of discriminant function analysis is an understanding of the data set, as a careful examination of the prediction model that results from the procedure can give insight into the relationship between group membership and the variables used to predict group membership (http://www.psychstat.smsu.edu/MultiBook/mlt03m.html#00).

Discriminant function analysis is also used to determine which variables discriminate between two or more naturally occurring groups. This is known as Stepwise Discriminant function analysis, because variables are entered stepwise. Stepwise entry of variables during DFA helped in selection of robust non-redundant variables along with other methods of variable selection (Johnson & Wichern, 1992). (http://www.statsoftinc.com/textbook/stdiscan.html).

During the first phase of the analysis, data from 8 tigers were subjected to analysis, by using 50 variables for left and right pugmarks. Later I used DFA on the entire data set of 18 tigers with 93 variables and tested the classification by 'jack-knife estimate' or 'leave one out estimate' or 'hold out procedure' (Lachenbruch & Mickey, 1968). DFA was also done on 18 tiger pugmark set after 47 out of 92 variables were selected prior to the stepwise procedure by the maximum F-ratio and maximum CV-ratio (explained earlier) and considering correlation between variables. The classification accuracy was again tested by 'hold out method'.

DFA was also done with final 11 variables after pooling right and left pugmarks and accuracy of the classification was examined by direct as well as hold out method.

Sex-Discrimination of Tiger:

Pugmark sets of 10 wild tigers, whose sex was known with certainity, were selected for analysis. The 11 variables of these 10 tigers were then subjected to PCA and a scatter plot of PC scores were plotted on PC1 and PC2 for differentiating the sex.

The same data was subjected to Stepwise DFA. The visual examination of histograms of length and breadth of pugmarks was also done following Paranjape *et al.* (1993). Only length and breadth data of these 10 tigers were then used as predictor variable for sex discrimination of tigers, by using Logistic Regression (Johnson & Wichern, 1992).

The sex discrimination model was then validated by introducing a test set of 3 tigers, whose sex was known (one male and two females). Two of them were captive tigers (National Zoological Garden, New Delhi) and one of them was a wild tigress (Bharatpur Tigress).

Analysis for Assessment of Variability due to Substratum:

The 11 predictor variables were measured from the scanned and processed tracings, and those variables were tested for Coefficient of variation (CV) between three sets. The data was analysed by Analysis of Variance (ANOVA) with three soil depth as the treatment, followed by Post-Hoc multiple comparison for observed means (Zar, 1984). DEA was also done on the same data set.

Analysis for Assessment of Tracer's Variability:

The predictor variables were analysed by one way Analysis of Variance (ANOVA) with tracers as treatment followed by Post-Hoc multiple comparison for observed means. To check the variation in individual variable, CV of each variable was examined.

Assessment of variability between Tracing and Photograph of Pugmark:

Predictor variables were measured from tracings and photographs (Figure 9) and then compared by considering the CV and testing by ANOVA. Paired t test was also done on the same data set to check variability between individual variable. DFA was also done to cross check the results given by above-mentioned methods.

Validation of model for Individual Discrimination of Tigers by pugmarks:

The use of DFA method for assigning correct classes to the pugmarks was tested and validated by pugmark set of known tigers. For these the data used for DFA of 18 tigers was divided into two halves, by randomly picking up 50% of the pugmark sets from each tiger's total pugmarks. First half of these data set was used as training data set to generate a model by DFA analysis. Then the remaining data set of pugmarks was entered as test-set. Leave one out classification or hold out classification (Lachenbruch & Mickey, 1968) was also done on the same data set. Classification accuracy was judged by examining the class assignment pattern for each pugmark-set and each pugmark.

Since the entire pugmark set (a series of continuous pugmarks made by the same tiger) and not a single pugmark signifies the identity of a tiger, it was the accuracy of correct classification of a pugmark set that is of relevance. The whole pugmark set was assumed as an identity of tiger and introduced for the analysis, the decision rule for correct classification of pugmark set was devised on the correct classification of more then 50% of pugmarks of that series into correct group. Probability of classification was also taken into account while classifying the pugmark-set as well as the pugmark. The cut-off value was again fixed at the probability level of 50%. If 50% of all pugmarks fall into correct class and rest 50% get misclassify, then the series/Pugmark was placed into 'ambiguous' category.

The above said exercise was repeated 5 times by randomly assigning 50% of the pugmarks from each set as the training set and the remaining as a prediction or test set.

'Census-Exercise':

In the previous test the actual number of tigers was known priori and the model was tested to predict the correct grouping of each pugmark-set and individual pugmark. However in a field census exercise several pugmark sets could be recorded without knowing the identity of the tiger.

An analytical technique needs to be developed that permits recognition to a set of pugmarks as belonging to a 'new' tiger or assigning the pugmark set to a tiger whose tracks have been recorded earlier. In a typical field census exercise there are all chances to receive multiple sets of the same tiger from two different locations.

To address this field problem, a population of tigers of different age groups and sexes, represented by 18 pugmark sets was simulated, by creating new pugmark-sets from pre-exiting ones. I considered the identity of the tiger pugmark sets as unknown. I further subdivided pugmark sets with larger number of pugmarks into two sets. In all 4 pugmark-set viz. Tiger Nos. 5, 6, 11, 12 were divided into two halves and given different identity number as Tiger nos. 5, 6, 11, 12, 21, 22, 23, 24. Thus eventually I had in all 18 pugmark sets and I had to determine the number of tigers represented by these pugmark sets.

This blind-set of 18 tiger pugmark-sets were then subjected to statistical model for a simulated '*Census-exercise*'. I attempted this by splitting each pugmark set into two halves, once again for all the 18 pugmark sets into two halves, one was used as the training data set and other half was used as a predictor (test) set.

The DFA model was prepared by training it with the training data set and then classes of the remaining pugmarks were predicted by examining the classification table. The criterion of 50% class assignment was fixed as 'cut-off value for class decision'. If more then

50% of all pugmarks from a pugmark set classified into a known class (here with the tiger) then that test set was classified as the same tiger and the data for both the tiger will be pooled. If the class assignment is 50% into class A and 50% into class B then that pugmark set was kept in an 'ambiguous identity' class. The same criterion was used for class assignment of individual pugmarks. But here if the pugmark gets distributed into two or more then two classes then the probability of those classes were compared.

'Expert-System' Evaluation:

One more exercise is conducted in the present study to assess the veracity and the subjectivity involved in the 'Expert system'. Experienced field personnel were provided with 15 pugmark tracings from a known number of tigers (Appendix 16) and were requested to identify the number of tigers and classification of those tracings into the respective tiger identities. Along with those tracings gait measurements associated with each tracing were also given. Experts were also requested to fill a questionnaire (Appendix 17) which was designed to assess their field experience and to elicit their views on pugmark census technique. Other groups of participants for this exercise were Indian ecologists, and laypersons. This 'Expert-System evaluation' test was also posted to a natural history discussion group (NATHIS) on the web, to secure response from people working in the relevant field as well as from the laypersons. A few experts from foreign countries also responded to this test.

The response received for the 'expert system' evaluation was divided into four classes.

Indian Field experts: This class includes all those people who have extensive field experience about tiger pugmarks, tracing methods and intricacies of the census system. All of the respondents of this class have been participating in the census and have been playing a 'decision making' role in census exercise. The field experience of the respondents of this class ranges from 10 years to more then 20 years.

Foreign field experts: in this class responses from those people were kept who are not from India and have been working on either the feline species or have field and research experience about animal tracks and intricacies of the animal tracks.

Indian ecologists: This class includes those respondents who are well aware of the tiger's pugmark and the methodology of pugmark census in India, but who have either never participated in a census or their participation in census exercise is not 'decision making'. Again there are respondents in this class whose experience ranged from level of < 5 years to > 20 years.

Lay persons: This class was assigned to those respondents who do not have any in-depth experience of 'pugmark' and census method. They are just aware of the 'Tiger-Census' and use of tiger pugmark in the census. They have never participated in any census exercise and most of them have never seen a tiger pugmark in wild.

The 'Expert System' was evaluated in terms of deviation from the truth. Biases if any, were evaluated in order to ascertain their impact on tiger census in the country. All responses were sorted and placed into respective classes. Accuracy in prediction of correct number of tigers and percentage misclassification of pugmark tracings was calculated with 95% confidence interval.

RESULTS

I collected pugmark-sets of individually known tigers from different Tiger reserves, Protected areas, Zoo and Tiger safari. Details of the sampling sites, number of pugmarks and pugmark sets collected from each site are given in Table 1.

Variable selection:

- By using a combination of maximum CV_r (Maximum CV ratio) and maximum F-ratio I identified 33 variables out of the 97 variables (93 pugmark variables and 3 gait variables) (Appendix 1) which were having maximum information from a tiger's pugmark for discrimination. Of the 33 variables selected on the basis of value of CV_r and F-ratio 25 variables (75.75%) were found to be similar for both the methods (Appendix 1).

- It was found that the average correlation (Pearson correlation coefficient at 0.01 level, two tailed) among area variables was high i.e. 0.83 (N=49), where N is the number of records. The same for linear variables was found to be 0.61 (N=2070). Rest of the variable groups were found to be correlated with a very low value for correlation coefficient i.e. 0.17 (N=144) for angle variables, 0.13 (N=272) for ratio variables and 0.08 (N=100) for shape variables.

- The average correlation coefficients (Pearson correlation coefficient at p=0.01) between various groups of variables e.g. linear-area, area-angle were found to be very low. (Table 3).

- Among gait variables i.e. stride, step and straddle, Step was removed from analysis due to high correlation with stride i.e. 0.831(n=40). The correlation among stride and straddle was found to be 0.215 (n=40).

- The step wise procedure of DFA using probability criteria of p = 0.05 for entry of variables into modal and p = 0.1 for removal of variables and variable selection criteria by judging maximum CV_r (Maximum CV ratio) and maximum F-ratio 11 parameters were found to be most robust and with good discrimination power. At the same time they were also found to be similar for left and right track by subjecting them to paired t-test.

- Of these 11 variables, 9 were pugmark variables and two gait variables. The correlation between these predictor variables is given in Table 4.

Individual Identification of Tigers by means of Pugmarks:

- PCA was not very successful in extracting information from the variable set of 95 variables. First two PC explained 65.35% variability among data, while the first three PC explained 73% variability in data. The scatter plot of pugmarks on PC 1 & PC 2 axis gave idea about some level of grouping in the pugmarks (Figure 10).
- Stepwise DFA on 25 variables, for left as well as right pugmark of 8 tigers selected 19 variables for the DFA model. All 18 tigers were discriminated with 100% accuracy in original classification method. Leave one out classification also gave 100% accuracy in classification. (Figure 11, Table 5, Appendix 2, 3).
- Stepwise DFA selected 47 variables out of 115 variables for 18 tiger pugmark sets discrimination. Discrimination accuracy was 100% for original as well as leave one out classification. (Figure 12, Appendix 4).
- Stepwise DFA was repeated once again by using only those top 33 variables (includes variables for left as well as right pugmark and three gait variables, which makes 69 variables in all), which were having maximum CV-ratio and maximum F-ratio. 33 variables were selected for model building, out of 69 variables entered. The classification

accuracy was 100% for original and 96.7% for the leave one out classification. (Figure 13, Appendix 5).

- Considering the principle of parsimony, my model though performing well, had a large number of variables in relation to the sample size of the pugmarks recorded in a set. The same variables of measurements of left and right pugmarks were being used as different variable in above models. Paired t-test results between those variables which were used by above said models for discrimination of individual tigers suggested that most variables did not differ between left and right pugmark. The variables that did not differ were replaced by highly correlated surrogate variables meeting the maximum CV-ratio and maximum F-ratio criteria that were similar between left and right pugmarks of the same tiger. This exercise permitted me to increase my sample size of pugmarks by pooling same variable measurements for left and right pugmarks, from the same track set. Attempts were also made to reduce geometrical redundancy by equal representation of variables from each variable group, along with the caution of maintaining the discriminatory power of those variables.

- Eleven variables of pooled pugmarks from 17 tigers were subjected to DFA, the accuracy level was 97.1 % for original count and 87.4 % for cross-validated count by leave one out classification. (Figure 14).

Validation of model for Individual discrimination of Tigers by Pugmarks:

Predictive DFA for class prediction of pugmarks into different groups was used for model validation. Predictive DFA was repeated five times for the same data set after assigning zero identity to half of the data set at random at every repetition.

- The test was found to be 89.41% accurate in assigning correct class to pugmark set, 90 % accurate for the correct classification of individual pugmark by five repetition of the similar validation exercise (Table 6).
- The misclassification rates were 1.18 % for pugmark-set and 6.97 % for individual pugmark.
- The ambiguous classification was found to be 9.41 % for pugmark-set and 3.01 % for individual pugmark. The process of class assigning for classification is shown in Table 7.
- Table 7 shows example of one validation exercise, accuracy of correct classification of pugmark set and pugmarks from 5 such exercise is given in this table .The results presented above are average of all those accuracy for five validation sessions.

Sex discrimination of Tigers:

(a) With 10 wild tigers of known sex:

- The visual examination of histogram of length and width of pugmark shows two distinct peaks, and indicates the presence of two populations (Figure 15).
- The results of PCA for sex discrimination of tigers generated two PCs, which accounted for 77.78% of variability in the data. The scatter plot between these two PC showed two distinct populations (Figure 16).
- The results of Stepwise DFA selected three variables D23 (distance between toe 2 and toe 3), DN1N2 (distance between notch 1 and notch 2) and H (distance main pad top to toe base line) out of 9 variables entered, in the model to discriminate between male and female tigers. The accuracy was 99.1% in original grouping of cases 98.1% in cross-validation. (Table 8. Appendix 6,7).

- When 'zero identity' was assigned to the sexes of 50% of total population of tigers for predictive DFA then the classification accuracy was 100% for track sets and 99.1% for the original grouping of individual pugmarks. The leave one out results for individual tracks gave 98.1% accuracy.

- When Stepwise DFA was used on only 2 variables i.e. length of pugmark and width of pugmark, then the model gave 100% correct classification in original as well as leave one out grouping.

- When 'zero identity' was assigned to the sexes of 50% of total population of tigers for predictive DFA then the classification accuracy was 100% for track sets as well as for the original grouping of individual pugmarks. The leave one out results for individual tracks also gave 100% accuracy (Table 9, Appendix 6,7).

- Logistic regression results with two variables i.e. length of pugmark and width of pugmark gave 100% accuracy in classifying the sexes of known wild tigers.

(b) Validation of Model for Sex-discrimination of Tigers:

When the models build by different techniques described above were tried for validation on three different tigers of known sexes (from zoo as well as wild), then following results were obtained:

- PCA generated two PCs, which on plotting explained 75.79% variance cumulatively (Figure 17).

- The results of Stepwise DFA selected for 9 variables entered, discriminated between male and female tigers with the accuracy level of 96.2% in original grouping of cases 96.2% in cross-validation (Table 10).

- When 'zero identity' was assigned to the all newly entered tigers for predictive DFA then the classification accuracy was 100% for track sets and 99.1% for the original grouping of individual pugmarks. The leave one out results for individual tracks gave 98.1% accuracy (Table 11).

- When Stepwise DFA was used by using only two variables i.e. length of pugmark and width of pugmark, then the model gave 100% correct classification in original as well as leave one out grouping.

- When 'zero identity' was assigned to the sexes of 50% of total population of tigers for predictive DFA by using length of pugmark and width of pugmark as predictor variables. Then the classification accuracy was 100% for track sets as well as for the original grouping of individual pugmarks. The leave one out results for individual tracks also gave 100% accuracy (Appendix 8,9).

