# Monitoring Tigers in Ranthambhore National Park using the Digital Pugmark Technique

## 6th – 20th May 2005

**Report prepared for:**

**Empowered Committee on Forests & Wildlife Management**
**Government of Rajasthan**

WILDLIFE PROTECTION SOCIETY OF INDIA

***Disclaimer***

*The authors of this report explicitly wish to state that the Digital Pugmark Technique carried out in Ranthambhore, the results of the findings, and this report in no way endorses other work done on pugmarks, and in particular the traditional plaster cast and tracing method. We would like to emphasise that the results in this report were possible because of the ideal conditions in Ranthambhore, trained personnel, excellent cooperation from the management, and the large amount of good data that was collected.*


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Sharma, S., & Wright, B. (2005). *Monitoring Tigers in Ranthambhore using the Digital Pugmark Technique*, Wildlife Protection Society of India.

**The Empowered Committee on Forests and Wildlife Management** was constituted by the Honourable Chief Minister of Rajasthan in February 2005. The Committee's reference was to look into various problems in Keoladeo Ghana National Park, Sariska Tiger Reserve and Ranthambhore National Park. The Committee was directed to come up with a set of concrete and practical recommendations that the Government of Rajasthan would consider with a view to improving the existing situation. The Empowered Committee members are:

Shri V.P. Singh, Hon'ble M.P. (Chairman)
Shri Bharat Singh, MLA
Ms Belinda Wright
Shri Valmik Thapar
Shri Rajpal Singh Tanwar
Dr V.B. Mathur
Shri R.P. Kapoor, PCCF Rajasthan (Member Secretary)

In the Empowered Committee's effort to be as thorough and as transparent as possible it decided to adopt a number of methods for the 2005 tiger census in Ranthambhore National Park. The Wildlife Protection Society of India was invited by the Committee to carry out the Digital Pugmark technique as a part of the official census. It is the first time this technique has been used to assess the tiger population of a protected area.

## CONTENTS

## Summary

During the May 2005 tiger population estimation exercise in Ranthambhore National Park, extensive data was collected and analysed using the Digital Pugmark technique, the software PUGMARK 1.0. It was found that there were 26 distinct individual tigers in Ranthambhore; six adult males, fifteen females and five cubs.

## Introduction

Estimation of the number of individuals of a species in a population is an important function in the field of ecology and wildlife conservation. Population estimates of any species are required to formulate a conservation strategy, prioritise and allocate resources, evaluate the success of conservation programs, and also for political reasons. The tiger (*Panthera tigris*) is considered an icon for conservation in all the ecosystems where it occurs. Due to its endangered and flagship status, accurate and reliable population estimates are critical for implementation and assessment of conservation measures and management practices.

**Ranthambhore Fort & Jogi Mahal**

After the debacle in Sariska National Park, there were fears that Ranthambhore had also suffered from inflated census figures and perhaps large-scale tiger poaching. A new and more transparent approach was needed to establish existing tiger numbers in Ranthambhore. One of India's best known tiger reserves, Ranthambhore lies at the junction of the Aravalli and Vindhya Ranges. Its stunning topography consists of steep gorges, narrow ravines and windswept plateaus. Ranthambhore National Park (282 sq km) constitutes the core area of the 1,394 sq km Tiger Reserve, and its rich bio-diversity is one of finest examples of a Northern Tropical Dry Deciduous Forest. The official tiger census of May 2004 reported 45 to 47 tigers in Ranthambhore Tiger Reserve, of which 39 to 41 tigers were reported from within the National Park. However, in 2005 there were no confirmed reports of tigers outside the boundary of the National Park (FD, Ranthambhore TR, *pers. comm.*).

The Empowered Committee on Forests and Wildlife Management, which was constituted by the Honourable Chief Minister of Rajasthan in February 2005, decided to adopt a multi-pronged approach to estimate the tiger population in Ranthambhore National Park. The Committee proposed that three different methods should be used: (1) Plaster cast and pugmark tracing method (used traditionally by the Forest Department), (2) Camera traps (conducted by Wildlife Institute of India), and (3) Digital Pugmark technique (conducted by Wildlife Protection Society of India).

The 2005 tiger census in Ranthambhore took place from 6$^{th}$ to 20$^{th}$ May. Around 400 pugmark impression pads (PIPs) were prepared by the authorities for the census, each located on a road or a trail that had a high probability of a tiger walking there. A PIP consists of an area approximately 6 metres long and as wide as the road (~2.5 m), where the soil is finely pulverized to an optimal soil depth of 0.5 to 1 cm, in order to provide the best possible surface for recording pugmark impressions.

This was the first time that the Digital Pugmark technique had been used to monitor and estimate a single tiger population in a protected area. The objective was to take digital photographs of fresh pugmarks on PIPs and on trails where good quality pugmarks could be obtained. The basic premise for this new approach for tiger population estimation is extracting quantitative information from sets of pugmarks using the software PUGMARK 1.0 (Sharma, 2002), and then estimating the tiger population figure using the statistical approach.

## Digital Pugmark Technique

Traditionally tiger censuses in India have been carried out by collecting plaster-of-Paris casts and hand tracings of pugmarks (usually of a tiger's left hind foot) found in an area during a specified time. These are then analysed, along with movement and other data, to deduce the tiger population. However, this method has long been criticised by scientists and conservationists for being too subjective and open to error.

The Digital Pugmark technique is also based on the theory that each tiger leaves a distinctive set of pugmarks. The difference is that the use of the software PUGMARK 1.0 eliminates human error. Digital photographs of a series of pugmarks and stride and straddle measurements, where a tiger has walked in a normal gait, and a GPS location, are taken from a single pugmark trail. This data is then entered into a computer which calculates the values of several variables from the photographs. Statistical analysis of the data creates a 'profile' of the tiger, which can be used to identify it from other pugmarks.


**PUGMARK 1.0**

Twelve predictor variables are used to accurately identify individual tigers from their pugmark impressions. It is important to note that an entire pugmark set (a series of continuous pugmarks made by the same tiger) provides the identity of a tiger, i.e. the accuracy depends on data from a set of pugmarks, and not an individual pugmark.

PUGMARK 1.0 was designed and programmed by Sandeep Sharma in 2002, while he was a student at the Wildlife Institute of India. The design of the software also formed a part of Sharma's Advanced Diploma in Information Technology at the Centre for Development of Advanced Computing, Pune. The software was further developed with support from the Wildlife Protection Society of India.

The software PUGMARK 1.0 was developed using Visual Basic 6.0. It can be used for pugmark image analysis and pugmark database management. The software is equipped with self-explanatory GUI (Graphical User Interface) to make it user-friendly. The PUGMARK 1.0 software has been registered for copyright. For additional information the software author can be contacted at Email: <san_cobra@rediffmail.com>.

## Sampling methodology

In Ranthambhore we divided the entire national park into 5 different zones, i.e. Jogi Mahal (which included Jhalra, Nalghati, Ran, Sultanpur, Rajbagh, Milik Talao, Manduk, Kukraj Top, Phuta kot, Singh Dwar, Tambakhan, Tutti-ka-nala, Sonkutch, Patwa Baori, and Guda), Anatpura I and Anatpura II (which included Bhir, Dhundarmal Darra, Chiroli, Bakola, Lakarda, High Point, Semli, Berda, Bandarwal Baori, Kachida, Bagda and Bhootkhora), and Lahpur and Thumka (which included Jailkho, Sakri, Kukraj, Khatola, Chindawali, Odhi Khoh, Indala, Peeli talai, Sarkari talai and Galai Sagar).

**Sharma explaining the DP technique to Forest staff**

To cover these five regions, two teams with digital cameras were based at Anatpura, two at Lahpur, and one at Jogi Mahal. The Forest Guards of each region would inform the nearest camera team by wireless handsets once they found a set of tiger pugmarks during their morning census survey. For the Digital Pugmark technique at least 10 good hind pugmarks (left as well as right) are required to be photographed from a set of tracks. Similarly 10 measurements of gait variables, i.e. stride and straddle, must also be recorded from the same pugmark trail.

After arriving at the site and selecting the best pugmarks for digital photography, the following steps were undertaken by the teams and the results noted on prescribed data sheets:

1. Switch on the GPS to calculate an accurate position.
2. Lay ruler on ground with centimetre side next to pugmark, and take digital photograph.
3. Repeat step 2 for at least 10 pugmarks, ensuring ruler is visible in all photographs.
4. Insert ruler into soil to measure depth, and note texture & moisture.
5. Measure stride – the distance between two successive pugmarks on the same side – by placing a steel measuring tape on the base of the pad of the pugmarks.
6. Measure straddle – the perpendicular distance between the left and right hind pugmarks - by placing the tape on its edge and pressing it into the soil to make a straight line between the outer edges of the trail of the hind pugmarks.
7. Repeat steps 5 & 6 for successive pugmarks on both sides, to obtain series of stride and straddle measurements (10 each).
8. Note GPS location and remaining information, including direction of pugmarks.

The procedure takes about 15 minutes. The camera teams also informally recorded sightings, alarm calls, scats and kills.

Good communication between field staff and prompt mobility by vehicles and motorbikes provided by the Forest Department enabled us to collect a large amount of pugmark data. Every alternate day, the Coordinator would collect the data sheets from the field camps and download the photographs from the camera memory cards into a laptop. The pugmark dataset information and the photographs were then catalogued to the respective pugmark sets on a daily basis for analysis.

Tigress in Ranthambhore, May 2005

## Analytical Technique

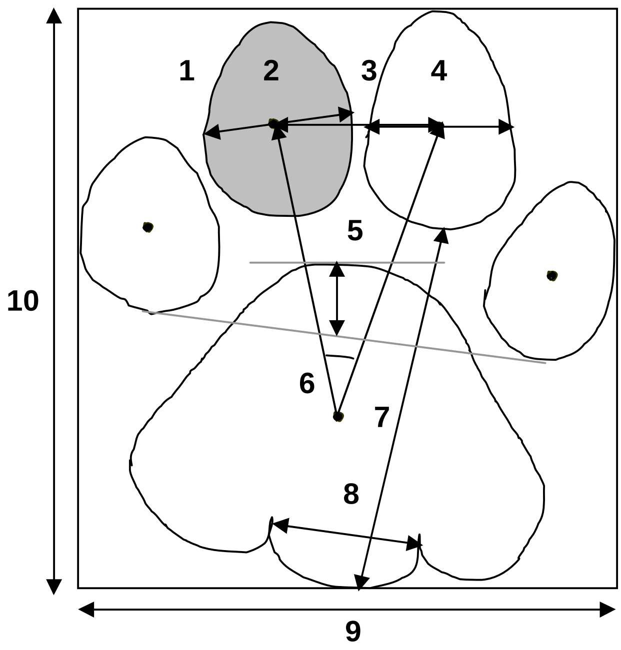
The paragraph given below briefly explains the analytical method adopted for the Digital Pugmark technique for the tiger population estimation in Ranthambhore. For further details about the technique please refer to the published paper (Sharma *et.al. Identification of Individual Tigers from their Pugmarks.* Journal of Zoology, in press) attached to this report.