- When the logistic regression model was used for predicting the sexes of newly entered tigers, it misclassifies only one pugmark of a male tiger into females. The classification accuracy was 97.94% for a group of 97 pugmarks in case of females and 94.12% for a group of 34 pugmarks in case of male tiger. The overall accuracy of correct classification was 96.95%, but if the identity of tiger is assigned by its pugmark-set then the classification accuracy was again100% (Table 12).

Variability due to Substratum:

Three different substratum were tested to bring in the variability in the pugmark shape and size, only three pugmark-sets from one known wild tiger on three different soil substratum depth i.e. <0.5 cm, 0.5 cm, 2 cm, were subjected for analysis. Results are as follows:

- When the difference between group means of three soil depths were compared by two way ANOVA for substratum and variable as main effect, followed by Post-Hoc test (Duncun's). The ANOVA results suggested that pugmarks are significantly different (p-value 0.005, df-2, df-11) between morphometric measurement of third pugmark-set taken from the soil depth <0.5 cm differed the group means of two other soil substratum.

- It was indicated by the ANOVA results for effect of soil depth on morphometric measurement of pugmark that there is no significant effect between soil depth 0.5 cm to 2 cm on morphometric measurement of pugmark.

For cross-validation of the above said interpretation, Stepwise DFA was done on five pugmark-sets, two sets were from two different tigers and three sets were from the same tiger over three different soil depths i.e. <0.5 cm, 0.5 cm, 2 cm.

- It was found that the pugmark set of the same tiger from three different soil substratum formed an over-lapped group of all the three sets, while the two different tigers were distantly placed in canonical space (Figure 18).

- The classification table indicated that 33.3% of pugmarks from 0.5 cm and 2 cm soil depth were misclassified with each other. While 10% pugmarks from the third soil depth (<0.5 cm) was misclassified in the other two classes. The cross-validation by leave one out classification distributed 33.33% pugmarks of two soil depths i.e. 0.5 cm and 2 cm, equally into all three classes. Results for the third class was the same as in original grouping (Appendix 10,11,12).

Variability associated with Tracers:

Three different tracers traced 7 pugmarks of two different tiger. Data was subjected to two way ANOVA followed by Post-Hoc test for main effects.

- It was found that, the tracers were significantly different for both the tigers (p-value 0.052 with df-2, df-53).

Variability between Pugmark Tracing and Pugmark Photo:

- The paired t-test for all 11 variables, showed significant difference between only a few variables measured from photographs and tracings for the same Pugmark, only one set of photo was compared with the tracings. The p-values for each variable pair is given in (Table 13)
- The one way ANOVA with tracings and photos as main effect showed that tracings and photos are different at the significance of p-value 0.002 with df-1, df-53.

DFA was also done using three-pugmark set. Measurements from tracings and photos of the same pugmark set were introduced for DFA.

- The results of this analysis showed that there is no difference between the morphometric measurements from tracings and photos when subjected to DFA (Figure 19). The classification table (Table 14) shows that pugmark tracings and pugmark photographs for the same tiger's pugmark misclassify into each other (Appendix 13,14,15).

'Census-Exercise':

The census exercise done on simulated population of 18 pugmark sets gave following results:

- Table 15 shows the classification accuracy of census,100% accuracy was achieved in predicting correct number of tigers i.e. 14 tigers based on the interpretation of membership of pugmark-sets as an identity of tiger.
- Probabilities of group membership of each pugmark were summed up to assign the class to a pugmark-set as well as pugmarks. The cut off value was fixed at 50%. For example: in one case the predicted class was 21 for a single pugmark of the whole set, while the other sets were grouping into tiger no. 5 and 20 (which were found to be the same tiger), here if the pugmark set was used as an identity then the correct

classification based on class assignment to 50% of pugmarks of the same data-set was either tiger no. 5 or 20, but if individual pugmark is thought of for classification then one has to look for probability of grouping. In this case the probability for class 21 is 47%, while the probability for class 5 and 21is respectively 0.08 and 0.44. It was known that both 5 and 20 were the same tiger after this test, so if we sum up the probabilities for class 5 and 10 then the resultant probability i.e. 0.52 places the pugmark into tiger no. 5 or 20, by following 50% cut-off value criteria.

Expert-System Evaluation:

- I received total 40 responses for the test, out of which 8 were from Indian experts, 6 from foreign experts, 11 from Indian ecologists and 15 from lay persons.

- Overall accuracy from expert group was very high. Some of the experts (37%) who were also strong believers of the pugmark technique gave 100% accurate results for tiger numbers and pugmark classification from 15 pugmark tracings of 7 different tigers. Two experts overestimated the tiger number by 1. The average accuracy in prediction of tiger number was 7.25 (sd=0.46) tigers. The classification accuracy for pugmarks was 92% (sd=7.77) (Figure 20, 21).

- For foreign experts, the accuracy was 7 (sd=2.16) for tiger number prediction and 83% (sd=24.96) for pugmark classification (Figure 20, 21).

- For Indian ecologists the accuracy was 8.45 (sd=1.1) for tiger number prediction and 67% (sd=10.95) for pugmark classification (Figure 20, 21).

- For laypersons the accuracy was 8.12 (sd=2.6) for tiger number prediction and 64% (sd=25.87) for pugmark classification (Figure 20, 21).

Table 3. Correlation between different variable groups.

Variable groups	Correlation coeffiicient	No. of cases
Linear-Area	-0.010	644
Linear-Angle	0.000	540
Linear-Ratio	0.014	1564
Linear-Shape	0.003	920
Area-Angle	0.017	168
Area-Ratio	0.056	238
Area-Shape	0.000	140
Angle-Ratio	-0.026	408
Angle-Shape	-0.005	240
Ratio-Shape	-0.006	340
Stride-step	0.830	40
Stride-Straddle	0.220	40
Step-Straddle	0.250	40

Table 4. Correlation between the 11 final predictor variables.

Pooled Within-Groups Matrices

	AT1	Mit3	Wpg	D23	Q23	DN1N2	LT'2	HLTL	H	stride	stradle
AT1	1.00	0.83	0.80	0.39	0.62	0.67	0.80	0.33	0.69	0.38	0.52
Mit3	0.83	1.00	0.77	0.43	0.64	0.68	0.84	0.32	0.61	0.45	0.47
Wpg	0.80	0.77	1.00	0.55	0.67	0.68	0.80	0.41	0.72	0.45	0.40
D23	0.39	0.43	0.55	1.00	0.61	0.43	0.40	0.65	0.37	0.28	0.16
Q23	0.62	0.64	0.67	0.61	1.00	0.62	0.67	0.53	0.57	0.42	0.39
DN1N2	0.67	0.68	0.68	0.43	0.62	1.00	0.73	0.35	0.62	0.51	0.33
LT'2	0.80	0.84	0.80	0.40	0.67	0.73	1.00	0.29	0.68	0.44	0.54
HLTL	0.33	0.32	0.41	0.65	0.53	0.35	0.29	1.00	0.13	0.28	-0.08
H	0.69	0.61	0.72	0.37	0.57	0.62	0.68	0.13	1.00	0.31	0.58
stride	0.38	0.45	0.45	0.28	0.42	0.51	0.44	0.28	0.31	1.00	0.07
stradle	0.52	0.47	0.40	0.16	0.39	0.33	0.54	-0.08	0.58	0.07	1.00

Correlation is significant at the 0.05 level (2-tailed).

Table 5. Classification accuracy for DFA of 8 tigers, using 25 variables.

		Predicted Group Membership								Total
	TIGER	1	2	3	4	5	6	7	8	
Original Count	1	5	0	0	0	0	0	0	0	5
	2	0	4	0	0	0	0	0	0	4
	3	0	0	4	0	0	0	0	0	4
	4	0	0	0	5	0	0	0	0	5
	5	0	0	0	0	5	0	0	0	5
	6	0	0	0	0	0	6	0	0	6
	7	0	0	0	0	0	0	6	0	6
	8	0	0	0	0	0	0	0	5	5
%	1	100	0	0	0	0	0	0	0	100
	2	0	100	0	0	0	0	0	0	100
	3	0	0	100	0	0	0	0	0	100
	4	0	0	0	100	0	0	0	0	100
	5	0	0	0	0	100	0	0	0	100
	6	0	0	0	0	0	100	0	0	100
	7	0	0	0	0	0	0	100	0	100
	8	0	0	0	0	0	0	0	100	100
Cross-validate	1	5	0	0	0	0	0	0	0	5
	2	0	4	0	0	0	0	0	0	4
	3	0	0	4	0	0	0	0	0	4
	4	0	0	0	5	0	0	0	0	5
	5	0	0	0	0	5	0	0	0	5
	6	0	0	0	0	0	6	0	0	6
	7	0	0	0	0	0	0	6	0	6
	8	0	0	0	0	0	0	0	5	5
%	1	100	0	0	0	0	0	0	0	100
	2	0	100	0	0	0	0	0	0	100
	3	0	0	100	0	0	0	0	0	100
	4	0	0	0	100	0	0	0	0	100
	5	0	0	0	0	100	0	0	0	100
	6	0	0	0	0	0	100	0	0	100
	7	0	0	0	0	0	0	100	0	100
	8	0	0	0	0	0	0	0	100	100
a	Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the f									
b	100.0% of original grouped cases correctly classified.									
c	100.0% of cross-validated grouped cases correctly classified.									

Table no. 6. Average classification accuracy in Predictive DFA for pugmark sets as well as pugmark as individual identity of tiger.

No. of test rounds	*Pugmark-set*			*Pugmarks*		
	Correct classification	Misclassified	Ambiguous	Correct classification	Misclassified	Ambiguous
1	88.24	5.88	5.88	93.02	6.98	0.00
2	94.12	0.00	5.88	91.01	3.37	5.62
3	82.35	0.00	17.65	85.06	11.49	3.45
4	88.24	0.00	11.76	89.53	8.14	2.33
5	94.12	0.00	5.88	91.46	4.88	3.66
Average accuracy	**89.41**	**1.18**	**9.41**	**90.02**	**6.97**	**3.01**

Table 7. Classification accuracy in Predictive DFA for pugmark sets as well as pugmark as individual identity of tiger, in one test case.

	Pugmark-set			*Pugmarks*		
	Correct classification	**Misclassified**	**Ambiguous**	**Correct classification**	**Misclassified**	**Ambiguous**
1	1			4		1
2	1			3		
3	1			3		
4	1			5		
5	1			5		
6	1			6		
7	1			5		1
8	1			5		
9	1			5		
10	1			7		
11	1			7		
12	1			4		
13	1			3	2	
14			1	1		1
15	1			4		
16	1			3	2	
17	1			5		
Total	16	0	1	75	4	3
%	94.12	0.00	5.88	91.46	4.88	3.66

Table 8. Classification accuracy matrix for sex-discrimination of 10 tigers. (9 variables are used for DFA)

Classification Results [b,c]

		SEX	Predicted Group Membership 1	2	Total
Original	Count	1	83	1	84
		2	0	22	22
	%	1	98.8	1.2	100.0
		2	.0	100.0	100.0
Cross-validated [a]	Count	1	82	2	84
		2	0	22	22
	%	1	97.6	2.4	100.0
		2	.0	100.0	100.0

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 99.1% of original grouped cases correctly classified.

c. 98.1% of cross-validated grouped cases correctly classified.

Table 9. Predictive classification accuracy matrix for sex-discrimination of 10 tigers. (2 variables are used for DFA)

Classification Results [b,c]

		SEX	Predicted Group Membership 1	2	Total
Original	Count	1	84	0	84
		2	0	22	22
	%	1	100.0	.0	100.0
		2	.0	100.0	100.0
Cross-validated [a]	Count	1	84	0	84
		2	0	22	22
	%	1	100.0	.0	100.0
		2	.0	100.0	100.0

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 100.0% of original grouped cases correctly classified.

c. 100.0% of cross-validated grouped cases correctly classified.

Table 10. Classification accuracy matrix for sex-discrimination of 13 tigers in validation of DFA modal when 3 new tigers are entered as test set. (only 2 variables are used for DFA)

Classification Results [b,c]

		SEX	Predicted Group Membership 1	2	Total
Original	Count	1	95	2	97
		2	3	31	34
	%	1	97.9	2.1	100.0
		2	8.8	91.2	100.0
Cross-validated [a]	Count	1	95	2	97
		2	3	31	34
	%	1	97.9	2.1	100.0
		2	8.8	91.2	100.0

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 96.2% of original grouped cases correctly classified.

c. 96.2% of cross-validated grouped cases correctly classified.

Table 11. Predictive classification accuracy matrix for sex-discrimination of 13 tigers in validation of DFA modal when 3 new tigers are entered as test set. (only 2 variables are used for DFA)

Classification Results b,c

		PSEUDO	Predicted Group Membership 1.00	2.00	Total
Original	Count	1.00	83	1	84
		2.00	0	22	22
		Ungrouped cases	19	6	25
	%	1.00	98.8	1.2	100.0
		2.00	.0	100.0	100.0
		Ungrouped cases	76.0	24.0	100.0
Cross-validated a	Count	1.00	82	2	84
		2.00	0	22	22
	%	1.00	97.6	2.4	100.0
		2.00	.0	100.0	100.0

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 99.1% of original grouped cases correctly classified.

c. 98.1% of cross-validated grouped cases correctly classified.

Table 12. Logistic regression modal for sex determination of tigers, where only 2 variables, length & width of pugmark are used as variables.

Varibale	B	S.E.	Wald	df	Sig.	R	Exp(B)
LPG	2.1729	0.8189	7.0402	1	0.008	0.1833	8.7834
WPG	5.4964	1.5178	13.1139	1	0.0003	0.2722	243.8065
Constant	-4.7226	1.3308	12.5929	1	0.0004		

Table 13. p values for paired t-test of 11 variables from pugmark trace and photo comparison.

		Left	Right
Tiger 1	*AT1*	0.48	0.70
	Mit3	0.72	0.32
	Wpg	0.46	0.48
	D23	0.99	0.54
	Q23	0.22	0.60
	DN1N2	0.78	0.94
	LT22	0.77	0.55
	HLTL	0.80	0.32
	H	0.41	0.52
Tiger 2	*AT1*	0.05	0.07
	Mit3	0.00	0.61
	Wpg	0.11	0.00
	D23	0.36	0.69
	Q23	0.06	0.55
	DN1N2	0.56	0.99
	LT22	0.22	0.00
	HLTL	0.99	0.22
	H	0.01	0.00
Tiger 3	*AT1*	0.40	0.37
	Mit3	0.21	0.82
	Wpg	0.08	0.21
	D23	0.41	0.02
	Q23	0.03	0.03
	DN1N2	0.08	0.54
	LT22	0.59	0.49
	HLTL	0.15	0.14
	H	1.00	0.73

Table 14. Classification accuracy table for comparison of pugmark tracing and photo of pugmark sets of three tigers.