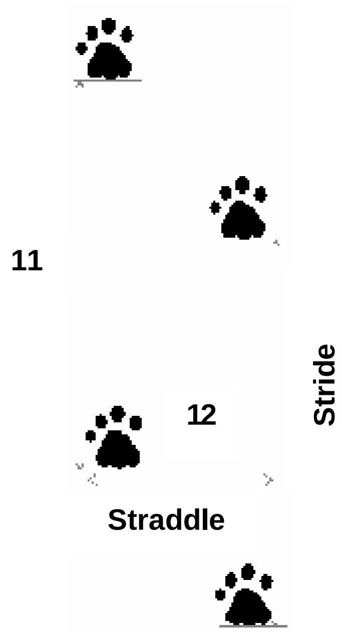
The digital pugmark photographs taken from the field were scrutinised for quality and minimum sample requirement, per pugmark set of an individual tiger, before proceeding to the variable extraction process. The pugmark photographs were also digitally enhanced in terms of brightness and contrast, if required.

We measured 10 different predictor variables (shown in the following figure) from the pugmarks using the software PUGMARK 1.0, and added two additional variables, stride and straddle. This quantitative information was then subjected to an analytical technique using the multivariate method DFA (Discriminent Function Analysis). The detailed methodology for the analytical technique is given in the paper described above.

**Table 1: Predictor Variables**

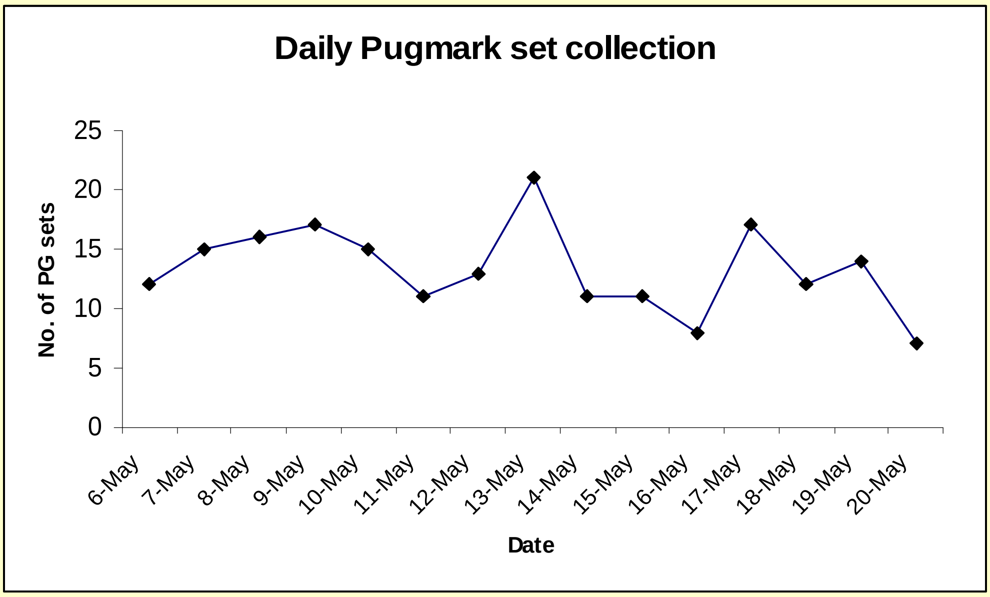
1. Area of toe #3 (AT3)
2. Length of minor axis of toe #3 (MiT3)
3. Distance between toe #2 and toe #3 (DT2T3)
4. Length of minor axis of toe #2 (LT'2)
5. Distance between main pad top to toe base-line (H)
6. Angle between toe #2 and toe #3 (QT2T3)
7. Heel to lead toe length (HLTL)
8. Distance between notch 1 and notch 2 (DN1N2)
9. Width of the pugmark (Wpg)
10. Length of the pugmark (Lpg)
11. Stride
12. Straddle




## Results

Five days, 1st to 5th May, were spent surveying the area and demarcating the sub-sampling zones. We collected the pugmark data from 6th to 20th May. In all 200 pugmark sets were collected by the five teams over a period of 15 days. A detailed daily pugmark collection has been given in the graph. The teams collected an average of 13 pugmark sets a day, with a range of 7 to 21 sets. We selected 140 pugmark sets for the final analysis, based on the quality of pugmarks and minimum number of pugmarks per set.

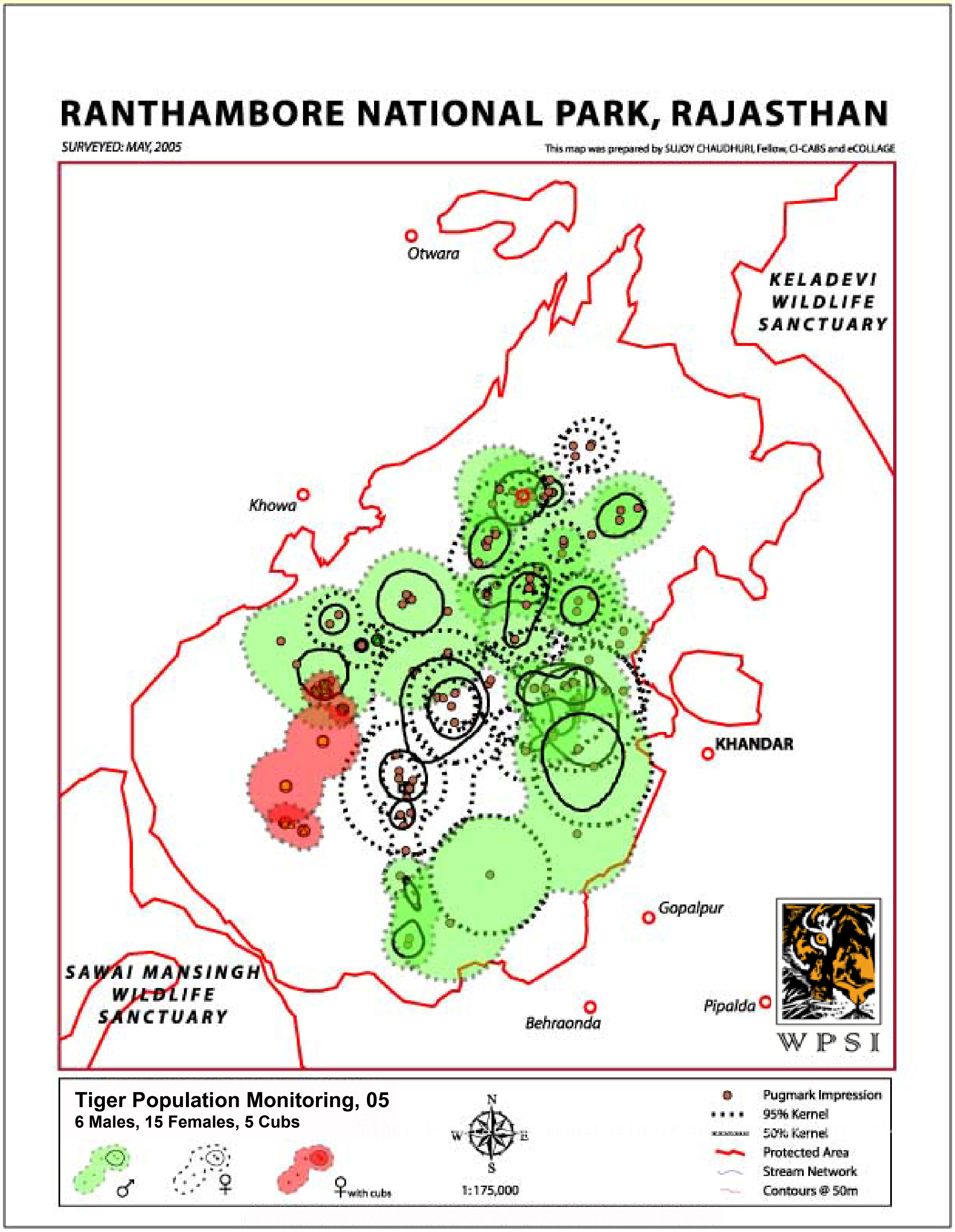



The final analysis of the pugmark pictures using PUGMARK 1.0 gave us unique variables for each pugmark set. When this quantitative information was subjected to statistical analysis it was found that there were a total of 26 tigers in Ranthambhore National Park – 6 males, 15 females, and 5 cubs. Except for two individual tigers, that we deduce could be transients, pugmark sets of all other individuals were recaptured on different days more than three times using the Digital Pugmark technique.

The GPS locations associated with each pugmark set was plotted after attaching the individual tiger identity information. The Kernel Utilization Density method (KUD) was used to plot the 95% kernel and 50% kernel for each tiger. These maps are merely indicative of the distribution of these individual tigers during a brief sampling period. However, it would appear that similar information, collected across different seasons and analysed using the methodology outlined in this report, would be a useful tool to monitor tigers in Ranthambhore and a number of other protected areas.