Classification Results [b,c]

		F10	Predicted Group Membership						Total
			1.00	2.00	3.00	4.00	5.00	6.00	
Original	Count	1.00	7	3	0	0	0	0	
		2.00	4	5	1	0	0	0	
		3.00	0	0	12	0	0	0	
		4.00	0	0	0	12	0	1	
		5.00	0	0	0	0	11	1	
		6.00	0	0	0	0	1	9	
	%	1.00	70.0	30.0	.0	.0	.0	.0	100
		2.00	40.0	50.0	10.0	.0	.0	.0	100
		3.00	.0	.0	100.0	.0	.0	.0	100
		4.00	.0	.0	.0	92.3	.0	7.7	100
		5.00	.0	.0	.0	.0	91.7	8.3	100
		6.00	.0	.0	.0	.0	10.0	90.0	100
Cross-validated [a]	Count	1.00	5	5	0	0	0	0	
		2.00	5	4	1	0	0	0	
		3.00	0	1	10	1	0	0	
		4.00	0	0	3	9	0	1	
		5.00	0	0	0	0	10	2	
		6.00	0	0	0	0	7	3	
	%	1.00	50.0	50.0	.0	.0	.0	.0	100
		2.00	50.0	40.0	10.0	.0	.0	.0	100
		3.00	.0	8.3	83.3	8.3	.0	.0	100
		4.00	.0	.0	23.1	69.2	.0	7.7	100
		5.00	.0	.0	.0	.0	83.3	16.7	100
		6.00	.0	.0	.0	.0	70.0	30.0	100

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 83.6% of original grouped cases correctly classified.

Table 15. Classification Accuracy in a 'Simulated' census exercise, with 18 pugmark sets from known tigers.

Tiger	Pseudo	Training	Predicted	Probability of Group membership							
ID	ID	Set	Membership	5	6	10	11	20	21	22	23
5	5	5	***5***	0.51	0	0	0	0.49	0	0	0
5	20	0	***20***	0.45	0	0	0	0.55	0	0	0
5	5	0	***20***	0.31	0	0	0	0.69	0	0	0
5	20	20	***20***	0.40	0	0	0	0.60	0	0	0
5	5	5	***5***	0.58	0	0	0	0.42	0	0	0
5	20	0	***20***	0.45	0	0	0	0.55	0	0	0
5	5	0	***5***	0.58	0	0	0	0.42	0	0	0
5	5	5	***5***	0.67	0	0	0	0.33	0	0	0
5	20	20	***20***	0.40	0	0	0	0.60	0	0	0
5	20	0	***20***	0.35	0	0	0	0.64	0	0	0
5	5	0	***21***	0.08	0	0	0	0.44	0.47	0	0
5	20	20	***20***	0.43	0	0	0	0.57	0	0	0
6	6	0	***21***	0	0.33	0	0	0	0.67	0	0
6	6	6	***6***	0	0.98	0	0	0	0.02	0	0
6	21	21	***21***	0	0.02	0	0	0	0.98	0	0
6	21	0	***21***	0	0.05	0	0	0	0.95	0	0
6	6	6	***6***	0	0.61	0	0	0	0.39	0	0
6	21	21	***21***	0	0.02	0	0	0	0.98	0	0
6	6	0	***21***	0	0.33	0	0	0	0.67	0	0
6	21	0	***6***	0	0.54	0	0	0	0.45	0	0
6	6	6	***21***	0	0.46	0	0	0	0.54	0	0
6	21	21	***6***	0	0.86	0	0	0	0.14	0	0
6	6	0	***21***	0	0.47	0	0	0	0.53	0	0
6	21	0	***6***	0	0.86	0	0	0	0.14	0	0
6	21	21	***21***	0	0.07	0	0	0	0.93	0	0
6	6	6	***6***	0	0.99	0	0	0	0.01	0	0
6	6	0	***21***	0.02	0.16	0	0	0.06	0.76	0.01	0

Continued..........

10	10	10	***10***	0	0	0.99	0	0	0	0.01	0
10	22	22	***22***	0	0	0.08	0	0	0	0.92	0
10	22	0	***10***	0	0	1.00	0	0	0	0	0
10	10	0	***10***	0	0	0.95	0	0	0	0.05	0
10	10	10	***10***	0	0	0.99	0	0	0	0.01	0
10	22	22	***22***	0	0	0.08	0	0	0	0.92	0
10	10	0	***10***	0	0	1.00	0	0	0	0.00	0
10	22	0	***10***	0	0	0.98	0	0	0	0.02	0
10	10	10	***10***	0	0	0.99	0	0	0	0.01	0
10	22	22	***22***	0	0	0.00	0	0	0	1.00	0
10	10	0	***22***	0	0	0.00	0	0	0	1.00	0
10	22	0	***10***	0	0	0.98	0	0	0	0.02	0
10	10	10	***10***	0	0	0.89	0	0	0	0.11	0
10	22	22	***22***	0	0	0.00	0	0	0	1.00	0
10	10	10	***10***	0	0	0.84	0	0	0	0.16	0
10	22	22	***10***	0	0	0.93	0	0	0	0.07	0
11	11	0	***23***	0	0	0	0.49	0	0	0	0.51
11	23	23	***23***	0	0	0	0.01	0	0	0	0.99
11	11	11	***11***	0	0	0	0.70	0	0	0	0.30
11	23	0	***23***	0	0	0	0.16	0	0	0	0.84
11	11	0	***11***	0	0	0	0.91	0	0	0.03	0.06
11	23	23	***11***	0	0	0	0.66	0	0	0	0.34
11	11	11	***11***	0	0	0	0.70	0	0	0	0.30
11	23	0	***11***	0	0	0.07	0.63	0	0	0.01	0.29
11	11	11	***11***	0	0	0	0.88	0	0	0.06	0.06
11	23	0	***23***	0	0	0	0.16	0	0	0	0.84
11	11	0	***11***	0	0	0	0.96	0	0	0	0.04
11	23	23	***23***	0	0	0	0.14	0	0	0	0.86
11	11	11	***11***	0	0	0	1.00	0	0	0	0.00
11	23	23	***23***	0	0	0	0.33	0	0	0	0.67
11	11	11	***11***	0	0	0	0.76	0	0	0	0.24
11	23	0	***11***	0	0	0	0.77	0	0	0	0.23

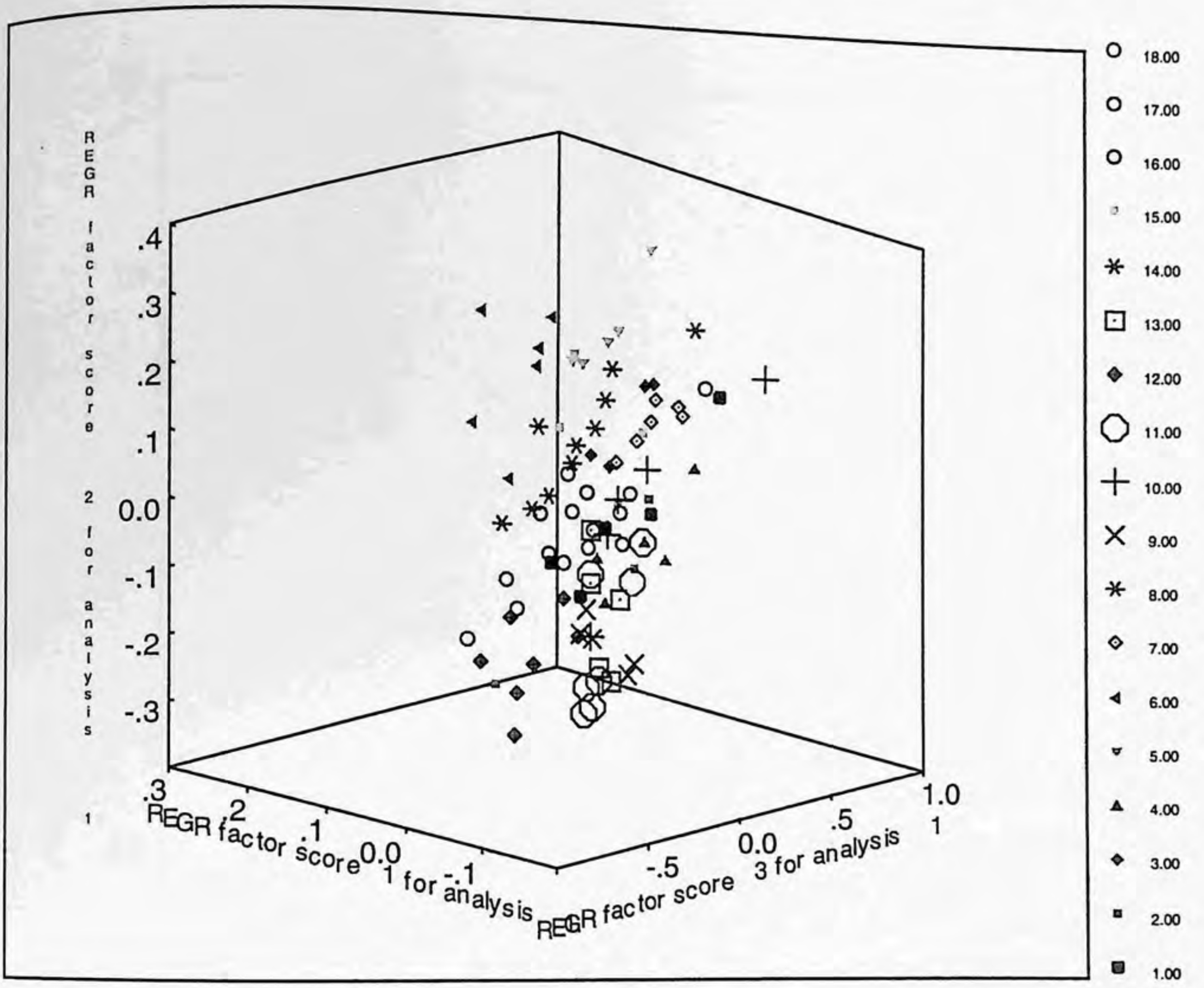


Figure 10. Scatter plot between PC1 and PC2 for 18tigers, by using 95 variables.

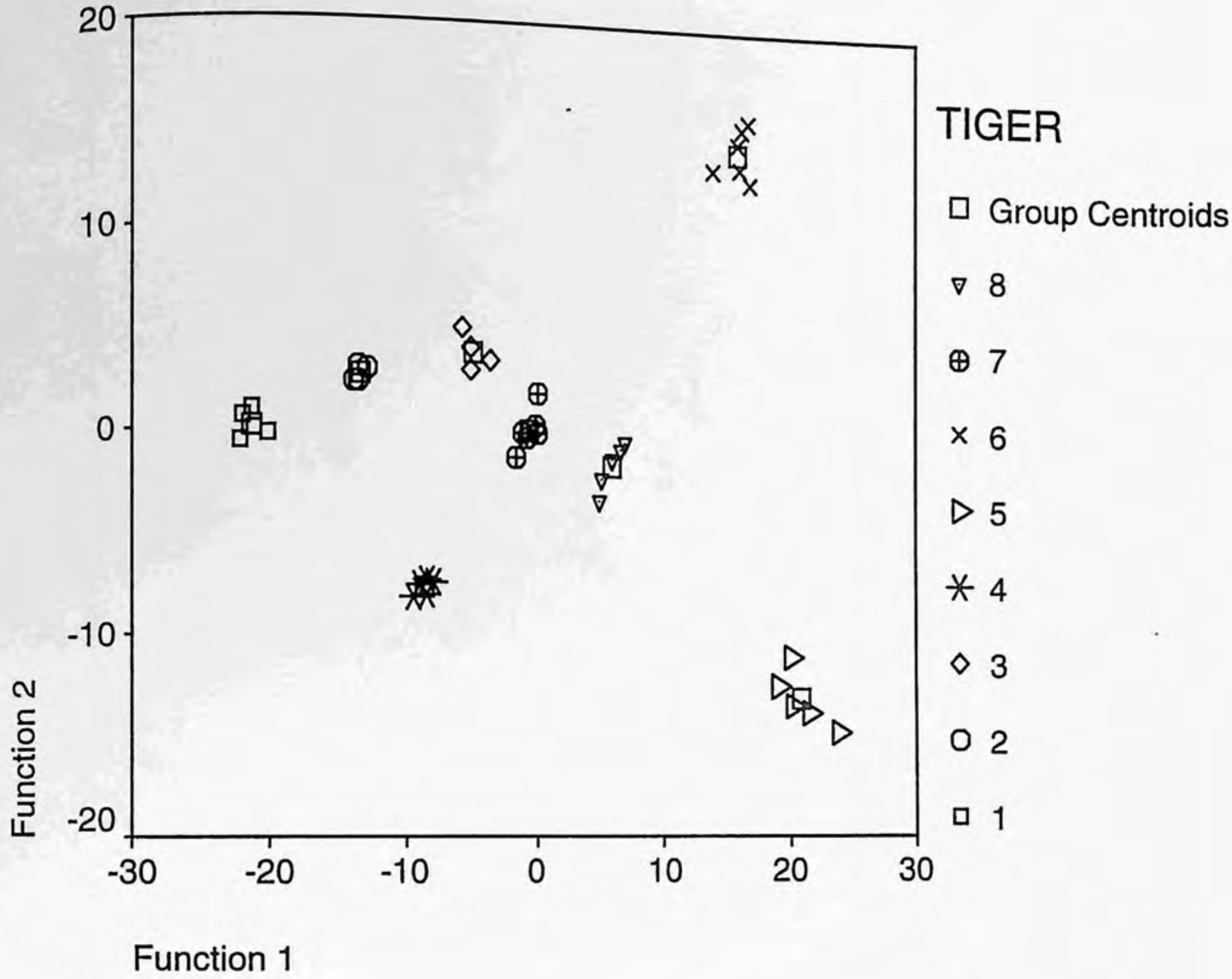


Figure 11. Group centroids and pugmark clusters of 8 tigers on canonical function axis, using 25 variables in DFA analysis.

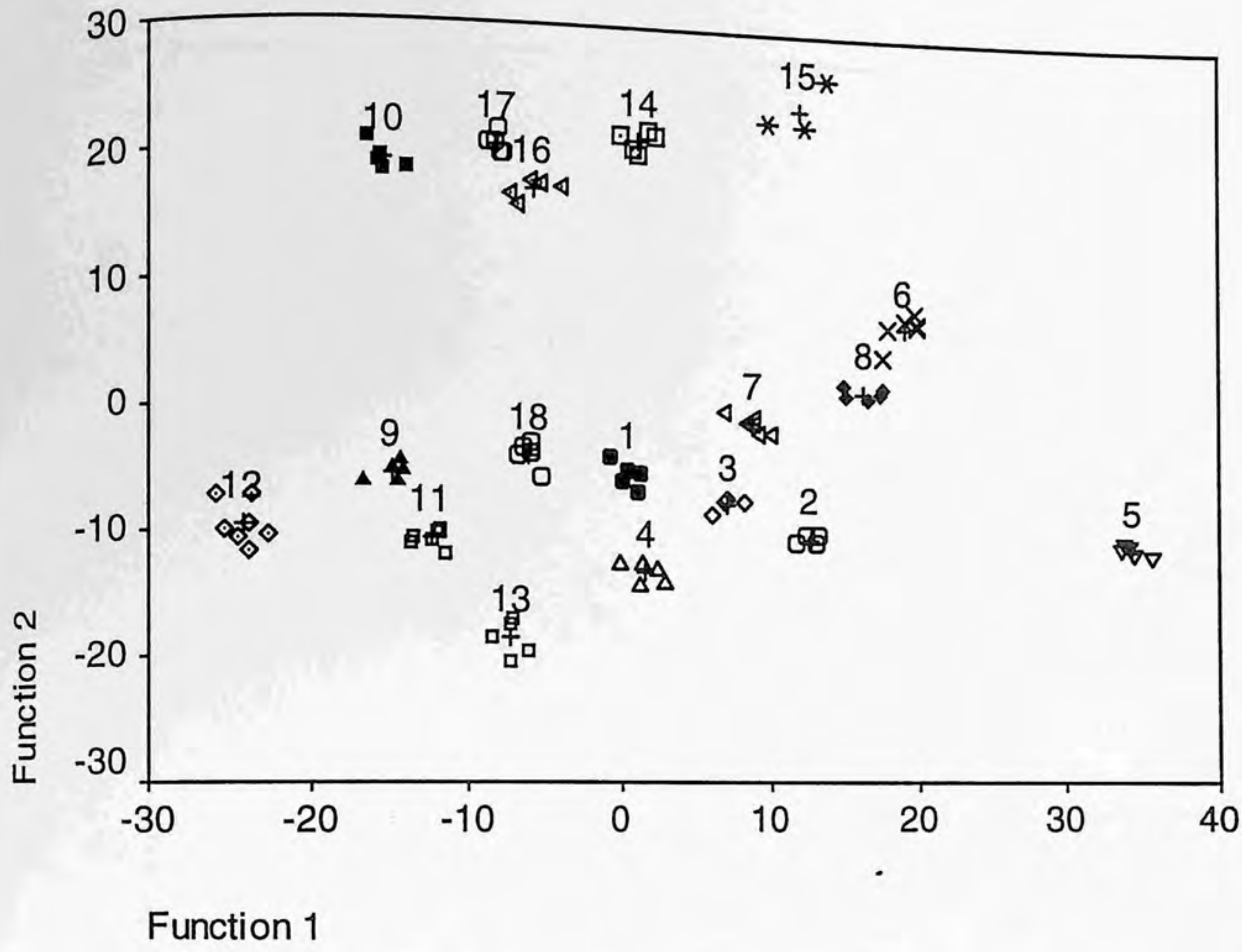


Figure 12. Group centroids and pugmark clusters of 18 tigers on canonical function axis, using 115 variables in DFA analysis.

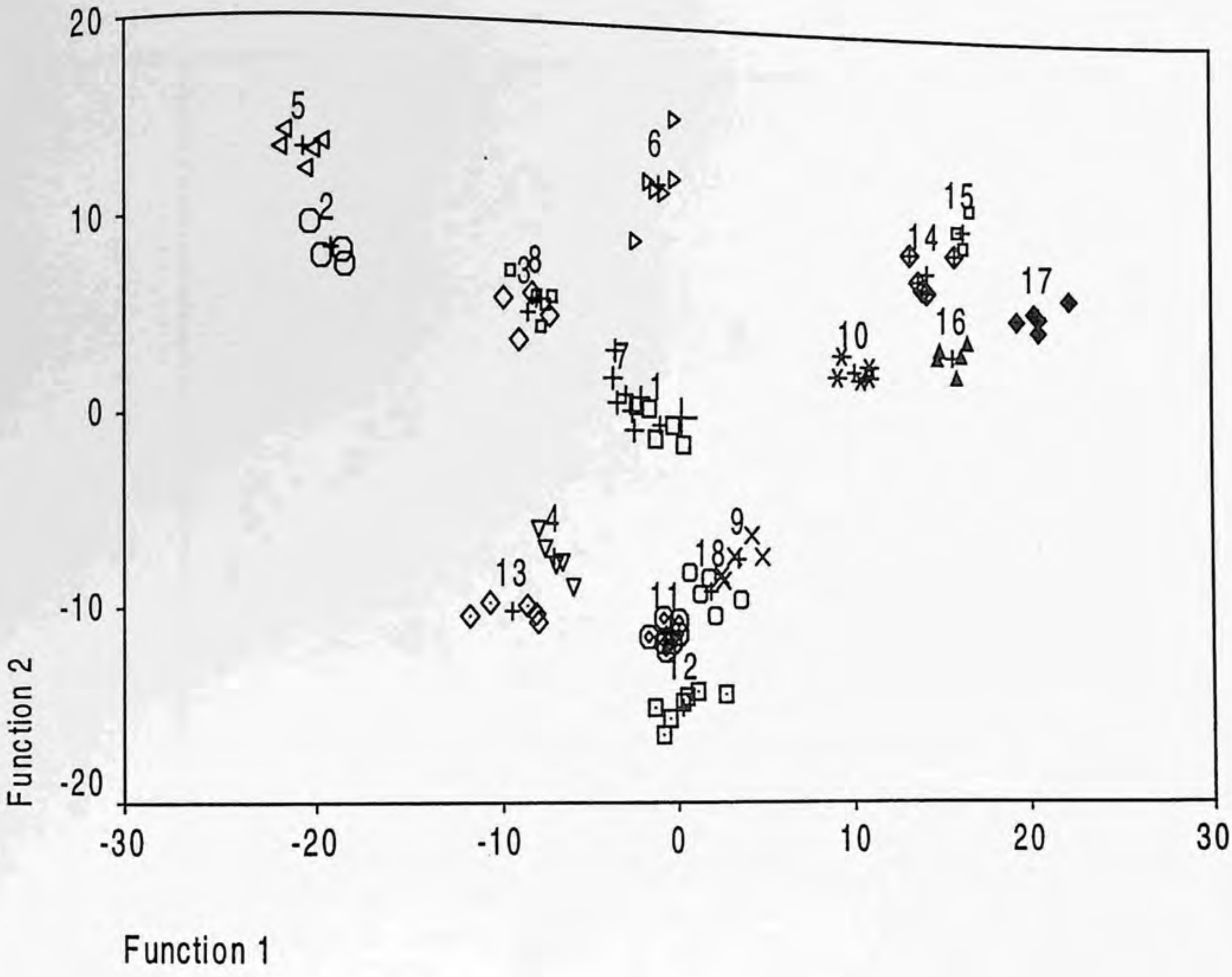


Figure 13. Group centroids and pugmark clusters of 18 tigers on canonical function axis, using 33 variables selected by maximum CV ratio and maximum F-ratio in DFA analysis.

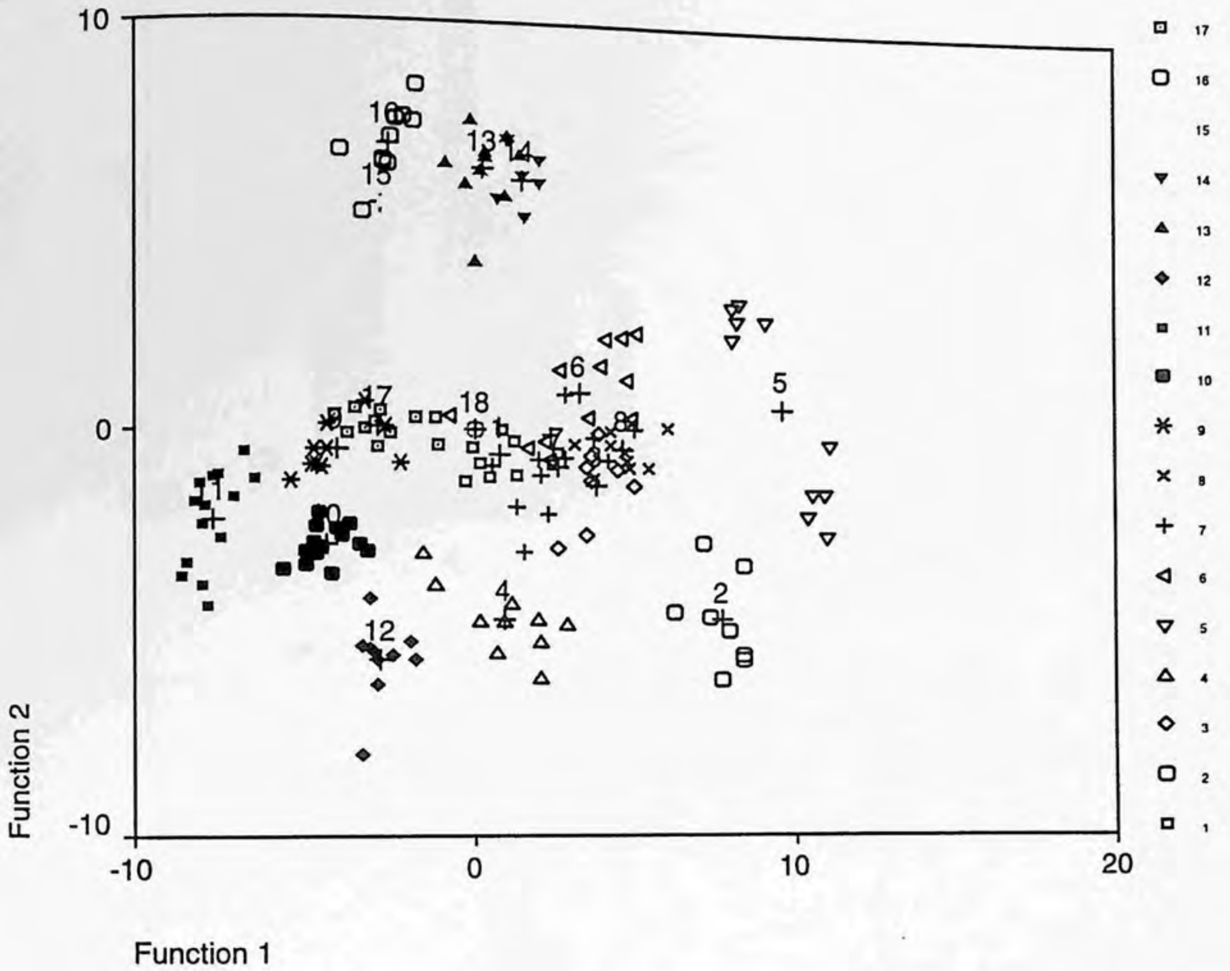
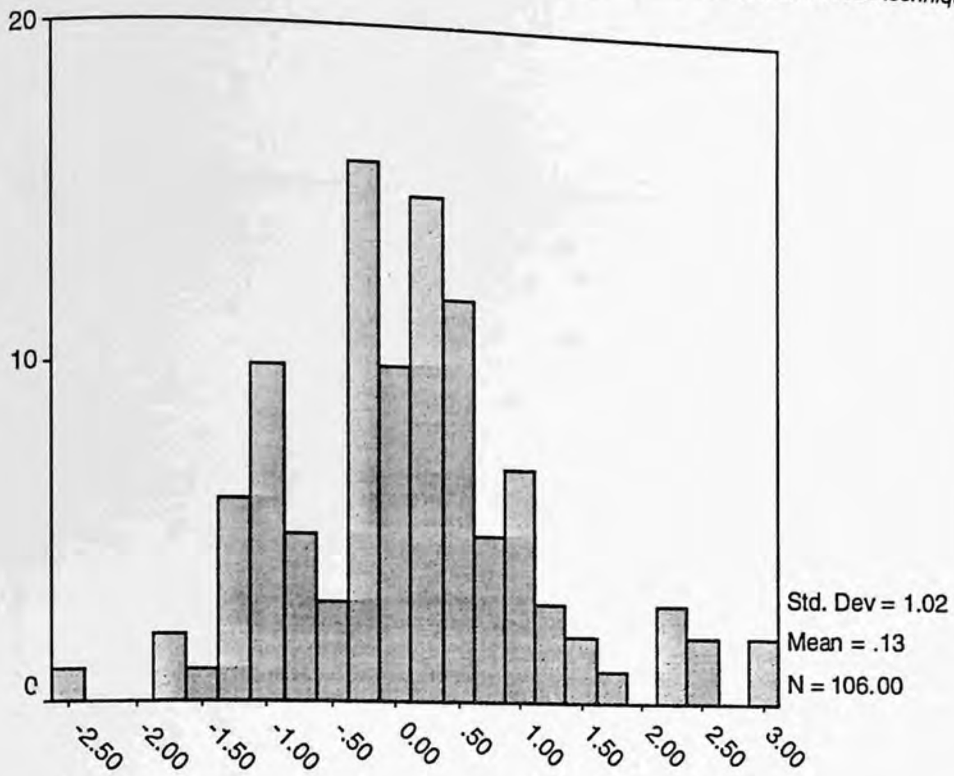


Figure 14. Group centroids and pugmark clusters of 17 tigers on canonical function axis, using 11 variables pooled for left and right pugmark.



Histogram for Length of Pugmark

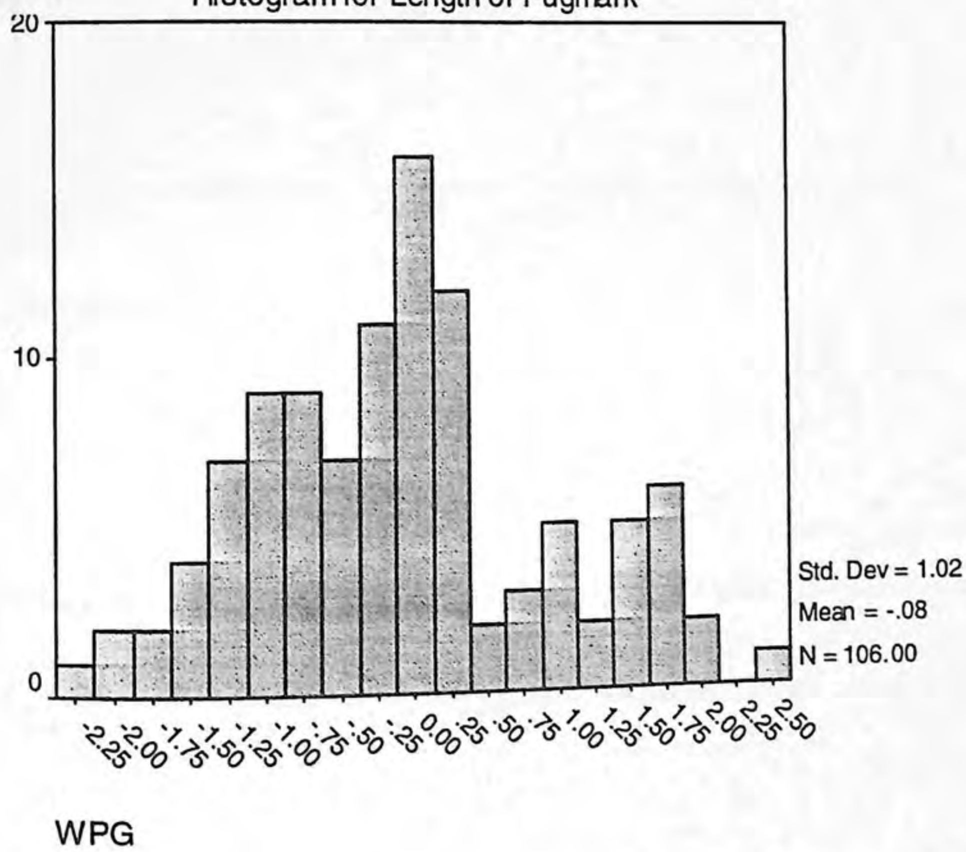


Figure 15. Histograms of length of pugmarks and width of pugmarks for a population of 10 tigers representing two peaks as distinct male and female population among 10 tigers