**Table 2:** Profile of Tigers found in Ranthambhore (May 2005)

| Tiger ID | Gender | Name | Area Occupied |
|---|---|---|---|
| **001 M** | Male | **Berda male** | *Berda village, Berda water hole, Berda tiraha, Lahpur road, Chiroli, Kalakhet* |
| **002 M** | Male | **Chiroli male** | *Naya road, Chiroli, Bakola, Phuta kot, Rani deh, Purana pani, Bagdah, Ama Ghati, Peepli deh* |
| **003 F** | Female | **Berda female** | *Berda, Bhanwarda, Kachida, Bakola, Bagdah, Bhootkhorra* |
| **004 F** | Female | **Bakola female** | *Bakola, Bagda, Semli tiraha, Durrah anicut* |
| **005 F** | Female | **Dhakada female** | *Dhakda* |
| **006 F** | Female | **Ranideh female** | *Ranideh, Chor gali, Lalghati, Anatpura waterhole, Bagdah, Durrah anicut* |
| **007 M** | Male | **Lakarda male** | *Lakarda High Point, Jhalra, Kukraj top, Jhokha, Bhoot khorra, Gurla tiraha* |
| **008 F** | Female | **Lahpur female** | *Lahpur khet, Circular road, Chindawali tiraha* |
| **009 F** | Female | **Odikho female** | *Odikho, Chindawali tiraha, Chindawali ghatee* |
| **010 F** | Female | **Chindawali female** | *Chindawali tiraha, chindawali ghatee* |
| **011 M** | Male | **Indala male** | *Indala, Peeli talai* |
| **012 F** | Female | **Jhalra female** | *Jhalra, Milik talao, Bada gate, Chhota gate, Jogi Mahal, Nalghati* |
| **013 C** | | **Jhalra cub 1** | *Jhalra, Milik talao, Bada gate, Chhota gate, Jogi Mahal, Nalghati* |
| **014 C** | | **Jhalra cub 2** | *Jhalra, Milik talao, Bada gate, Chhota gate, Jogi Mahal, Nalghati* |
| **015 F** | Female | **Guda female** | *Guda triujnction, Guda, Soleshwar* |
| **016 C** | | **Guda cub 1** | *Guda triujnction, Guda, Soleshwar* |
| **017 C** | | **Guda cub 2** | *Guda triujnction, Guda, Soleshwar* |
| **018 F** | Female | **Sultanpur female** | *Jagner, Phootakot, Sultanpur* |