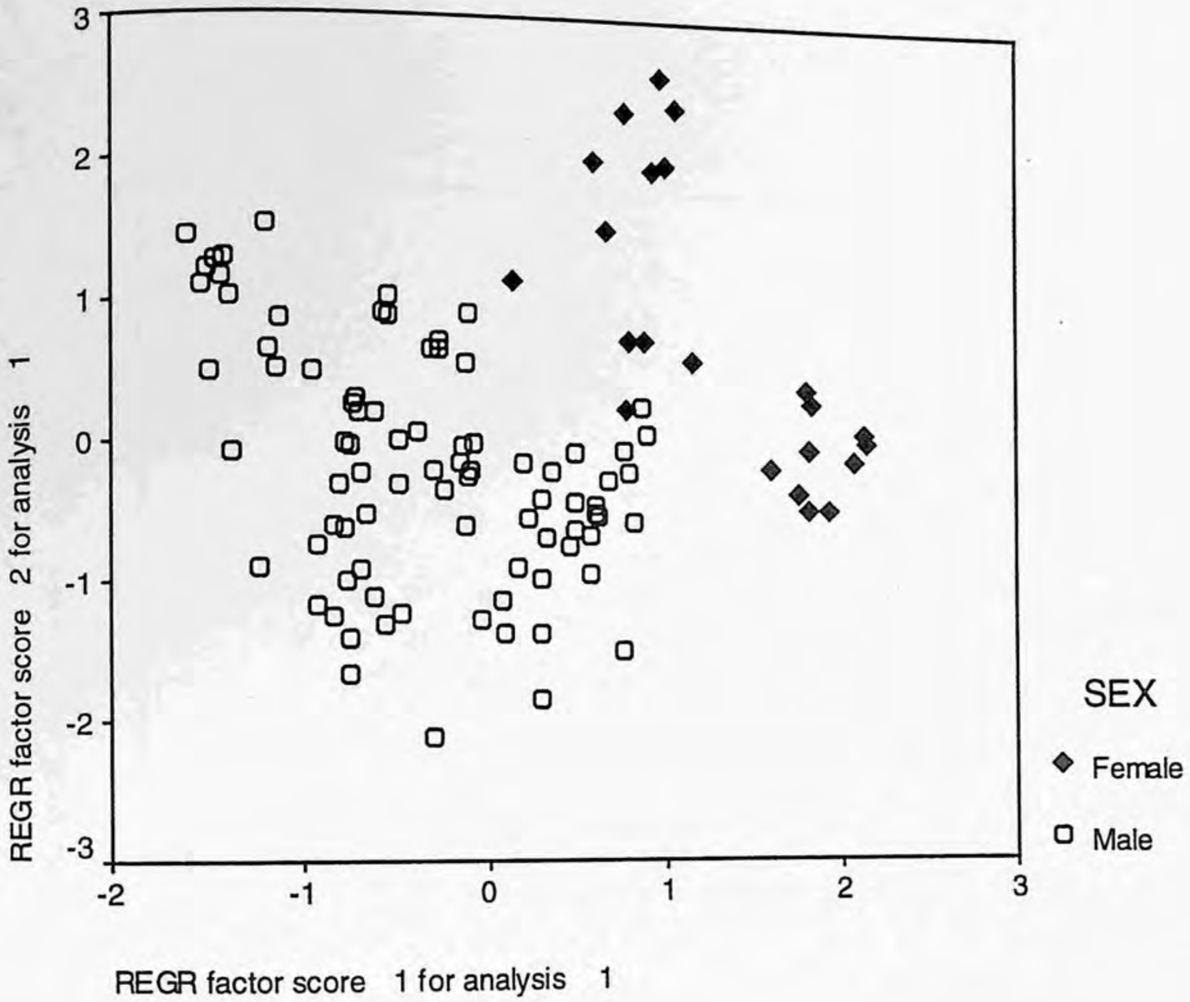


Figure 16. Scatter plot between PC1 and PC2 for 10 tigers of known sex, showing two distinct population of males and females, based on pugmark measurements.

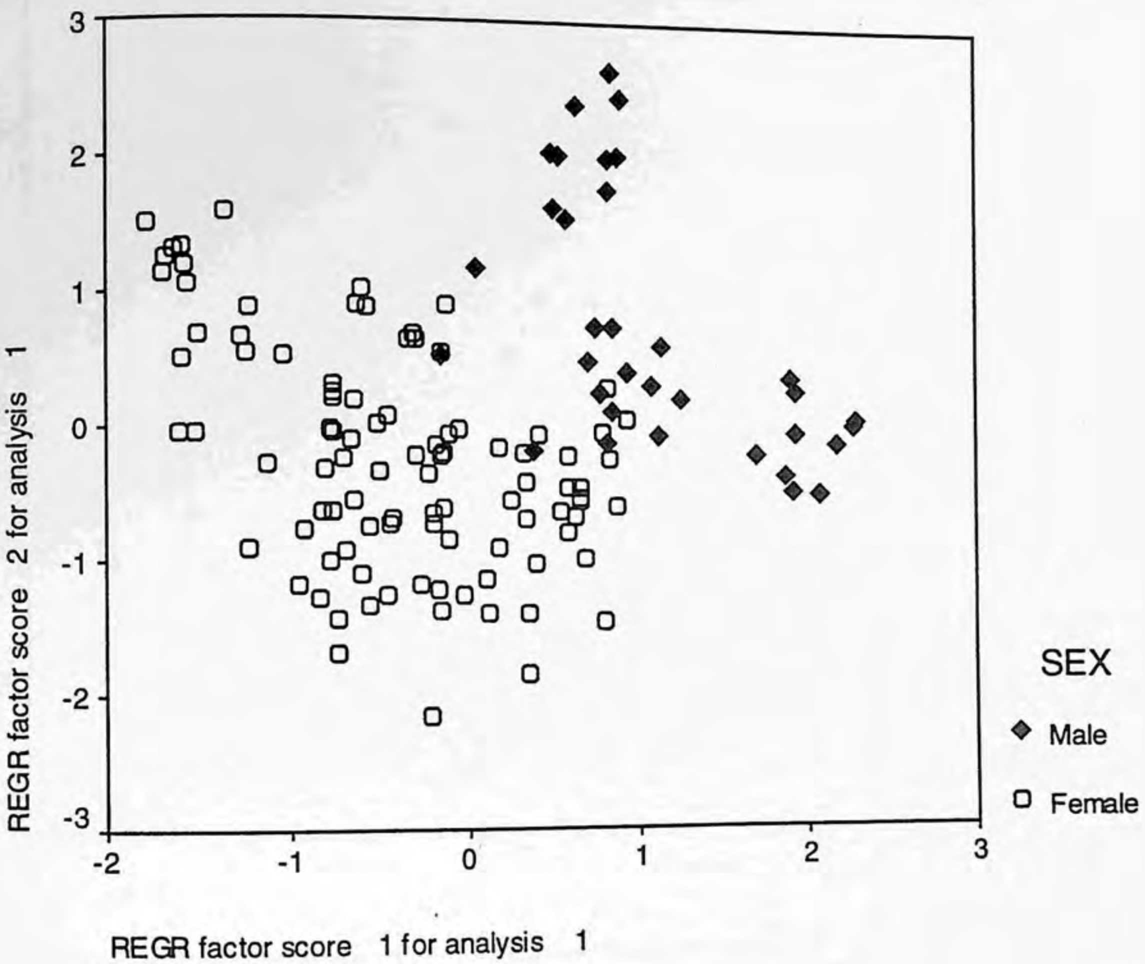


Figure 17. Scatter plot between PC1 and PC2 for 13 tigers of known sex, showing two distinct population of males and females, based on pugmark measurements.

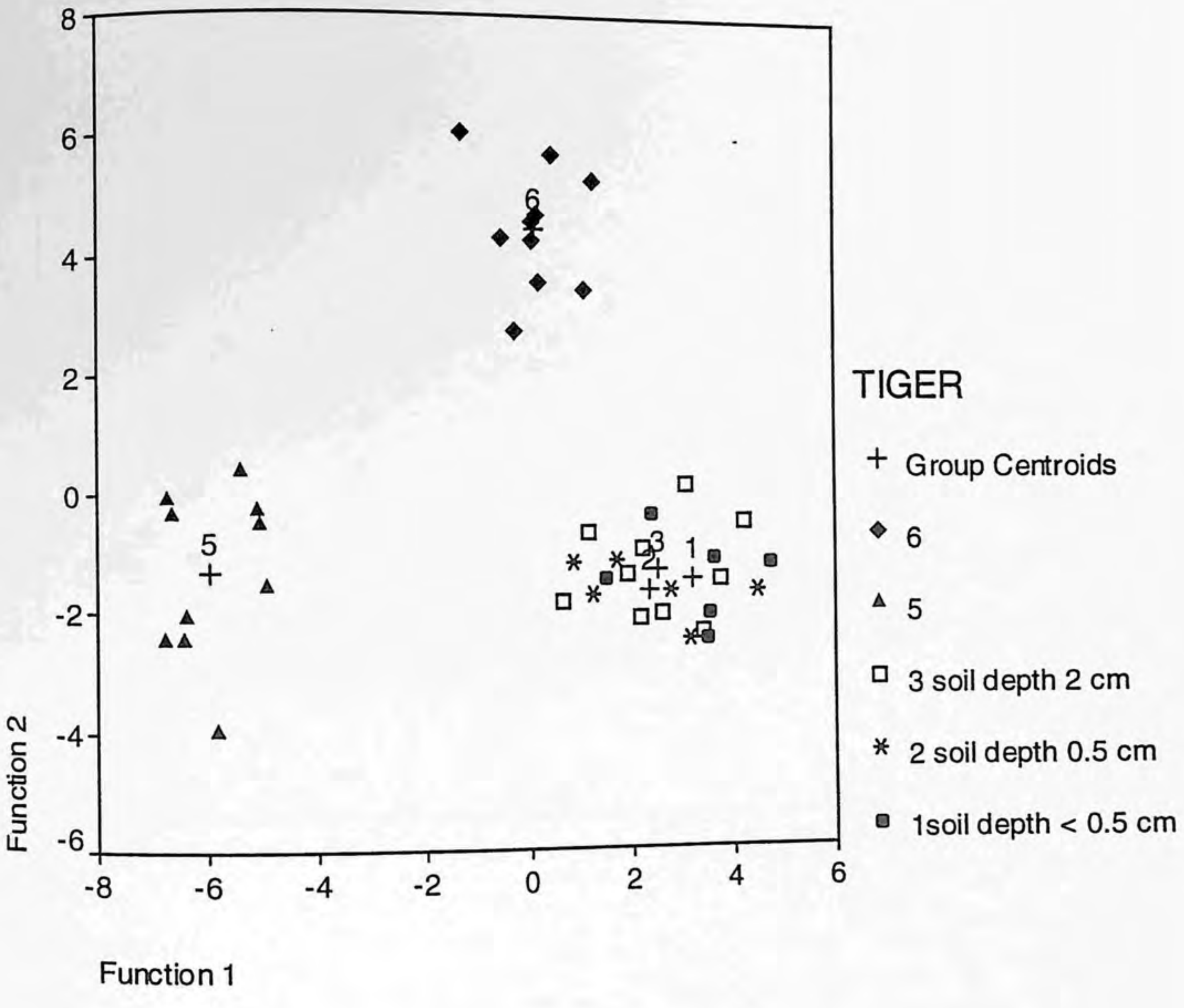


Figure. 18. Group centroids and pugmark clusters of 5 pugmark sets on canonical function axis, using 11 variables pooled for left and right pugmark. three of the total five sets shown here are from a single tiger, traced on three different soil depths.

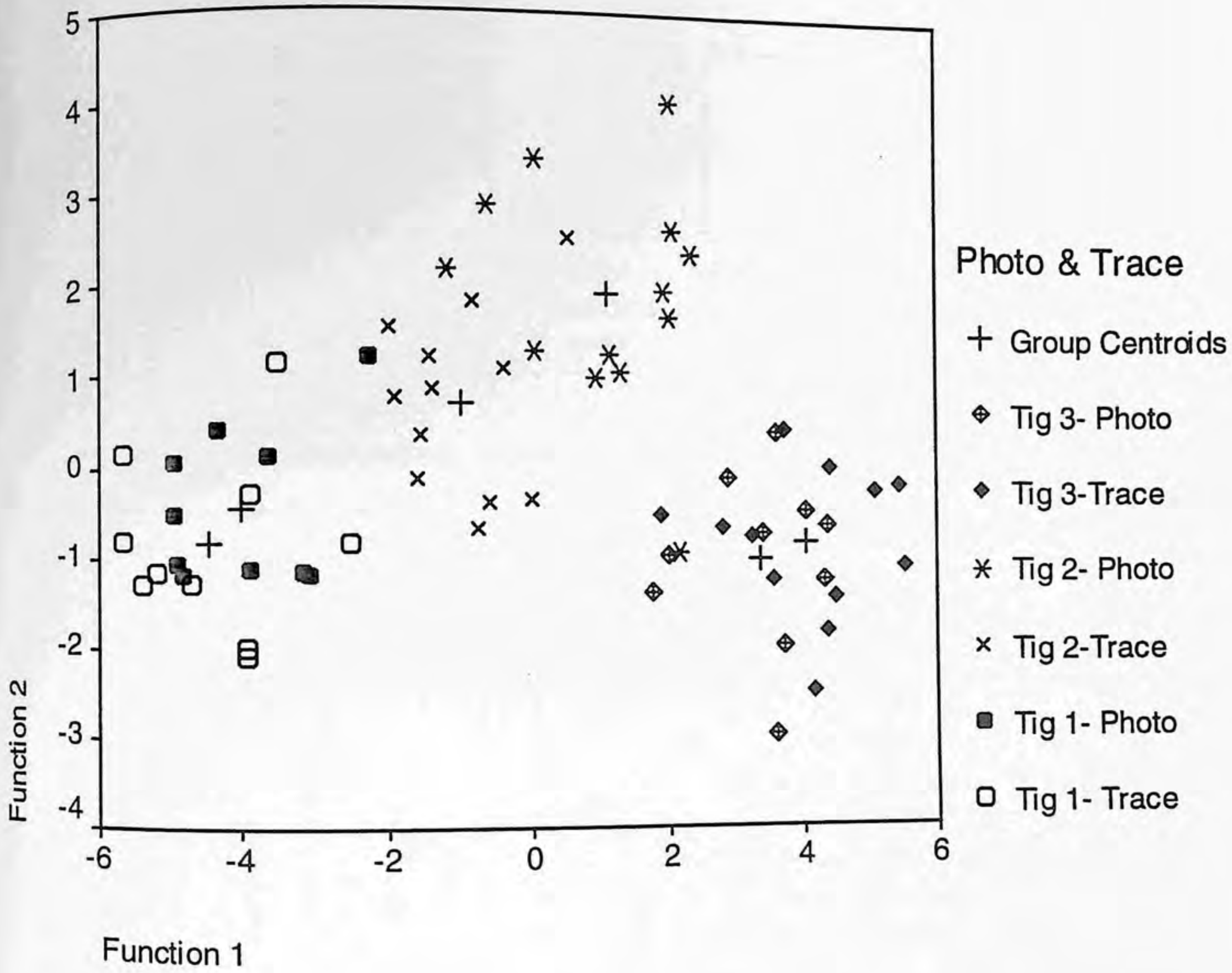


Figure. 19. Group centroids and pugmark clusters of 6 pugmark sets on canonical function axis, using 11 variables pooled for left and right pugmark. these six sets are from 3 different tigers and pairs of pugmark tracing and pugmark photograph are compared here.

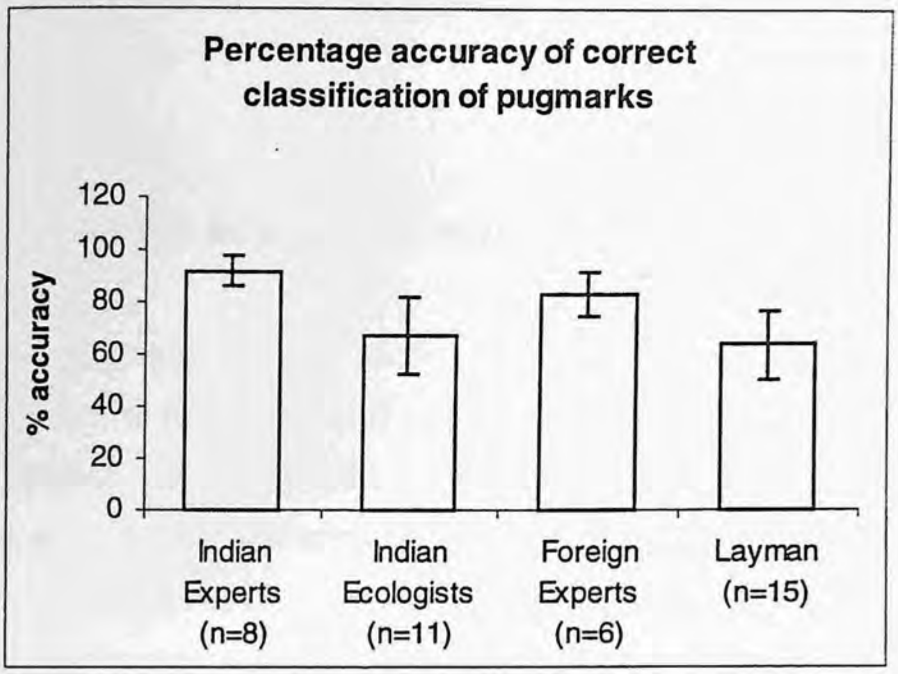


Figure 20. Classification accuracy of respondents of 'Expert System' evaluation, regarding the correct classification of pugmark tracings into the class of respective tiger.

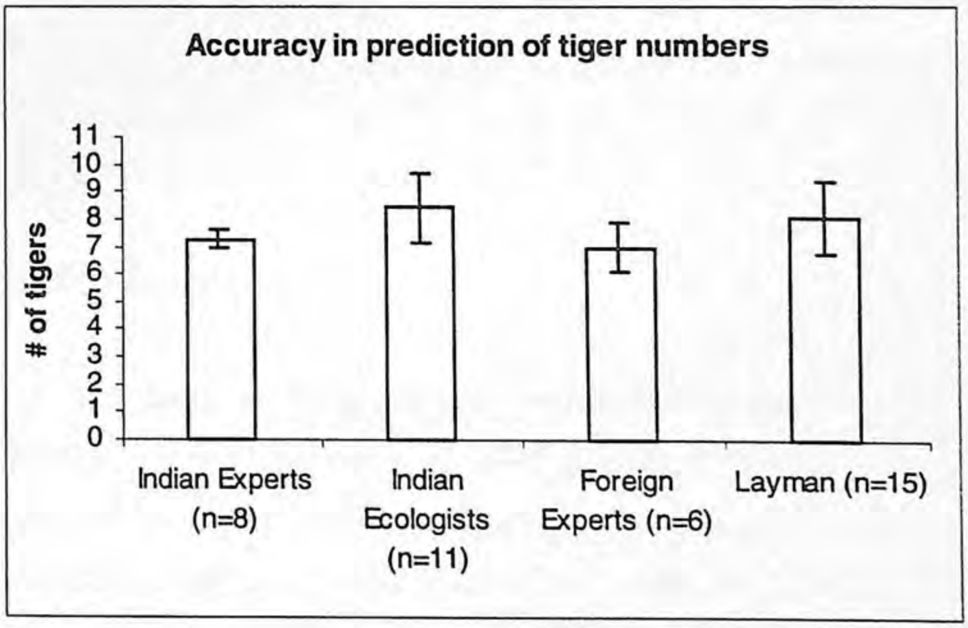


Figure 21. Accuracy in predicting correct number of tigers from given set of 15 pugmark tracings, for different classes of respondents, during 'Expert System' evaluation.

DISCUSSION

Tiger Pugmark as a 'Census Tool':

Pugmark census technique has been used for population estimation of the tigers in all tiger reserves, since the time of inception of 'Project Tiger'. My study objectives were to evaluate the basic premises of pugmark census technique. This technique believes that each tiger has unique pugmark features, and this information from each tiger's pugmark can be used for counting them. I tried to explore the information revealed in tiger pugmarks using statistical methods. I also looked upon the other factors, which were often been quoted to affect the shape and size of pugmark in the field conditions, and eventually to affect the 'census figures'.

The first objective of this study was to check if the tiger pugmarks had enough information to discriminate it from pugmarks of another tiger?

Variable Selection:

An array of variables was measured to extract out maximum information from geometry of tiger pugmark. Earlier experiment by Goate *et al.* (1989), Das and Sanyal (1995) and Gore *et al.* (1993) attempted to select out those variables which do not vary much within the same tiger's pugmark and give enough variation between the tigers. Gore *et al.* (1993) found that out of 36 variables used for analysis, 28 variables were found to be statistically robust for tracer's variation as well as pugmark to pugmark variation. Of the eight remaining variables, six showed significant difference between tracers and two showed significant replication effect. In an experiment to examine the effect of substratum, 32 variables turned out to be unaffected by the substrate. Eventually they gave a list of 26 variables, which they found to be fairly insensitive to extraneous factors and hence potentially useful for discriminating tigers.

Das and Sanyal (1995) suggested 18 variables as a robust set for differentiating tigers, on the basis of CV of those variables. Their results were based on only tracings prepared from plaster casts, and sample size was only two tigers. In case of gore *et al.* (1993) they did not mention, whether they have used the selected variables to discriminate any tigers in the field.

I did a rigorous exercise for variable selection and found 11 variables, which could discriminate 18 tigers with 100% accuracy and at the same time are significantly similar for left and right hind pugmark. These variables are also insensitive for a soil depth of 0.5 cm to 2 cm.

Identification of individual tiger:

Statistical methods have been used by biologists to discriminate between individual animals of a particular species. Smallwood and Fitzhugh (1993), Grigione *et al.* (1998), Lewison *et al.* (in press) have used DFA for discrimination of individual Mountain lion. DFA was also used by Jewell *et al.* (2001) to identify individual Black rhino. Zalewaski (1999) used DFA to discriminate between sexes and individuals of Pine Marten. DFA is also being used for discrimination of Jaguar (Carolyn Miller *pers. comm.*). Baysian statistics based classification technique and neural network based Self Organising Maps (SOMs) were used by Riordan (1998) to classify individual tigers and Snow leopards. Grigione and Burman (2000) used a new approach, shape analysis for pad, to discriminate between Individual Mountain lions. Das and Sanyal (1995) used cluster analysis to classify tracings into groups.

I used Stepwise Multiple Group Discriminant Function analysis for discriminating individual tigers on the basis of morphometric measurement of their pugmarks.

I found the technique very effective in discrimination of 18 tigers (maximum samples introduced for DFA) by using 11 parameters with the accuracy of 100% correct classification by direct as well as Jack-knifing of the data. Low sample size of the pugmarks per pugmark-set was found to hamper the discriminating efficacy of the DFA so we tried to pool left and right pugmark. It is also suggested by my study that left and right pugmarks can be pooled together for DFA. For DFA to work best, I recommend a minimum of 10-15 good quality pugmarks from a pugmark trail for pugmark-set.

Validation of the Technique:

I did cross validation of the DFA models by assigning pseudo ID's to pugmarks and looking for their classification. The DFA modals were found very accurate in classification of pugmarks. One more important conclusion came out of these exercise that only those pugmark sets which had less then five pugmarks (left as well as right) in the set, gave misclassification for the pugmarks and ambiguous classification for the series. So I suggest using at least 5 pugmarks to train the model, it would be better if more number of pugmarks are used for the training set. So ideally it would be best to collect 10-15 tracings of either pugmark from the field.

Sex-Discrimination of Tigers:

Some quantitative methods have also been used by researchers to discriminate between male and female tigers. All of them were working on the basic premise that pugmark of male tiger is supposed to be squarish while that of female is rectangular.

Sagar & Singh (1991) used '1.5 cm rule' to discriminate male and female. Gogate *et al.* (1989) suggested the use of angle between toe number two and three in pugmark as the sex discriminating criterion. Paranjape *et al.* (1993) tried the statistical discrimination of tiger pugmark by visual inspection of histograms of length, breadth and their differences of pugmark for judging the 'cut-off value' for sex-discrimination. They also used Bhattacharya technique (1967) and logistic regression for sex discrimination of tigers.

The technique given by Sagar & Singh (1991) was criticised for not being validated on known tigers (Gore *et al.*, 1993). Gore *et al.* (1993) attempted to validate the logistic regression technique on five known zoo animals. But till the present study no other study has used wild tigers for validation of sex discrimination model.

I used PCA, DFA and logistic regression. I found that by using only two parameter i.e. length and breadth of pugmark, I could discriminate sexes of a population of 10 wild tigers, whose sexes were known priori with 100% accuracy. I further tried to validate the model by introducing three tigers in model. The classification accuracy was 97.94%.

Effect of Extraneous Factors:

Effect of soil depth and variability due to tracers was also addressed during this study. The results indicate that there is no effect of soil on the selected 11 pugmark variable at the soil depth (range of 0.5 cm to 2 cm). DFA was done to validate this result, by grouping all the pugmark sets of the same tiger, which were picked up from different soil depths.

With three tracers and a set of seven pugmarks from two different tigers, tracers were found significantly different, while in another experiment where four tracers trace three pugmarks, no significant difference was found between tracers. So it is difficult to judge anything conclusive on this issue, without a proper sample size of pugmarks and tracers.

My results suggest that tracings should be done by trained personnel, with as small a number of tracers as possible within a protected area (if possible then by a single individual for a given area). This would reduce noise in the tracings that could creep in for subsequent analysis.

Comparison of Pugmark Tracing and Pugmark Photograph:

Variability in pugmark tracings due to tracer's effect was found to be significant in ANOVA results. However, DFA was unable to discriminate between three pairs of pugmark tracings and photographs suggesting that either could be used in the model.

'Census-Exercise':

For this exercise a typical field scenario of tiger census exercise was simulated, I used a blind set of 18 track-sets which were simulating a field census exercise condition, where the co-ordinator receives pugmarks whose identity is not known, and the task here is to get the total number of tigers after examining this tracings. Here in this 'census-exercise' I was intended to test the statistical model developed, over these pugmark sets and to estimate the number of tigers from these set.

The results showed that the model and census protocol was found 100% accurate in estimating the actual number of tigers from those 18 pugmark sets.

This result proved that the model and census protocol developed here could be tested in the field for a census-exercise.

'Expert-System' Evaluation:

Animal tracking was defined as an art of reconstruction of activity from the spoor of animals, it is an age old technique that is still frequently used by modern-day hunter-gatherer communities, world over (Stander et al., 1997). Stander et al (1997) tested the expertise of Ju/' Hoan tribes of Namibia for their skills of tracking and identification of individuals. The tribes were found to be 93.8% accurate in identification of individual animals. They also raised the issue of importance of tracking in wildlife conservation and management and the need for scientific validation of the art of tracking in terms of its reliability and potential scientific contribution to the biological sciences.

Tracking tigers for hunting was a tradition among Indian hunters which flourished under royal patronage (Sankhla 1978), this is also described as one of the ethnic methods used by tribal and *Shikaris* all over the India (Singh, 1999).

There were attempts made to test the 'Expert knowledge' involved in 'tiger number' estimation in India (Karanth, 1987). He conducted one experiment, where 7 field experts who had ≥ 6 years of field experience, were asked to segregate 33 tracings obtained from two different substrate, from four captive tigers. All participants of that blind test overestimated the tiger number by 6 to 24 tigers.

Smallwood & Fitzhugh (1993) also conducted a similar test with mountain lion tracks. They asked 52 respondents from various fields and experience level on mountain lions to discriminate the tracks and to identify three tracks that were from the same mountain lion in a given set of six tracks. None of the 52 respondents were able to successfully discriminate all the three tracks from the others, and the success rate for grouping of tracks into two groups was found not to vary with the tracking experience of the respondents.

In present study, a similar kind of test was attempted with Indian field experts, ecologists, laypersons and foreign field experts. Before conducting this test, I discussed the art of identifying individual tigers by pugmark with a few field experts. They all pointed out that field census method for tigers, is not solely based on pugmark tracings, but other field data related to gait of animals, substrate information, time and geographical information plays an important role in qualitative discrimination of tigers. So in this experiment gait measurements i.e. stride, step and straddle associated with each tracing, were provided to the respondents. It was also informed to the respondents that the tracings were traced from a control substrate.

The high level of accuracy of Indian field experts indicates that there is an 'art' that exist in form of individual identification technique for tigers, but to perfect this art, it needs rigorous field experience and knowledge of tiger's ecology. Not all Indian field managers assumed to have this perfection in pugmark based tiger identification.

Among the 6 foreign respondents, 5 do not have any experience about tiger pugmarks, but they do have experience about animal tracks (mountain lion, jaguars and black rhino) and its intricacies. The classification accuracy and prediction of accurate number of tigers by them shows that certainly some logic is linked to the 'art' of spoor based individual identification technique, but again it could be perfected with rigorous and prolonged field experience.

CONCLUSION

- I found that pugmarks have sufficient information to discriminate between the tigers. The statistical protocol developed in this study was found to discriminate a population of 17 tigers with 97.1% accuracy, by using only 11 variables and had 87.4% accuracy in leave one out classification.

- I identified 11 variables that permitted maximum discrimination and were found robust to pool left and right pugmark measurements and also to substrate variation between 0.5 cm to 2 cm soil depth.

- A tentative protocol was developed for estimation of tiger numbers from unidentified tiger pugmark sets. The protocol was found to be 100% accurate in estimating the actual number of tigers represented by a simulated population of pugmark sets from the study samples.

- The gender of a tiger could be inferred with fairly high accuracy (i.e. 98.1 % with leave one out classification in DFA model and 97.94% accuracy in logistic regression modal). Both of the models are found useful for field application.

- The study suggests that there is significant variation in pugmark tracings traced by different individuals and caution is suggested in using tracings done by several people for the use of population estimation of tigers.

- The study results show that certain experienced 'experts' were very accurate in identifying tigers from their pugmarks in a population of 15 pugmark tracings. Overall the number of tiger estimated by this expert group did not differ from the actual number of tigers represented by the pugmarks. However caution is suggested in interpreting numbers from pugmark tracings, since all decision-makers on tiger numbers did not have the same level of accuracy as our expert category.

- I suggest the use of pugmark as a population estimation tool with a few precautions, regarding the tracer's efficacy in the pugmark tracings and maintaining a PIP of given soil depth (between 0.5 cm to 2 cm). The statistical protocol developed in this study has potential for estimation of tiger population in a tiger reserve, where the substratum is conducive for the registration of tiger pugmark. 10 to 15 pugmarks of good quality are required from each tiger pugmark set for quantitative discrimination of individuals.

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Appendix 1. List of 93 pugmark and 3 gait variables used to extract maximum information from pugmark. 33 variables selected maximum CV-ratio and maximum F-ratio criteria are marked with * and 11 robust variables selected for final analysis are marked in bold.