| **019 C** | | **Sultanpur cub** | *Jagner, Phootakot, Sultanpur* |
| **020 F** | Female | **Tambakhan female** | *Tambakhan, Milik talao, Singhdwar* |
| **021 F** | Female | **Thumka female** | *Thumka, Thumka top, Preet deh, Jharna mahadev, Mayee dang* |
| **022 F** | Female | **Preetdeh female 1** | *Sarkari talai, Preet deh, Thumka gate, Thumka top, Jailkho, Galai Sagar, Neela patta, Lahpur khet* |
| **023 F** | Female | **Preetdeh female 2** | *Preetdeh, Sarkari talai, Berda triangle* |
| **024 F** | Female | **Transient female** | *Sarkari talai* |
| **025 M** | Male | **Sarkari talai male** | *Sarkari talai, Preet deh, Sukhna, Khara chatta, Dholi bawali, Phirozpur talai* |
| **026 M** | Male | **Rawara dang male** | *Balaji, Mayee ghati, Macch ghati, Rawara dang* |


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
Otwara
KELADEVI WILDLIFE SANCTUARY
Khowa
KHANDAR
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
Tiger Population Monitoring, 05
6 Males, 15 Females, 5 Cubs
♂
♀
♀ with cubs
N
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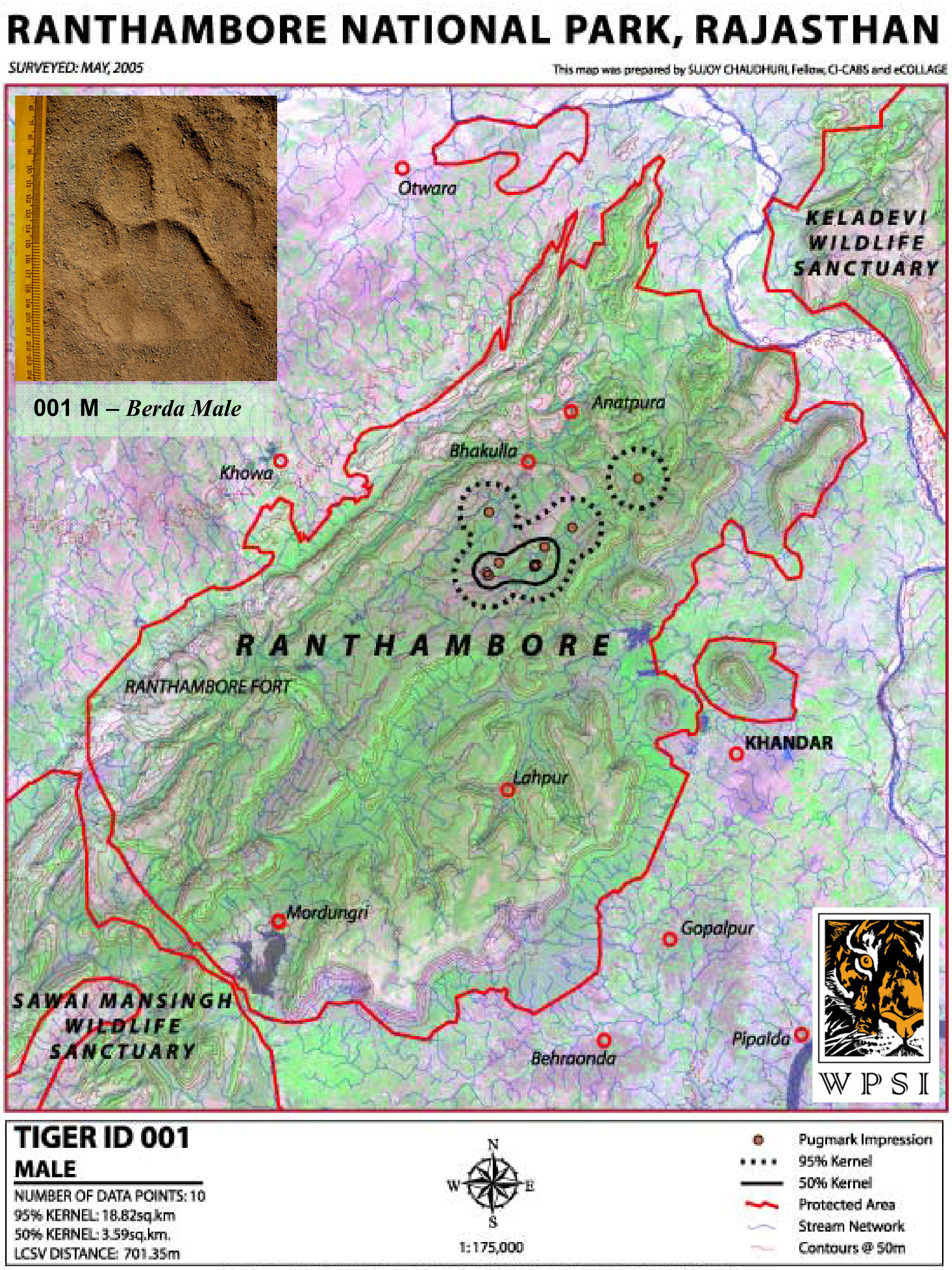
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
001 M – Berda Male
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 001
MALE
NUMBER OF DATA POINTS: 10
95% KERNEL: 18.82sq.km
50% KERNEL: 3.59sq.km.
LCSV DISTANCE: 701.35m
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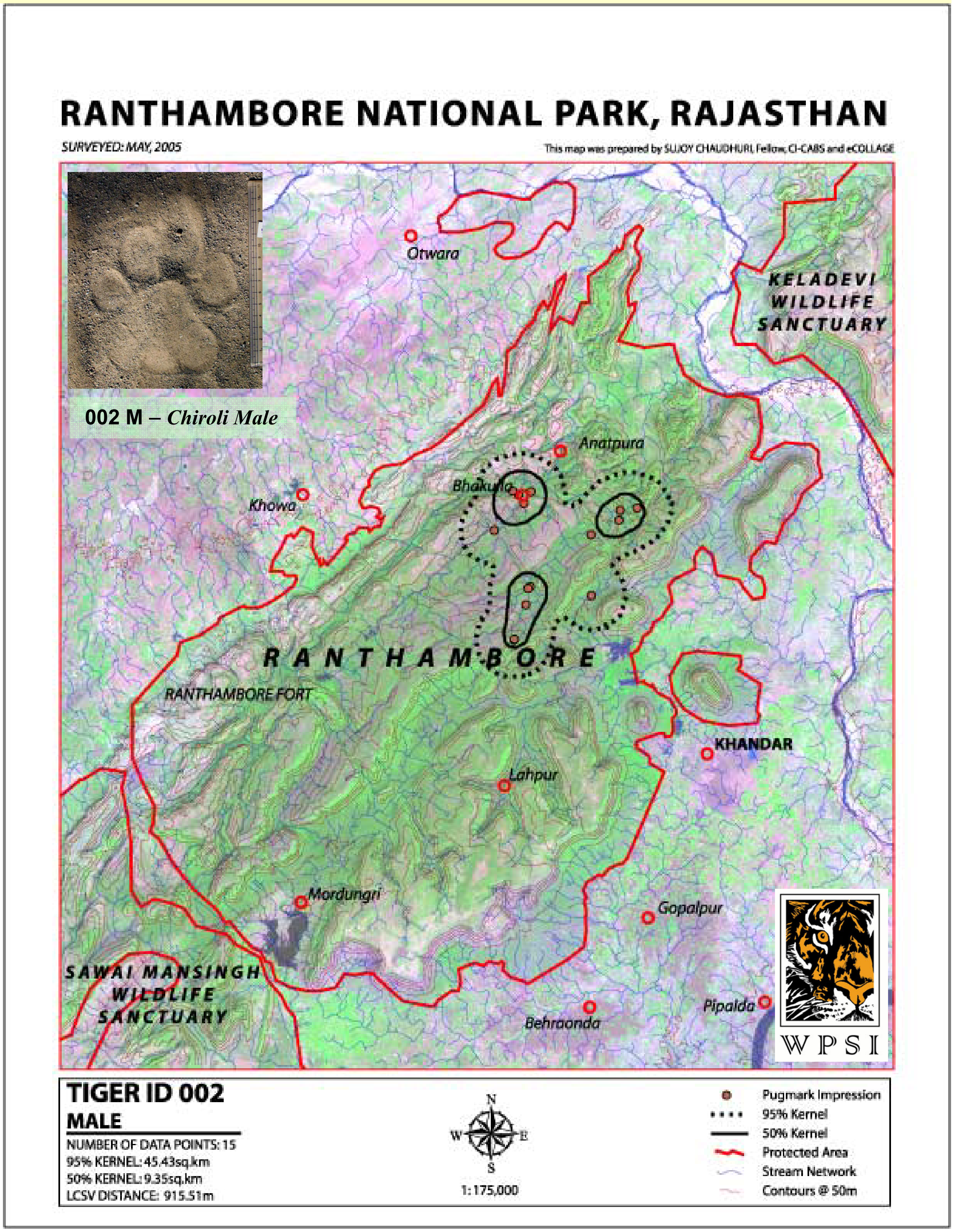
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
002 M – Chiroli Male
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakula
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 002
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50% KERNEL: 9.35sq.km
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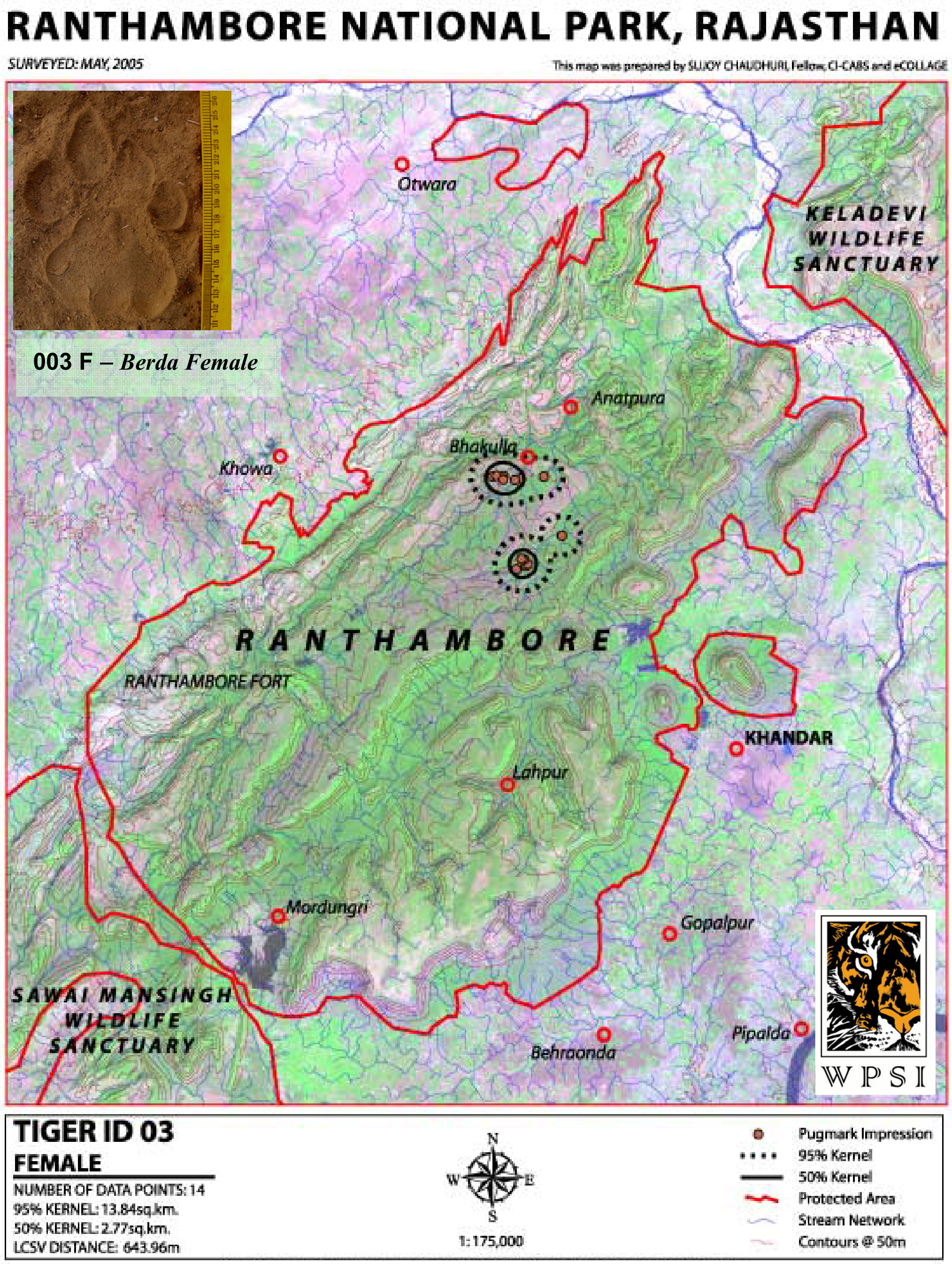
50% Kernel
Protected Area
Stream Network
Contours @ 50m



RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
003 F – Berda Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
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95% Kernel
50% Kernel
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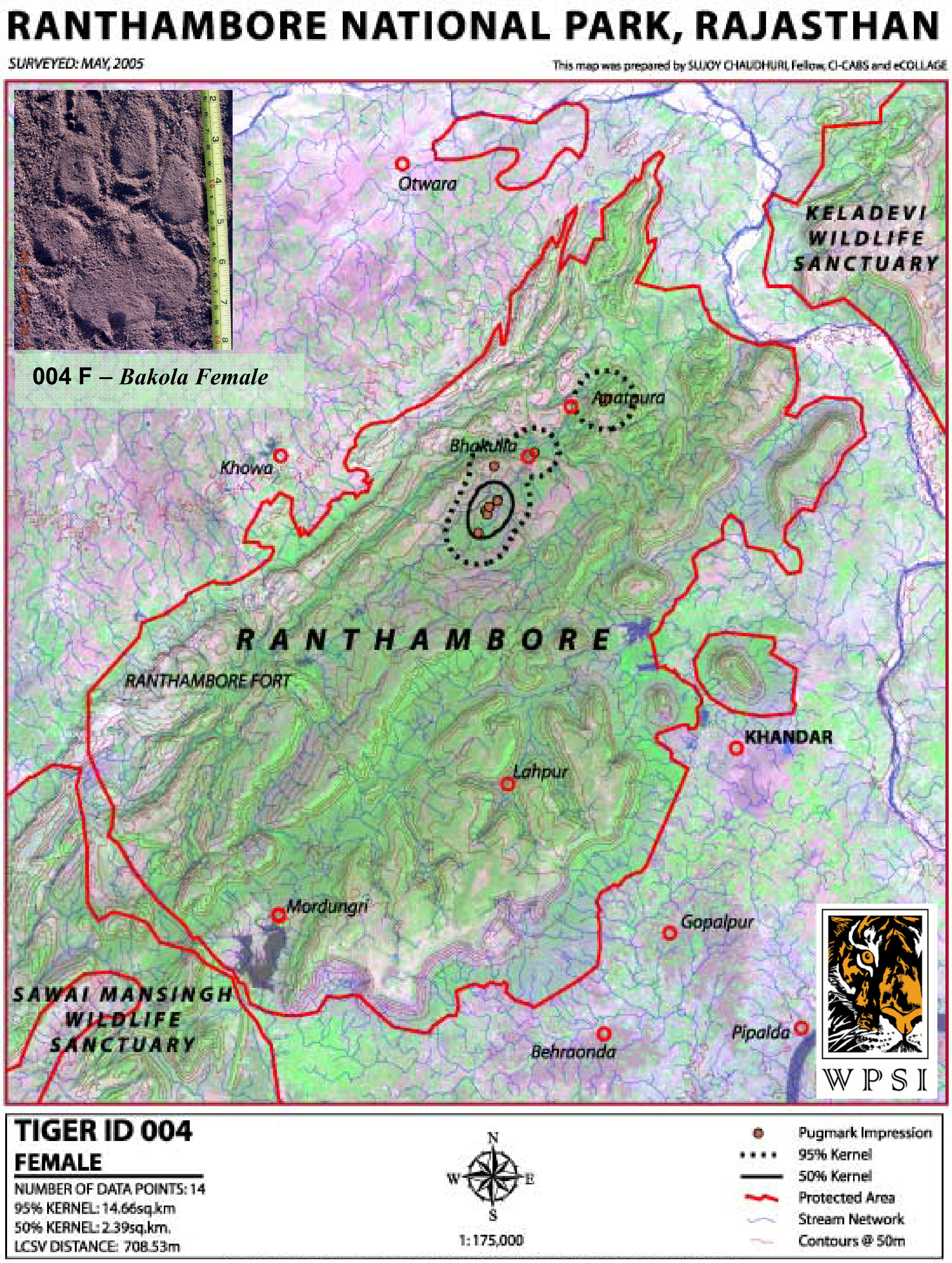
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
004 F – Bakola Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Amarpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
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Pipalda
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50% KERNEL: 2.39sq.km.
LCSV DISTANCE: 708.53m
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50% Kernel
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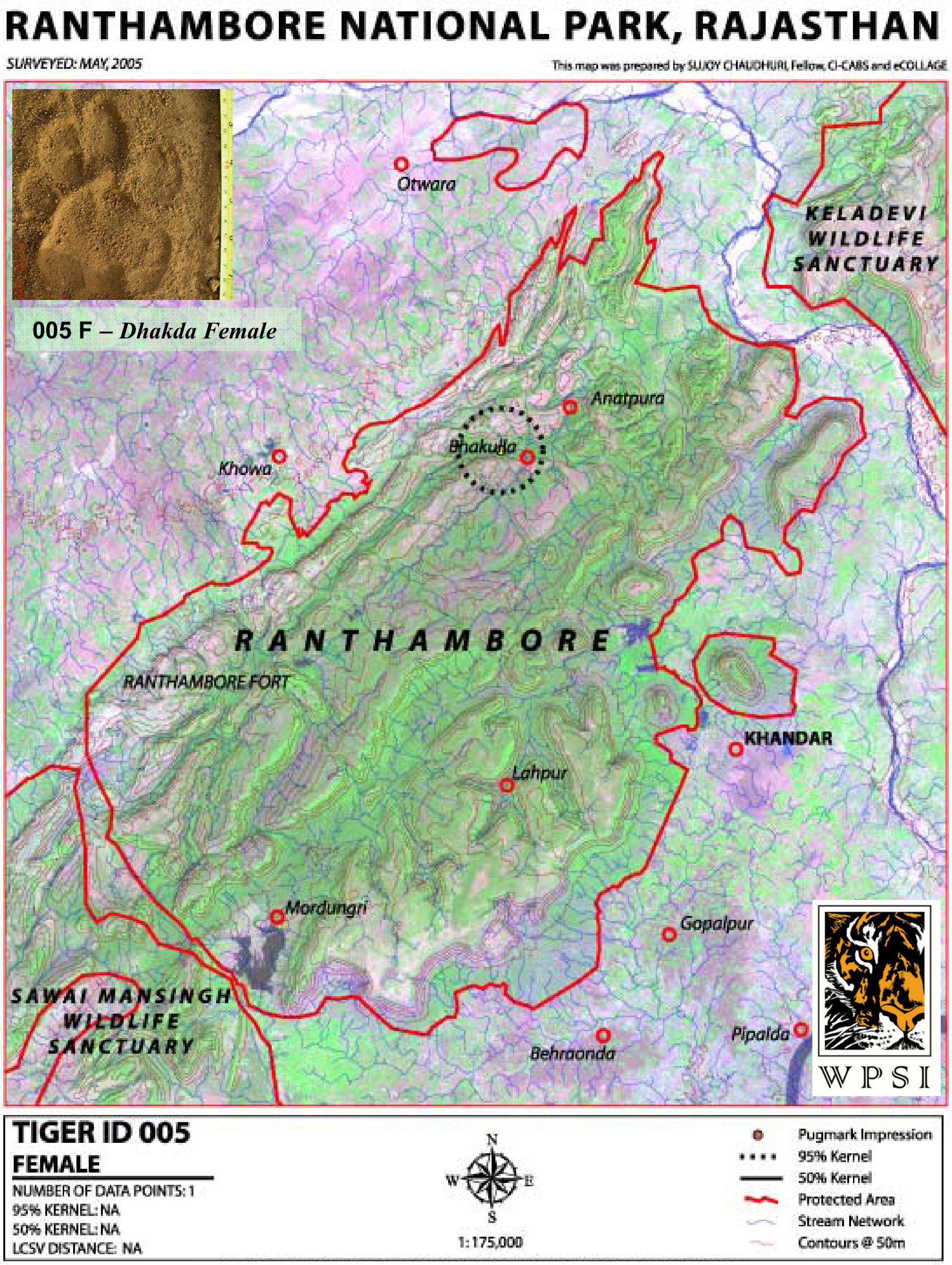