1. Area of T1 *
2. Area of T2 *
3. **Area of T3***
4. Area of T4 *
5. Area of pad *

6. Shape factor: Pad
7. Shape factor: T1
8. Shape factor: T2
9. Shape factor: T3
10. Shape factor: T4

11. Compactness : Pad
12. Compactness: T1
13. Compactness: T2
14. Compactness: T3
15. Compactness: T4

16. Length of major axis of T1
17. Length of major axis of T2
18. Length of major axis of T3
19. Length of major axis of T4
20. Length of Major axis of pad *

21. Length of minor axis of T1 *
22. Length of minor axis of T2 *
23. **Length of minor axis of T3** *
24. Length of minor axis of T4 *
25. Length of Minor axis of pad *

26. Pug length *
27. **Pug width** *
28. Area of rectangle containing pug *

29. Distance of Pad centre to T1 centre
30. Distance of Pad centre to T2 centre
31. Distance of Pad centre to T3 centre
32. Distance of Pad centre to T4 centre

33. Distance T1 centre to T2 centre *
34. **Distance T2 centre to T3 centre** *
35. Distance T3 centre to T4 centre

36. Angle between PT1 to PT2 *

37. Angle between PT2 to PT3
38. Angle between PT3 to PT4

39. Area of pentagon Pad centre and toe centre *

40. Distance of N1 from pad centre
41. Distance of N2 from pad centre *
42. Distance between N1 and N2 *
43. Angle between N1 and N2

44. Length of major axis (through centre) of T1
45. Length of major axis (through centre) of T2 *
46. Length of major axis (through centre) of T3 *
47. Length of major axis (through centre) of T4
48. Length of major axis (through centre) of pad *

49. Length of minor axis (through centre) of T1 *
50. Length of minor axis (through centre) of T2 *
51. Length of minor axis (through centre) of T3 *
52. Length of minor axis (through centre) of T4 *
53. Length of minor axis (through centre) of pad *

54. Heel to lead toe length
55. Heel length *
56. Heel width *

Angle of centroids from direction of walk
57. For T1
58. For T2
59. For T3
60. For T4
61. For Pad

Distances of centroids from direction of walk
62. For T1 *
63. For T2 *
64. For T3
65. For T4
66. For Pad *

67. Distance main pad top to toe base-line *

Distances of toes to pad baseline
68. For T1 *
69. For T2 *
70. For T3
71. For T4

72. Main pad top angle

73. Inner toe spread angle

74. Outer toe spread angle- a
75. Outer toe spread angle-b

76. Ratio of pug length / pug width
77. Ratio of pug rect. area / pug pentagon area

78. Ratio of major & minor axis of T1
79. Ratio of major & minor axis of T2
80. Ratio of major & minor axis of T3
81. Ratio of major & minor axis of T4
82. Ratio of major & minor axis of pad

83. Ratio of area of T1 to pad
84. Ratio of area of T2 to pad
85. Ratio of area of T3 to pad
86. Ratio of area of T4 to pad

87. Ratio of area of T1 to pentagon
88. Ratio of area of T2 to pentagon
89. Ratio of area of T3 to pentagon
90. Ratio of area of T4 to pentagon
91. Ratio of area of pad to pentagon *

92. Ratio of area of pad to area of rectangle containing the pugmark
93. Ratio of area of pad to area of inner pentagon of the pugmark

Gait Parameters:

1. **Stride ***
2. Step *
3. **Straddle ***

Appendix. 2 . Territorial map for discrimination of 8 tigers, using 25 variables in DFA analysis.

Canonical Discriminant

Function 2

```
          -24.0     -16.0      -8.0        .0       8.0      16.0      24.0
            +---------+---------+---------+---------+---------+---------+
    24.0 + 12        23           36                                    +
         I 12        23            36                                   I
         I  12       23             36                                  I
         I  12        23             36                                 I
         I   12       23             36                                 I
         I   12       23              36                                I
    16.0 +    12    + 23      +        +36      +         +             +
         I    12        23               36                 *           I
         I     12       23                36                            I
         I     12       23                 36                           I
         I      12      23                 36                           I
         I       12     23                  366                         I
     8.0 +       12 +    23    +       +    388666        +             +
         I        12     23                38  88866                    I
         I        12     23               38      88666                 I
         I         12    23         *     378       888666              I
         I         12  *  23            3378           88866            I
         I          12    23            37778             88666    6666I
      .0 +    *     12    23 +        33*+78      +         +8886665555+
         I           12  223333     377  78    *              85555     I
         I           1222444444333337   78                   85         I
         I           1444      444477   78                  85          I
         I          14            4477 78                 885           I
         I         14               4478                 855            I
    -8.0 +        14+        *+       48        +       85  +           +
         I       14                    48              85               I
         I      14                     48            885                I
         I     14                       48          855                 I
         I    14                         48        85                *  I
         I   14                           48      85                    I
   -16.0 +  14      +         +        +  48    885         +           +
         I 14                              48 855                       I
         I14                                485                         I
         I4                                 45                          I
         I                                  45                          I
         I                                  45                          I
   -24.0 +                                 45                           +
            +---------+---------+---------+---------+---------+---------+
          -24.0     -16.0      -8.0        .0       8.0      16.0      24.0
                          Canonical Discriminant Function 1
```

Symbols used in territorial map

Symbol	Group	Label
1	1	
2	2	
3	3	
4	4	
5	5	
6	6	
7	7	
8	8	
*		Indicates a group centroid

Appendix 3: Discrimination function coefficients for 8 tigers, using 25 variables.

Classification Function Coefficients

	TIGER							
	1	2	3	4	5	6	7	8
LD23	-374.30	-337.54	-323.74	-398.73	-212.80	-160.34	-327.92	-292.09
LApn	-691.60	-713.96	-731.15	-728.93	-782.81	-770.28	-742.91	-754.48
LLT1	2019.02	2017.26	2102.84	2168.79	2398.29	2158.81	2149.54	2216.49
LLpd	1283.46	1244.26	1280.71	1340.16	1281.22	1191.75	1236.17	1268.50
LLpdD	3484.10	3647.81	3677.34	3633.69	3809.98	3859.22	3749.55	3780.41
LHLTL	1125.78	1161.25	1253.22	1191.22	1391.74	1433.93	1257.91	1302.98
LH	-991.58	-934.78	-1015.22	-1002.19	-924.21	-995.72	-933.03	-985.44
LCQT1	718.44	736.92	743.51	764.17	797.00	759.91	759.89	767.73
LRAT4pd	43209.65	44452.56	45114.99	45741.13	47465.31	46651.06	45814.02	46104.62
LRApdApg	-24281.58	-25352.74	-26040.18	-25608.23	-27766.66	-27981.26	-27021.44	-27283.22
Apd	-691.03	-716.12	-693.77	-685.84	-615.47	-686.99	-698.28	-676.80
Mit4	-1165.62	-1253.66	-1206.03	-1288.36	-1591.38	-1222.05	-1307.25	-1396.41
Apn	919.75	963.58	938.15	911.31	839.49	956.54	939.17	914.59
i2	1446.70	1474.02	1512.15	1514.75	1549.16	1558.61	1518.92	1531.92
CQT1	265.09	269.03	274.98	284.23	314.68	279.03	282.73	291.46
CDT1	2370.53	2434.20	2481.18	2522.14	2770.04	2578.99	2578.87	2637.22
RAT1pd	-14898.72	-15018.02	-15889.46	-16003.83	-18097.00	-16703.68	-16415.74	-16857.85
RApdpn	16197.23	16846.30	16422.51	15782.00	14263.90	16649.18	16317.41	15838.52
RApdApg	3999.24	3782.43	2454.01	3930.65	-304.65	-538.57	2457.04	1698.17
(Constant)	-66340.15	-70020.73	-71498.89	-72261.22	-77530.51	-76088.93	-73334.92	-74719.16

Fisher's linear discriminant functions

Appendix 4. Territorial map for discrimination of 18 tigers, using 33 variables in DFA analysis.

(Assuming all functions but the first two are zero)
Canonical Discriminant

```
Function 2
      -24.0     -16.0     -8.0       .0       8.0      16.0      24.0
        +---------+---------+---------+---------+---------+---------+
  24.0 +                 56                        6E              EG+
       I                 56                        6E             EEG I
       I                 56                        6E            EEGG I
       I                 56                       6DDEE         EGG   I
       I                 56                       6D DDE      EEG     I
       I                 56                      6D    DEEEEGG        I
  16.0 +         +      5886 +       +          +6D     DDGG          +
       I               58  866                  6D       DG           I
       I    *      55558    886                 6D    DDDG            I
       I     5555552228        866    *        6DDDDDDFFFG            I
       I5555222222  28          886            6DFFFFF   F*           I
       I2222        28            8666666     6FF         FG          I
   8.0 +       *   +28      +     87777776666666F +     * +FG         +
       I            28          887       7777777F         FG         I
       I           28      **877                7F          FG  *     I
       I           28      877                  70F          FG       I
       I           28    887                    70F   *     *  FG     I
       I          28    877        *            70F              FG   I
    .0 +          28  887   +        * +      779FF         +    FG   +
       I        222CC88877                  77799 99F              FG I
       I   222CCC  CCCCC777               77999     9FF             FG I
       I222CCC              CCC777      7799       99F              FG I
       ICCC                   CCC777  7799            9FF           FG I
       I                        *CCC7799               99F           FGI
  -8.0 +         +         +    C9   +   *     +        9FF+           F+
       I                         C9    *                 99F            I
       I                    *    C9 *                      9FF          I
       I                          C9                        99F         I
       I                          C9                          9F        I
       I                          C9 *                         9FF      I
 -16.0 +         +         +       C9999         +        +    99F      +
       I                          CBBBBB9999                       9FF I
       I                         CB     BBBB9999                   99FI
       I                        CB          BBBB9999                 9I
       I                       CB               BBBB9999             I
       I                      CB                    BBBB9999         I
 -24.0 +                      CB                        BBBB9999     +
        +---------+---------+---------+---------+---------+---------+
      -24.0     -16.0     -8.0       .0       8.0      16.0      24.0
                         Canonical Discriminant Function 1
```

```
Symbols used in territorial map
Symbol  Group  Label                              1        1
  2       2
  3       3
  4       4
  5       5
  6       6
  7       7
  8       8
  9       9
  0      10
  A      11
  B      12
  C      13
  D      14
  E      15
  F      16
  G      17
  H      18
  *
                Indicates a group centroi
```

Appendix 5. Territorial map for discrimination of 17 tigers, using 11 variables in DFA analysis.

```
Canonical Discriminant
Function 2
        -12.0     -8.0      -4.0        .0       4.0       8.0      12.0
          +---------+---------+---------+---------+---------+---------+
     12.0 +                          FC         CD                   D+
          I                         FC          CD                  D5I
          I                         FC         CD                  D5 I
          I                        FC          CD                D5   I
          IFF                      FC          CD               D5    I
          IEEFFFFFFFFFF            FC         CD               DD5    I
      8.0 + EEEEEEEEEEFFFFFFFFFF  FC    +     CD +         +  D55     +
          I           EEEEEEEEEEF*FFC         CD             D5       I
          I                     EEEEC    *   CD             D5        I
          I                         EC     * CD            D5         I
          IEE                    *  EC       CD           D5          I
          IAAEEE                     EC     CD          DD5           I
      4.0 + AAAEEE  +         +      EC +   CD    +  DDD85 +          +
          I    AA9EEEEEEEE            EC    CDDDDDDDD88885            I
          I     A99999999EEEEEEE    EEECCCCCCDD7777788   85           I
          I      A9       9999999EEEHHHHHHHHH77    78    85           I
          I       A9             99H       H7      78    85           I
          I       A9               9H     HH7   *  78     85   *      I
       .0 +        A9         +  * 9H   *H117     + 78    85          +
          I         A9        *    9H  HH1*7  *    * 78   85          I
          I          A9            9H H11 17     *   78   88555       I
          I         * A9           9HH1   17         78 882222255555  I
          I           A99999*99999991111117          738822    2222255I
          I           A000000000BBBBB4444447777      7322           22I
     -4.0 +         + A0  000BBB     B4 +   44447777732     +         +
          I           A000BBB         B4  *     444422     *          I
          I          A0BBB       *    B4           42                 I
          I         ABB               B4           42                 I
          I        AB                  B4          42                 I
          I       AB                   B4          42                 I
     -8.0 +      AB+          +         B4        +42       +         +
          I     AAB                     B4         42                 I
          I    ABB                       B4        42                 I
          I   AB                         B4        42                 I
          I  AB                           B4       42                 I
          I AB                            B4       42                 I
    -12.0 +AAB                            B4       42                 +
          +---------+---------+---------+---------+---------+---------+
        -12.0     -8.0      -4.0        .0       4.0       8.0      12.0
                            Canonical Discriminant Function 1
```

Symbols used in territorial map

Symbol	Group	Label
1	1	
2	2	
3	3	
4	4	
5	5	
6	6	
7	7	
8	8	
9	9	
0	10	
A	11	
B	12	
C	13	
D	14	
E	15	
F	16	
G	17	
*		Indicates a group centroid

Appendix 6. Discrimination function coefficients for sex discrimination 10 tigers, using 9 variables.

Classification Function Coefficients

	SEX	
	1	2
LPG	-7.96E-02	1.887
WPG	-1.092	2.646
(Constant)	-.503	-4.899

Fisher's linear discriminant functions

Appendix 7. Classification accuracy matrix for sex discrimination 10 tigers, using 9 variables.

Classification Results [b,c]

		SEX	Predicted Group Membership 1	Predicted Group Membership 2	Total
Original	Count	1	84	0	84
		2	0	22	22
	%	1	100.0	.0	100.0
		2	.0	100.0	100.0
Cross-validated [a]	Count	1	84	0	84
		2	0	22	22
	%	1	100.0	.0	100.0
		2	.0	100.0	100.0

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 100.0% of original grouped cases correctly classified.

c. 100.0% of cross-validated grouped cases correctly classified.

Appendix 8. Discrimination function coefficients for sex discrimination modal validation for 13 tigers, using 2 variables.

Classification Function Coefficients

	PSEUDO	
	1.00	2.00
LPG	-7.96E-02	1.887
WPG	-1.092	2.646
(Constant)	-.503	-4.899

Fisher's linear discriminant functions

Appendix 9. Classification accuracy matrix for sex discrimination modal validation for 13 tigers, using 2 variables.

Classification Results [b,c]

			Predicted Group Membership		
		PSEUDO	1.00	2.00	Total
Original	Count	1.00	84	0	84
		2.00	0	22	22
		Ungrouped cases	17	8	25
	%	1.00	100.0	.0	100.0
		2.00	.0	100.0	100.0
		Ungrouped cases	68.0	32.0	100.0
Cross-validated [a]	Count	1.00	84	0	84
		2.00	0	22	22
	%	1.00	100.0	.0	100.0
		2.00	.0	100.0	100.0

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 100.0% of original grouped cases correctly classified.

c. 100.0% of cross-validated grouped cases correctly classified.

Appendix 10. Discriminant fumctions matrix for soil depth DFA modal.

Classification Function Coefficients

	TIGER				
	1.00	2.00	3.00	5.00	6.00
AT1	55.462	55.236	56.647	52.795	58.461
WPG	106.182	104.189	104.375	103.401	118.247
Q23	2498.407	2470.619	2413.328	2186.071	2394.921
DN1N2	-116.123	-109.885	-109.244	-132.164	-137.885
HLTL	-102.418	-100.198	-99.226	-83.103	-96.591
H	238.676	236.457	240.973	199.510	228.572
STRIDE	67.333	66.133	66.588	63.490	66.452
(Constant)	-5134.455	-4982.422	-5039.435	-4537.379	-5095.624

Fisher's linear discriminant functions

Appendix 11. Classification accuracy matrix for soil depth DFA modal.

Classification Results[b,c]

			Predicted Group Membership					
		TIGER	1.00	2.00	3.00	5.00	6.00	Total
Original	Count	1.00	4	2	0	0	0	
		2.00	2	4	0	0	0	
		3.00	1	1	8	0	0	1
		5.00	0	0	0	10	0	1
		6.00	0	0	0	0	10	1
	%	1.00	66.7	33.3	.0	.0	.0	100.
		2.00	33.3	66.7	.0	.0	.0	100.
		3.00	10.0	10.0	80.0	.0	.0	100.
		5.00	.0	.0	.0	100.0	.0	100.
		6.00	.0	.0	.0	.0	100.0	100.
Cross-validated[a]	Count	1.00	2	2	2	0	0	
		2.00	2	2	2	0	0	
		3.00	1	1	8	0	0	1
		5.00	0	0	0	10	0	1
		6.00	0	0	0	0	10	1
	%	1.00	33.3	33.3	33.3	.0	.0	100.
		2.00	33.3	33.3	33.3	.0	.0	100.
		3.00	10.0	10.0	80.0	.0	.0	100.
		5.00	.0	.0	.0	100.0	.0	100.
		6.00	.0	.0	.0	.0	100.0	100.

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classifi the functions derived from all cases other than that case.

b. 85.7% of original grouped cases correctly classified.

c. [illegible]

Appendix 12. Territorial map for soil depth DFA modal.

```
(Assuming all functions but the first two are zero)
Canonical Discriminant
Function 2
    -12.0      -8.0      -4.0        .0       4.0       8.0      12.0
       +---------+---------+---------+---------+---------+---------+
  12.0 +                                                           +
       I5                                                          I
       I455                                                        I
       I 445                                                       I
       I   455                                                     I
       I    445                                                    I
   8.0 +      455 +         +         +         +         +        +
       I       4455                                                I
       I         445                                             55I
       I           455                                        55511I
       I            445                                    555111 I
       I              455                 *             555111    I
   4.0 +         +     4455 +         +         +    5555111       +
       I                 445                      5551111          I
       I                   455                 555111              I
       I                    445            5555331                 I
       I                      455      55553333 31                 I
       I                       4455 55553333     31                I
    .0 +         +         +     4453333         31         +      +
       I                          4333           31                I
       I              *            4222333    * * 31               I
       I                           42  2223333  31                 I
       I                           42     22223331                 I
       I                           42         2221                 I
  -4.0 +         +         +       42  +        21          +      +
       I                           42            21                I
       I                           42            21                I
       I                          42              21               I
       I                          42              21               I
       I                          42              21               I
  -8.0 +         +         +      42  +         + 21        +      +
       I                          42               21              I
       I                          42                21             I
       I                          42                21             I
       I                          42                21             I
       I                          42                 21            I
 -12.0 +                          42                 21            +
       +---------+---------+---------+---------+---------+---------+
    -12.0      -8.0      -4.0        .0       4.0       8.0      12.0
                        Canonical Discriminant Function 1
```

Symbols used in territorial map

```
Symbol  Group  Label
------  -----  --------------------

  1       1
  2       2
  3       3
  4       5
  5       6
* Indicates a group centroid
```

Appendix 13. Discriminant function coefficients for DFA analysis of pugmark tracing and photo comparison.

Classification Function Coefficients

	F10					
	1.00	2.00	3.00	4.00	5.00	6.00
AT1	2.975	3.066	2.956	4.943	5.775	6.079
Wpg	73.528	75.468	83.414	87.118	84.423	83.027
D23	-65.131	-69.596	-68.398	-63.987	-55.505	-52.329
Q23	1086.504	1125.501	1181.019	1174.736	1193.361	1145.460
DN1N2	68.385	68.278	70.862	74.278	86.890	85.692
HLTL	37.300	39.157	40.336	35.823	40.237	37.538
H	81.347	80.170	82.977	93.286	92.799	91.734
(Constant)	-805.038	-839.948	-971.361	-1034.106	-1134.089	-1080.054

Fisher's linear discriminant functions

Appendix 14. Classification accuracy matrix for DFA analysis of pugmark tracing and photo comparison.

Classification Results[b,c]

			Predicted Group Membership						
		F10	1.00	2.00	3.00	4.00	5.00	6.00	Total
Original	Count	1.00	7	3	0	0	0	0	1
		2.00	4	5	1	0	0	0	1
		3.00	0	0	12	0	0	0	1
		4.00	0	0	0	12	0	1	1
		5.00	0	0	0	0	11	1	1
		6.00	0	0	0	0	1	9	1
	%	1.00	70.0	30.0	.0	.0	.0	.0	100.
		2.00	40.0	50.0	10.0	.0	.0	.0	100.
		3.00	.0	.0	100.0	.0	.0	.0	100.
		4.00	.0	.0	.0	92.3	.0	7.7	100.
		5.00	.0	.0	.0	.0	91.7	8.3	100.
		6.00	.0	.0	.0	.0	10.0	90.0	100.
Cross-validated[a]	Count	1.00	5	5	0	0	0	0	1
		2.00	5	4	1	0	0	0	1
		3.00	0	1	10	1	0	0	1
		4.00	0	0	3	9	0	1	1
		5.00	0	0	0	0	10	2	1
		6.00	0	0	0	0	7	3	1
	%	1.00	50.0	50.0	.0	.0	.0	.0	100.
		2.00	50.0	40.0	10.0	.0	.0	.0	100.
		3.00	.0	8.3	83.3	8.3	.0	.0	100
		4.00	.0	.0	23.1	69.2	.0	7.7	100.
		5.00	.0	.0	.0	.0	83.3	16.7	100.
		6.00	.0	.0	.0	.0	70.0	30.0	100.

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. 83.6% of original grouped cases correctly classified.

Appendix 15. Territorial map for discrimination of 17 tigers, using 11 variables in DFA analysis.

```
(Assuming all functions but the first two are zero)
Canonical Discriminant
Function 2
      -6.0      -4.0      -2.0        .0       2.0       4.0       6.0
       +---------+---------+---------+---------+---------+---------+
   6.0 +       23    34                                            +
       I       23     34                                           I
       I        23     34                                          I
       I         23     34                                         I
       I         23     34                                         I
       I          23     34                                       4I
   4.0 +         +23      34           +        +         +      45+
       I           23      34                                   445 I
       I            23      34                                 455  I
       I            23       34                              445    I
       I             23       34                           4455     I
       I              23       34                          455      I
   2.0 +          +   23   +    34   +    *    +         445        +
       I               23        34                     455         I
       I                23        34                  445           I
       I2               23         34                455            I
       I12               23    *    34             445              I
       I 122              23         34          44665              I
    .0 +  112      +      23         +34     44466  65    +         +
       I    12     *       23          34  44666    65              I
       I     122            23          34466        65   *         I
       I      11*           23          366          6*             I
       I        122          23         36            65            I
       I         112          23       36             65            I
  -2.0 +          +122    +   23     + 36      +       65+          +
       I            112        23     36               65           I
       I              122       23   36                65           I
       I               112      23   36                 65          I
       I                 122     23 36                  65          I
       I                  112     236                    65         I
  -4.0 +          +         122   236+         +         65         +
       I                     112   26                     65        I
       I                       122 26                     65        I
       I                        11226                      65       I
       I                          126                      65       I
       I                           16                      65       I
  -6.0 +                           16                       65      +
        +---------+---------+---------+---------+---------+---------+
       -6.0      -4.0      -2.0        .0       2.0       4.0       6.0
                         Canonical Discriminant Function 1
```

-

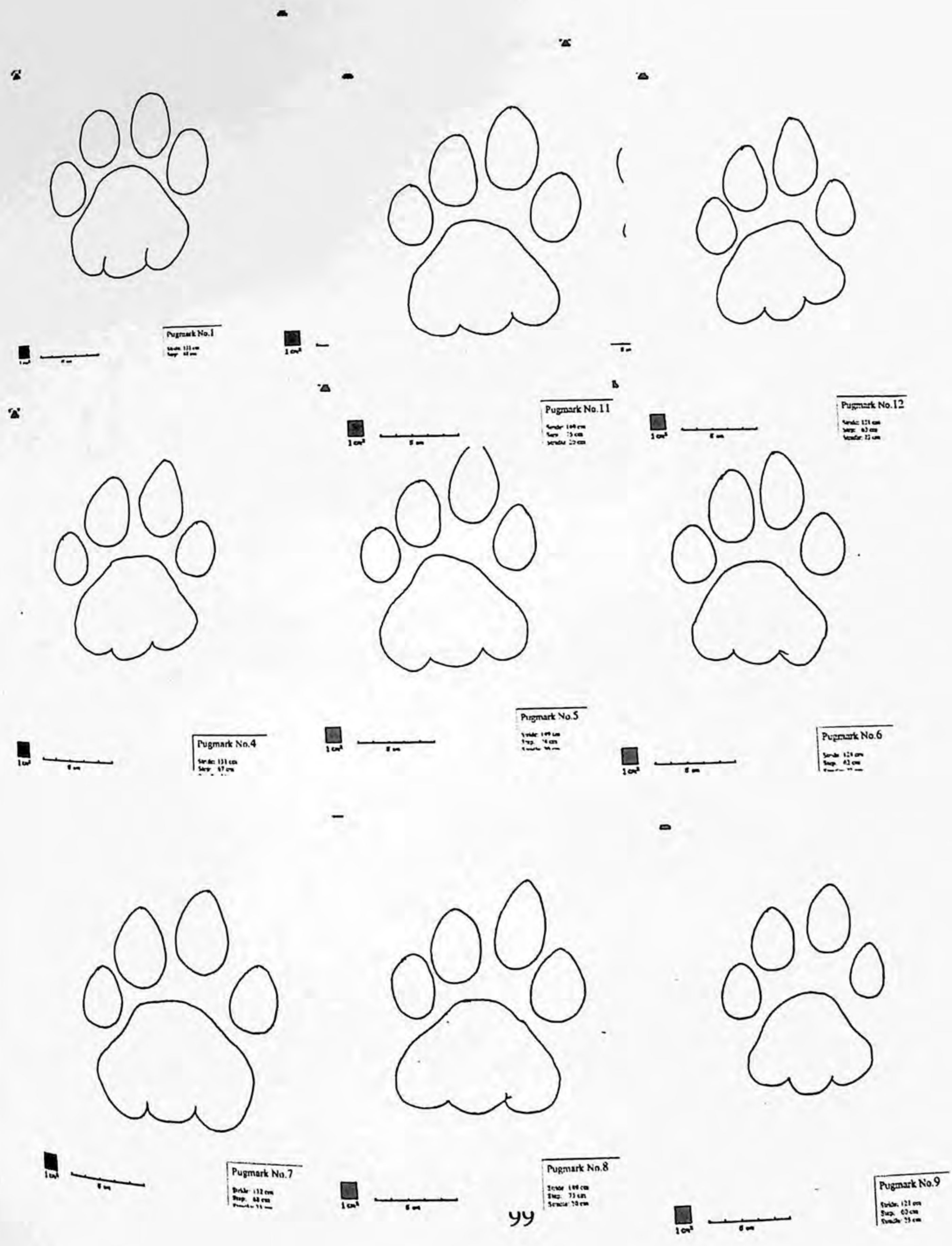
Symbols used in territorial map

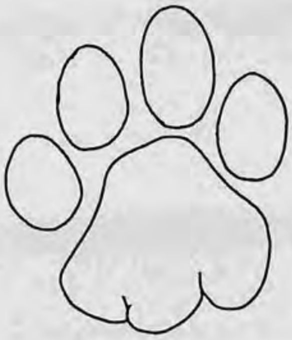
```
Symbol  Group  Label
------  -----  --------------------

  1       1
  2       2
  3       3
  4       4
  5       5
  6       6
```

* Indicates a group centroid

Appendix 16. The tiger pugmark tracing set used for 'Expert system' evaluation.

Can you identify numbers of tigers by visual inspection of given pugmark tracings?





Pugmark No.10

Pugmark No.11

Pugmark No.12

Pugmark No.13

Pugmark No.14

Pugmark No.15

Appendix 17. The 'Questionnaire' provided to the respondents of "Expert-system' evaluation.

Your name please:

Please put X in the front of your response and write wherever necessary.

- Do you believe that tiger pugmark is unique in terms of its features to an individual?

  (a) Yes (b) No (c) can't say

  If yes, then do you believe that pugmarks can be used for 'census' of tigers.

  (a) Yes (b) No

- Have you used tiger pugmarks for censusing tigers?

  (a) Yes (b) No

  If yes, please indicate your involvement in 'Tiger Census'.

  (a) < 5 years
  (b) 5- 10 years
  (c) 10-15 years
  (d) 15-20 years
  (e) > 20 years

- Do you consider yourself *excellent / good / satisfactory / poor* in identifying tiger by Pugmark? (*Please do not be modest while answering this*)

- In a few lines, please tell us about your profession/ interests in this and related fields.

- What is your opinion on the way the Tiger Census is currently conducted? In your opinion are any improvements desired. Please elaborate?

- Please tick one of the following:

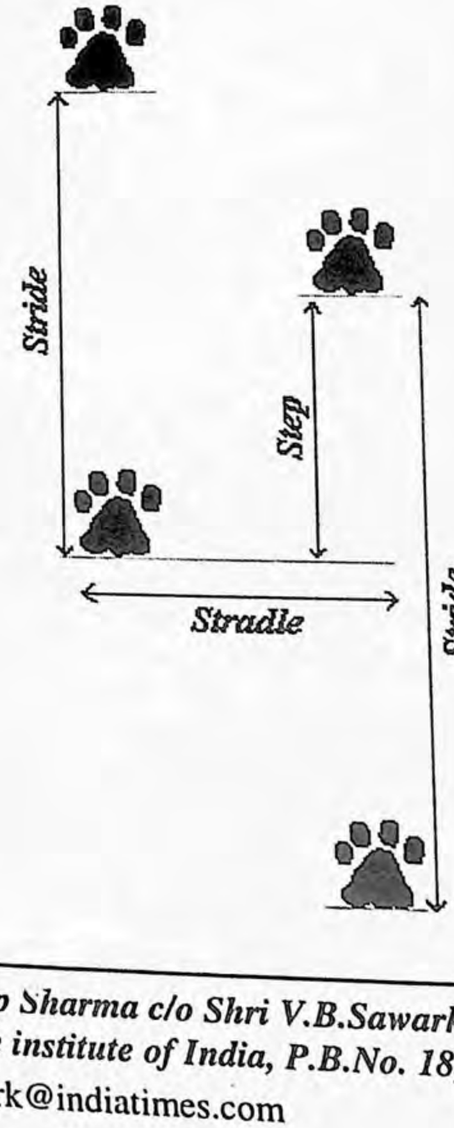
  (a) Please keep my identity confidential.

  (b) I do not mind my identity being revealed with reference to this study.

It is to assure you that we will strictly go by the professional ethic and honor your requirements as under (a) or (b) above.

Gait measurements of the tigers:

Pugmark No.	Stride	Step	Stradle
1	132	68	33
2	123	64	23
3	138	70	27
4	131	67	24
5	149	74	20
6	124	63	23
7	132	68	33
8	149	73	20
9	123	60	25
10	130	66	34
11	149	75	20
12	131	63	23
13	139	70	29
14	120	61	21
15	147	75	20



Please address your reply to: *Sandeep Sharma c/o Shri V.B.Sawarkar,*
Wildlife institute of India, P.B.No. 18, Chandrabani, Dehradun ,248001
e-mail : pugmark@indiatimes.com