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
005 F – Dhakda Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
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Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
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50% KERNEL: NA
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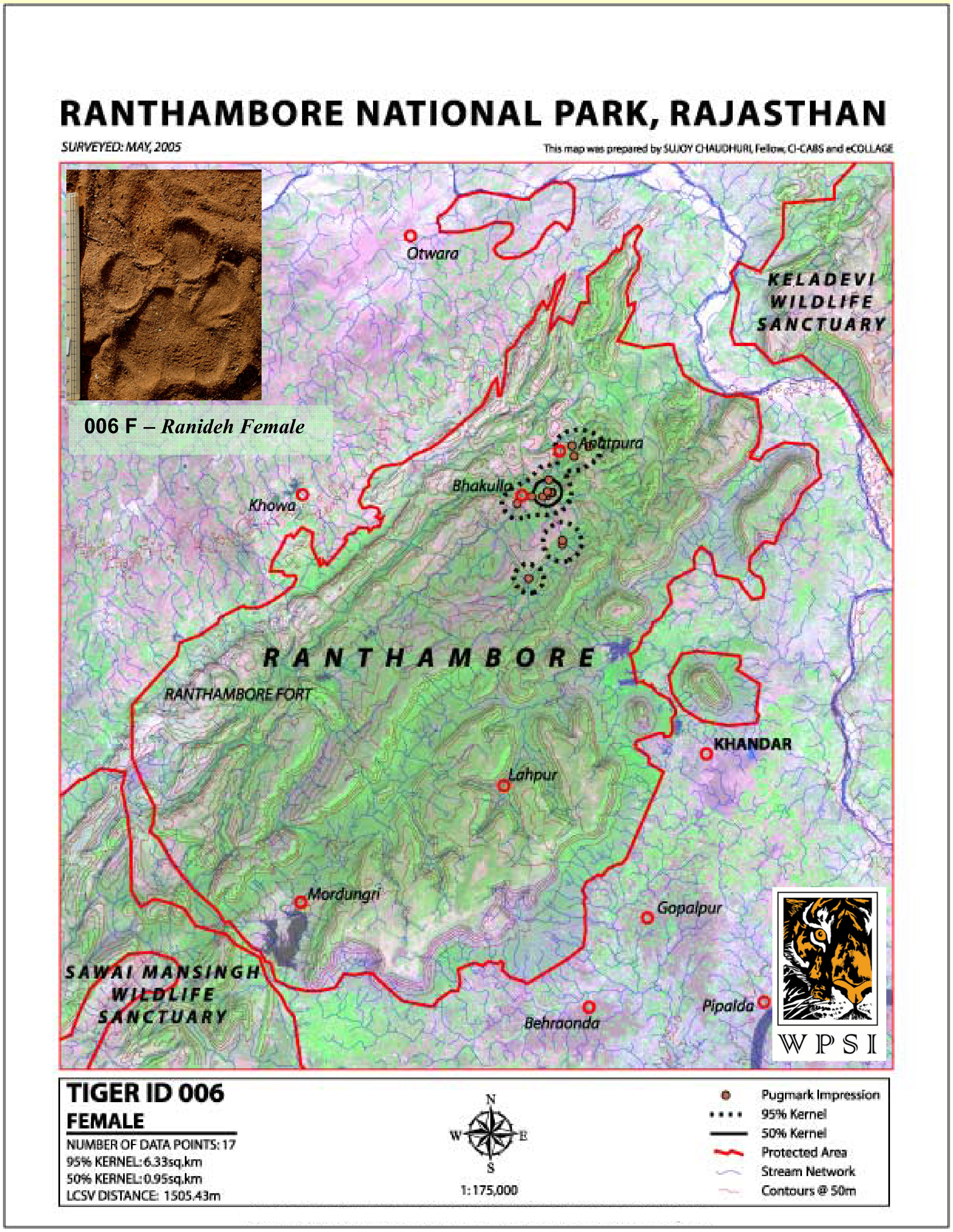
RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
006 F – Ranideh Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
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50% Kernel
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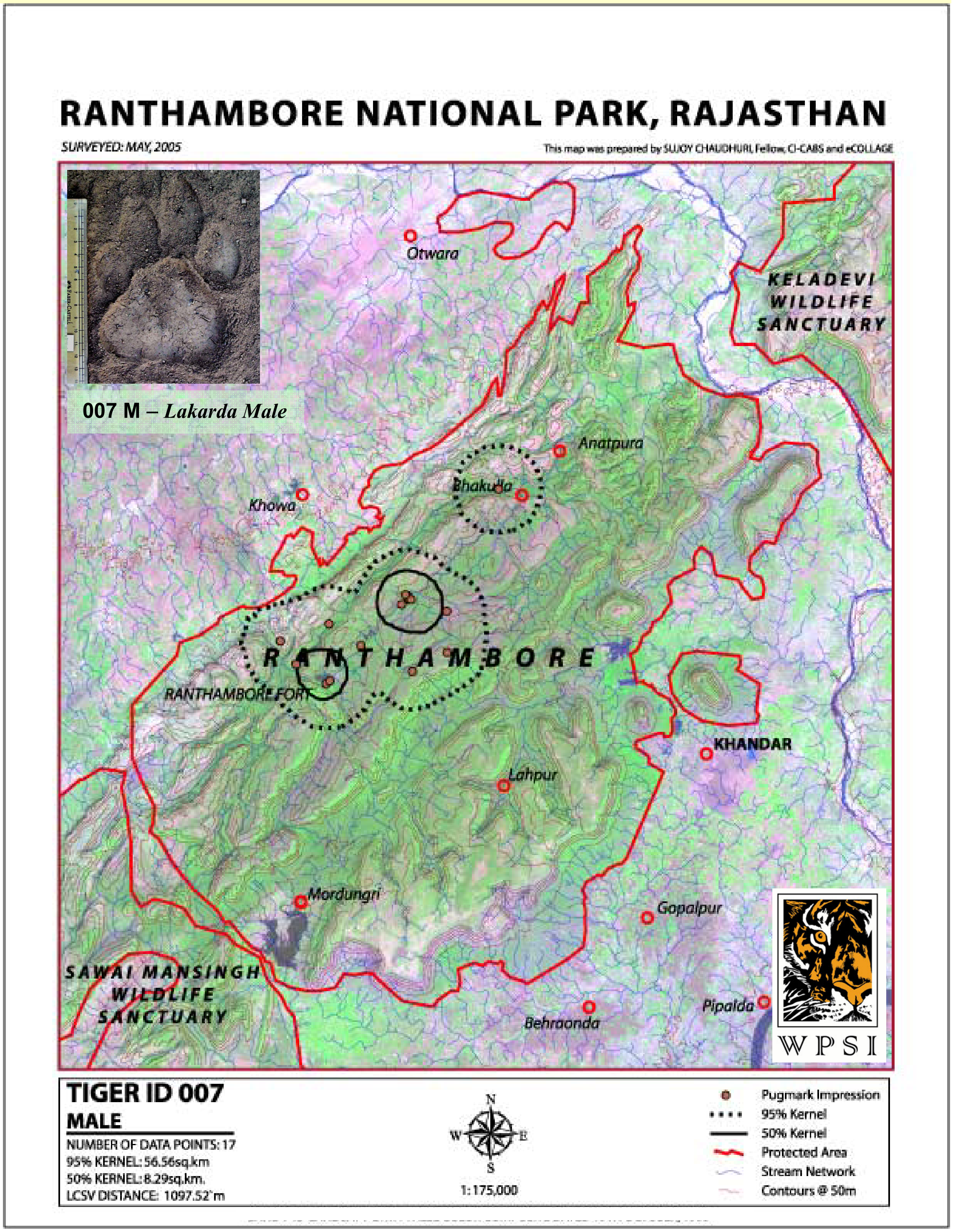
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
007 M – Lakarda Male
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakula
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 007
MALE
NUMBER OF DATA POINTS: 17
95% KERNEL: 56.56sq.km
50% KERNEL: 8.29sq.km.
LCSV DISTANCE: 1097.52`m
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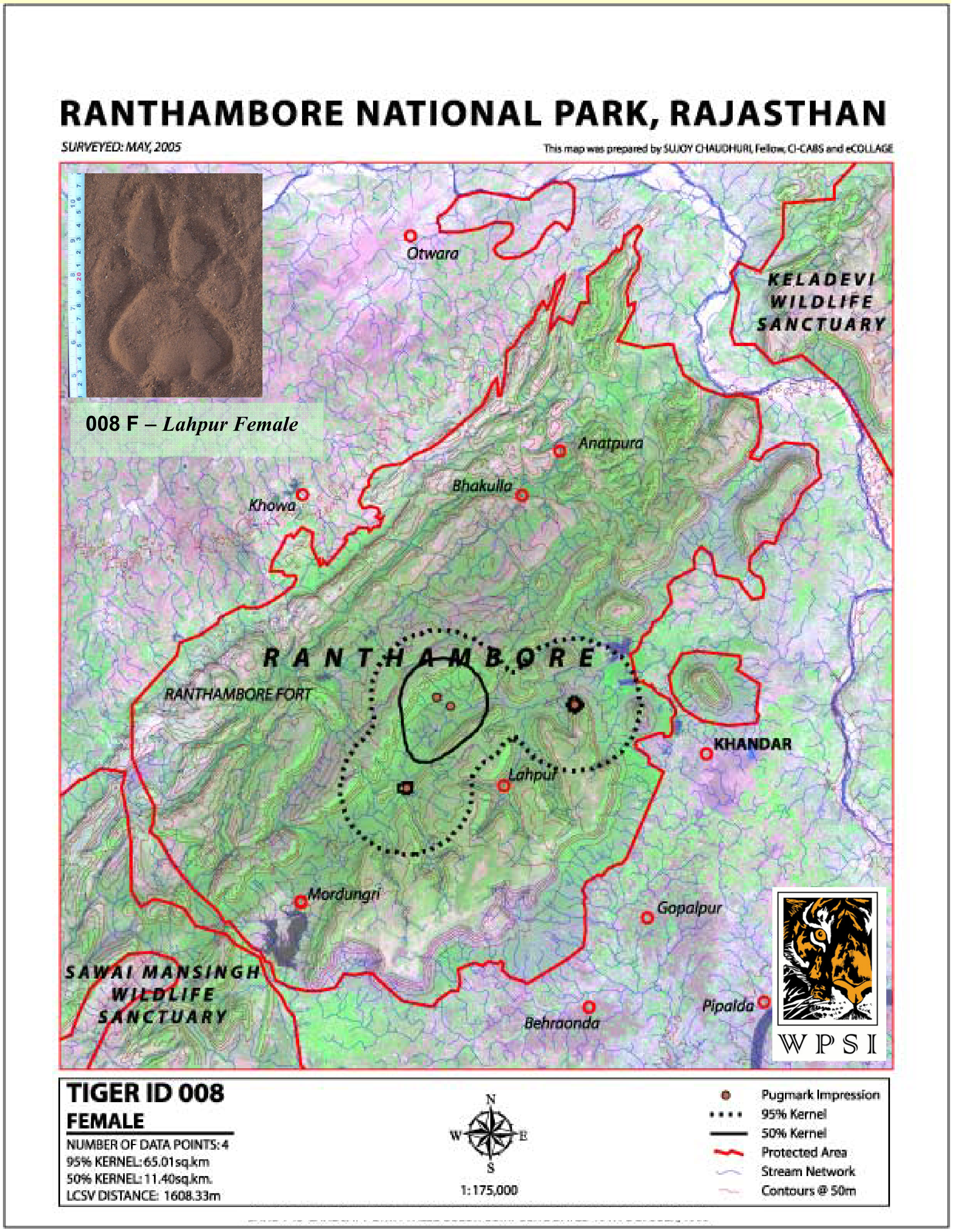
1:175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
008 F – Lahpur Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
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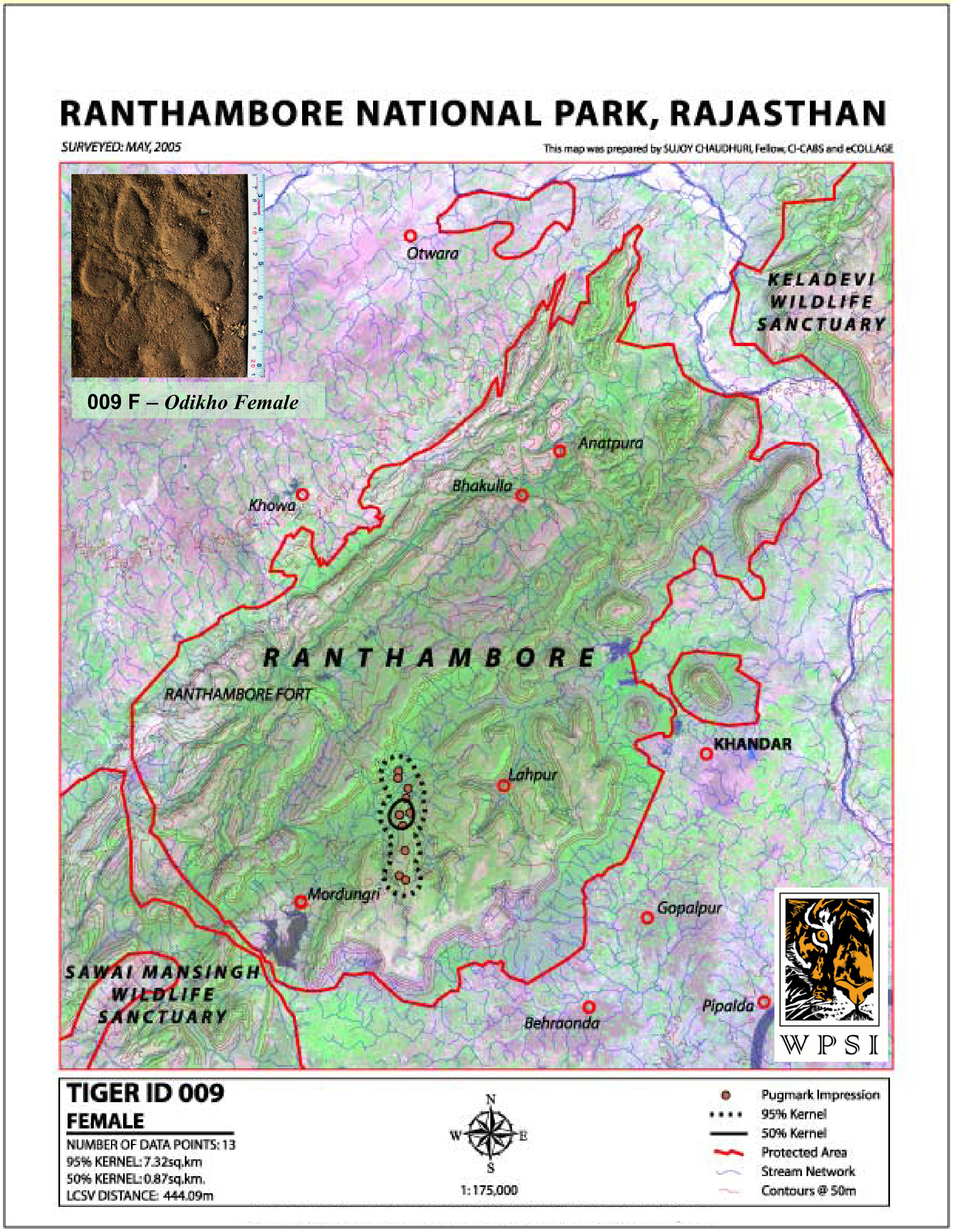
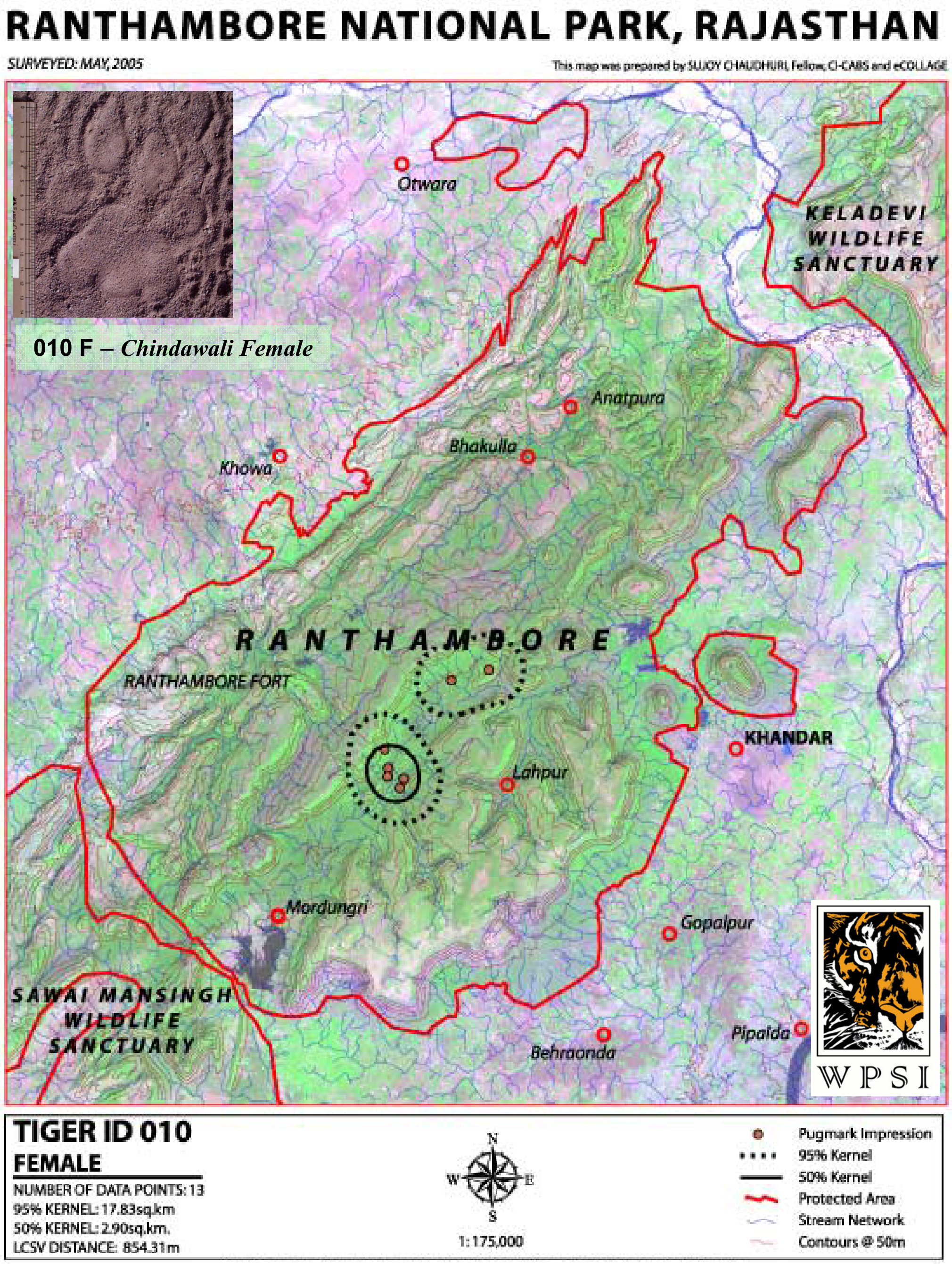
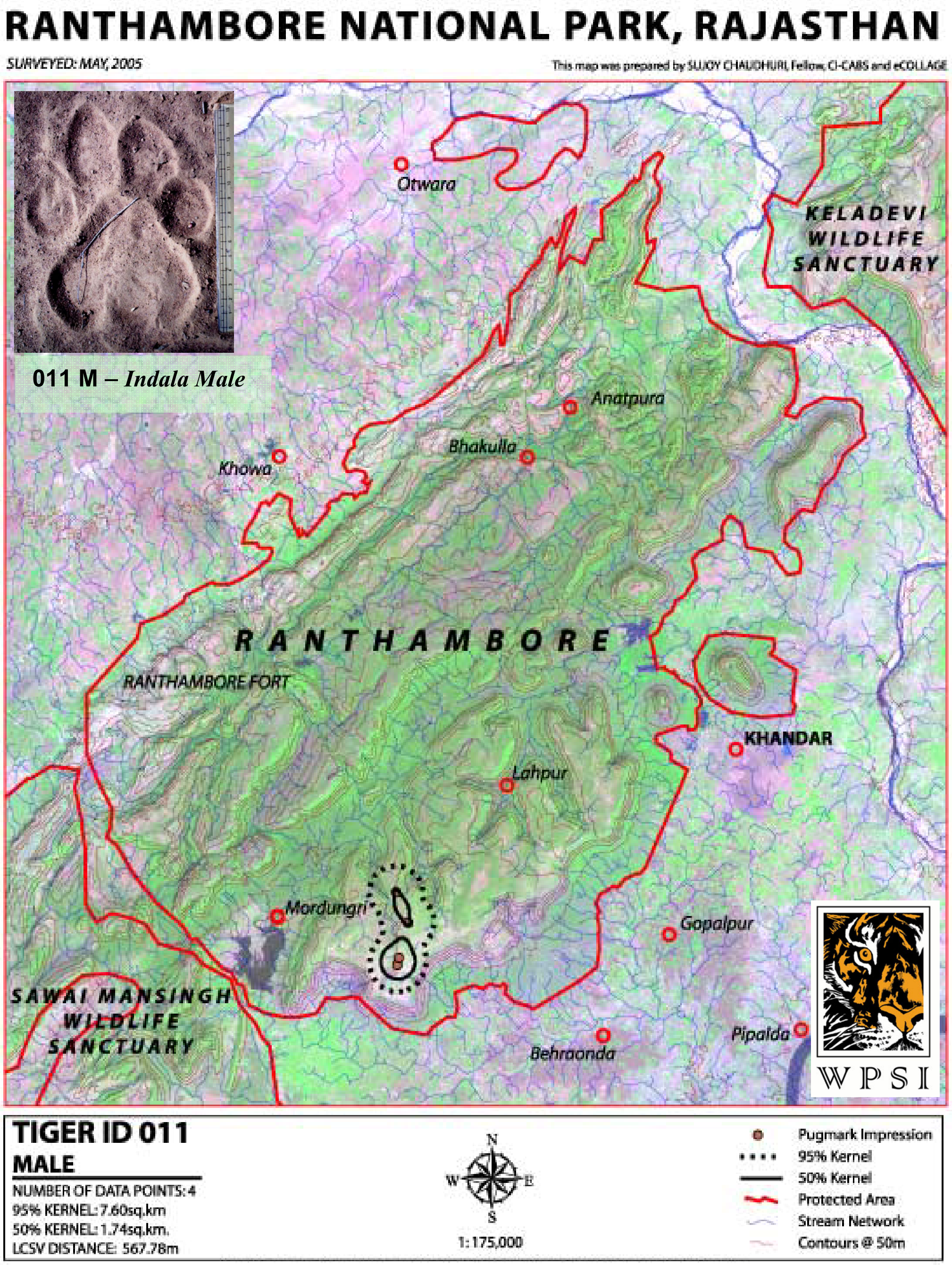
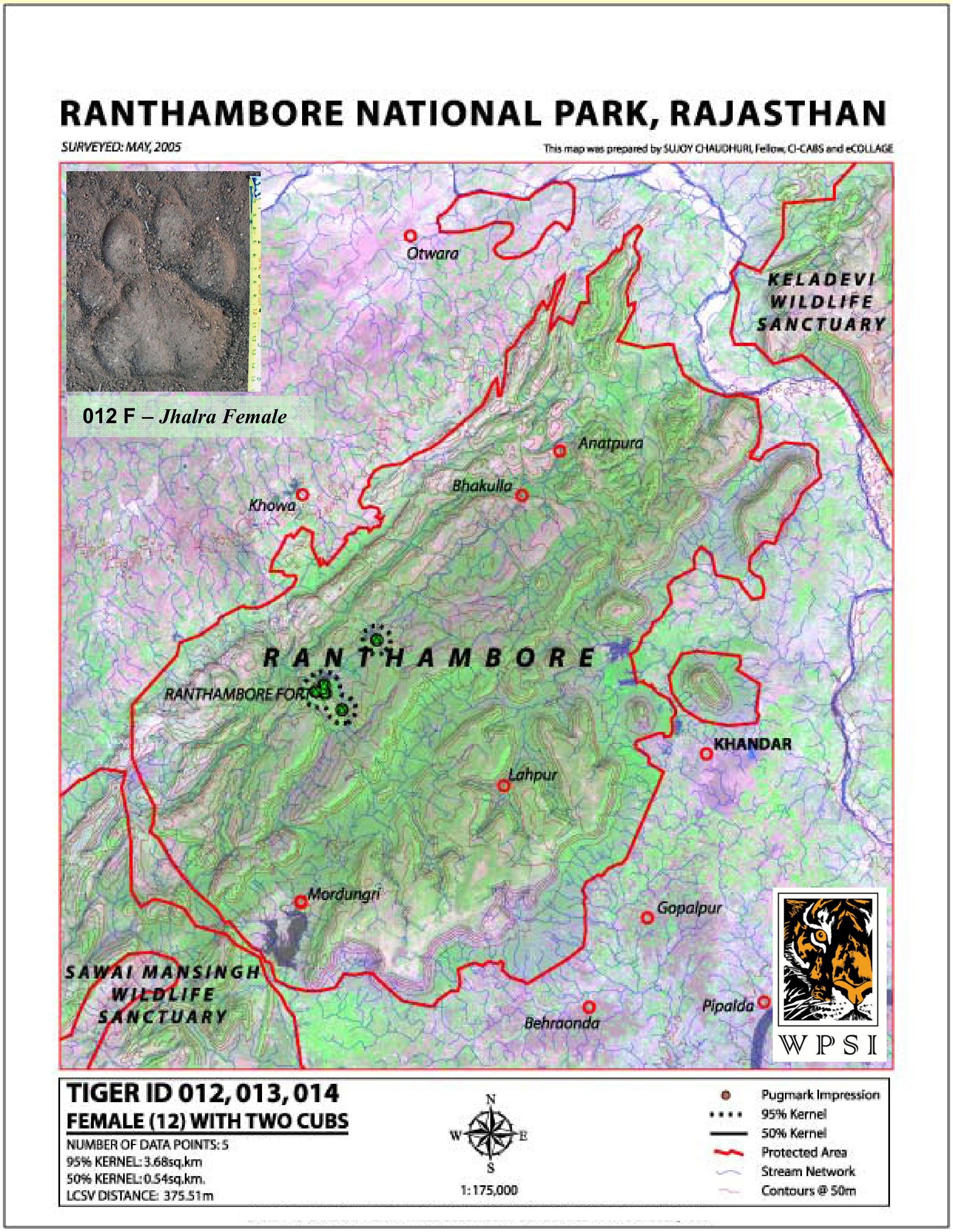
FEMALE
NUMBER OF DATA POINTS: 4
95% KERNEL: 65.01sq.km
50% KERNEL: 11.40sq.km.
LCSV DISTANCE: 1608.33m
N
W
E
S
1:175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

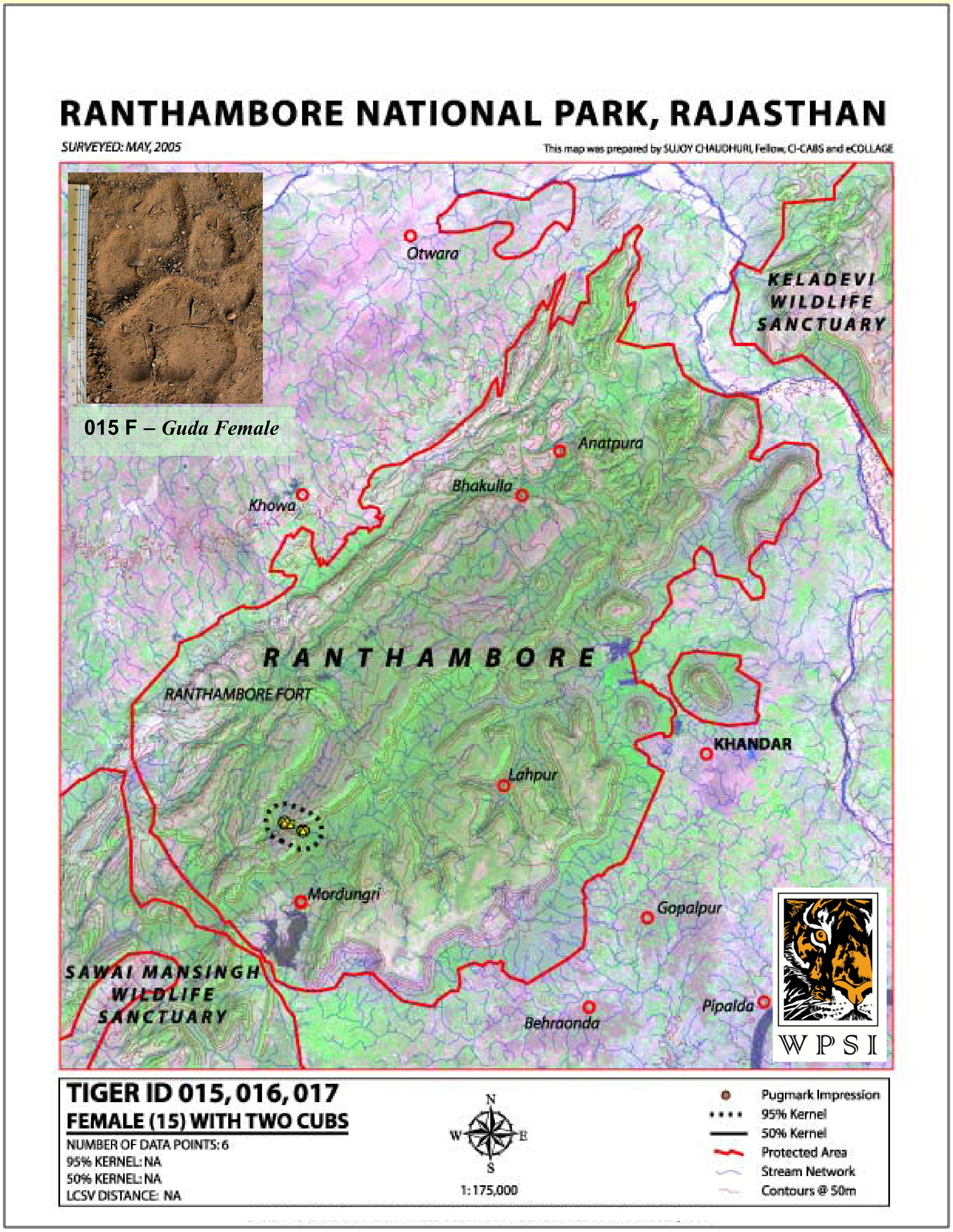

RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
009 F – Odikho Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Pipalda
Behraonda
WPSI
TIGER ID 009
FEMALE
NUMBER OF DATA POINTS: 13
95% KERNEL: 7.32sq.km
50% KERNEL: 0.87sq.km.
LCSV DISTANCE: 444.09m
N
W
E
S
1: 175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

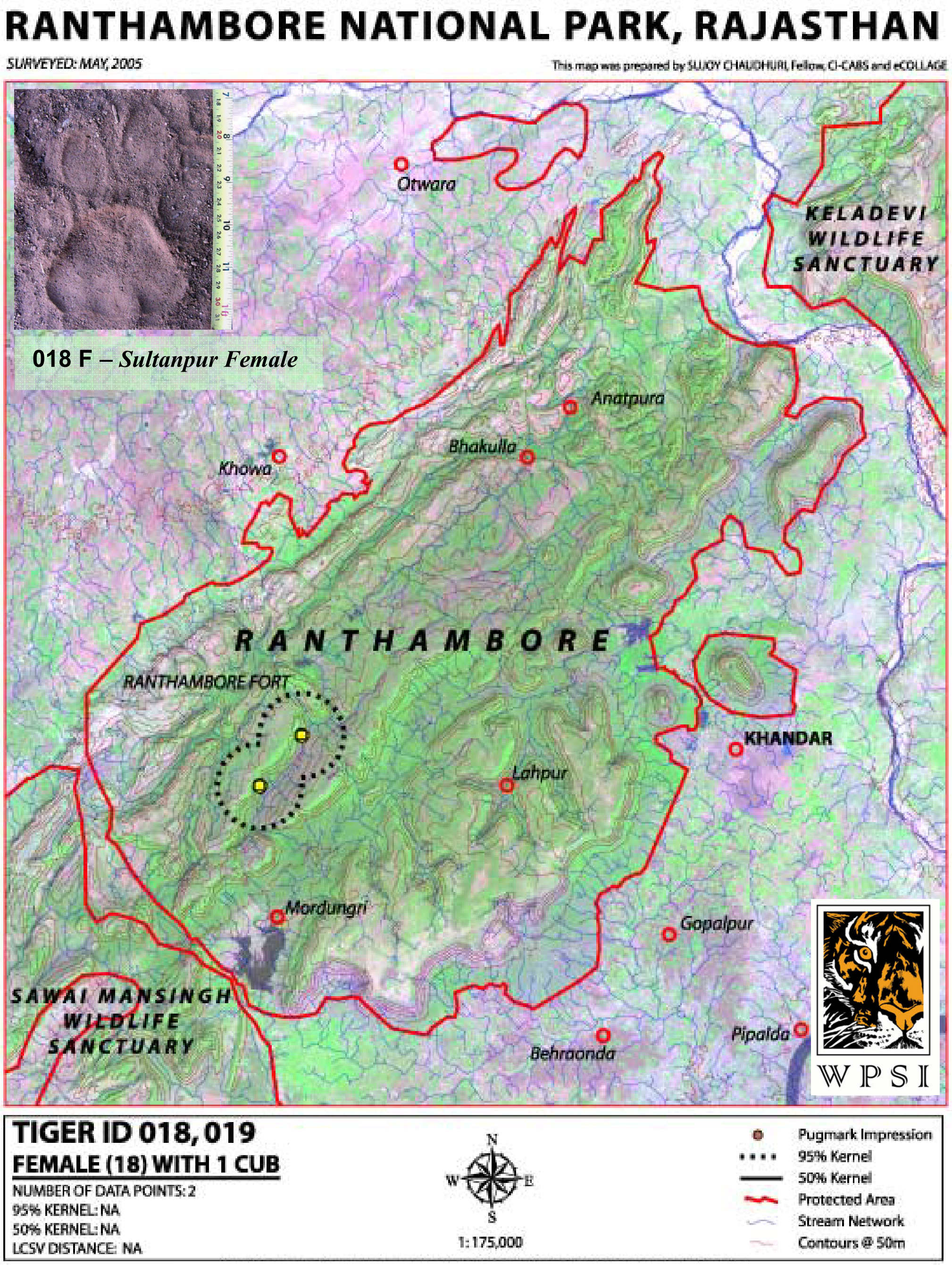

RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
010 F – Chindawali Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 010
FEMALE
NUMBER OF DATA POINTS: 13
95% KERNEL: 17.83sq.km
50% KERNEL: 2.90sq.km.
LCSV DISTANCE: 854.31m
N
W
E
S
1: 175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

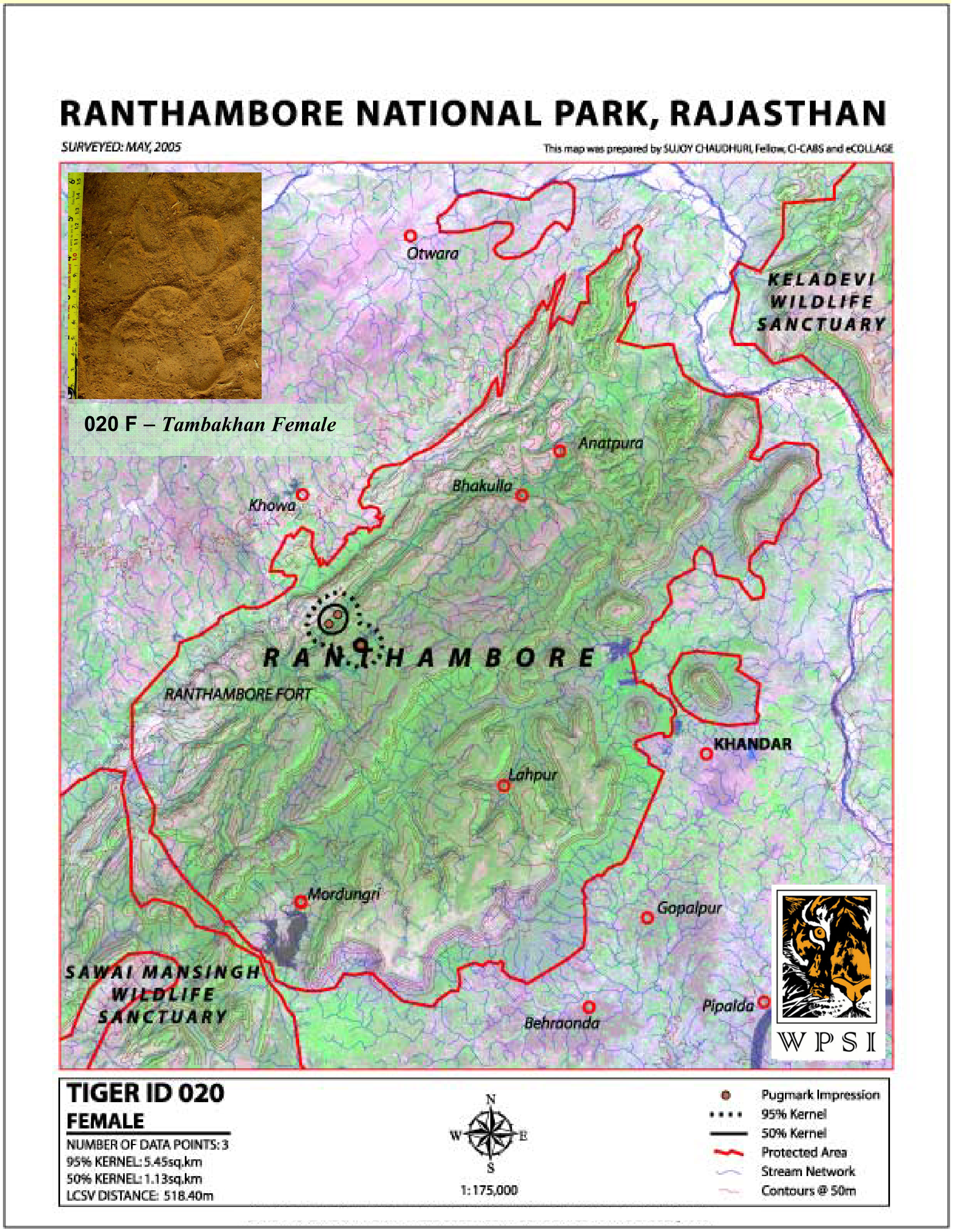

RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
011 M – Indala Male
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 011
MALE
NUMBER OF DATA POINTS: 4
95% KERNEL: 7.60sq.km
50% KERNEL: 1.74sq.km.
LCSV DISTANCE: 567.78m
N
W
E
S
1:175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

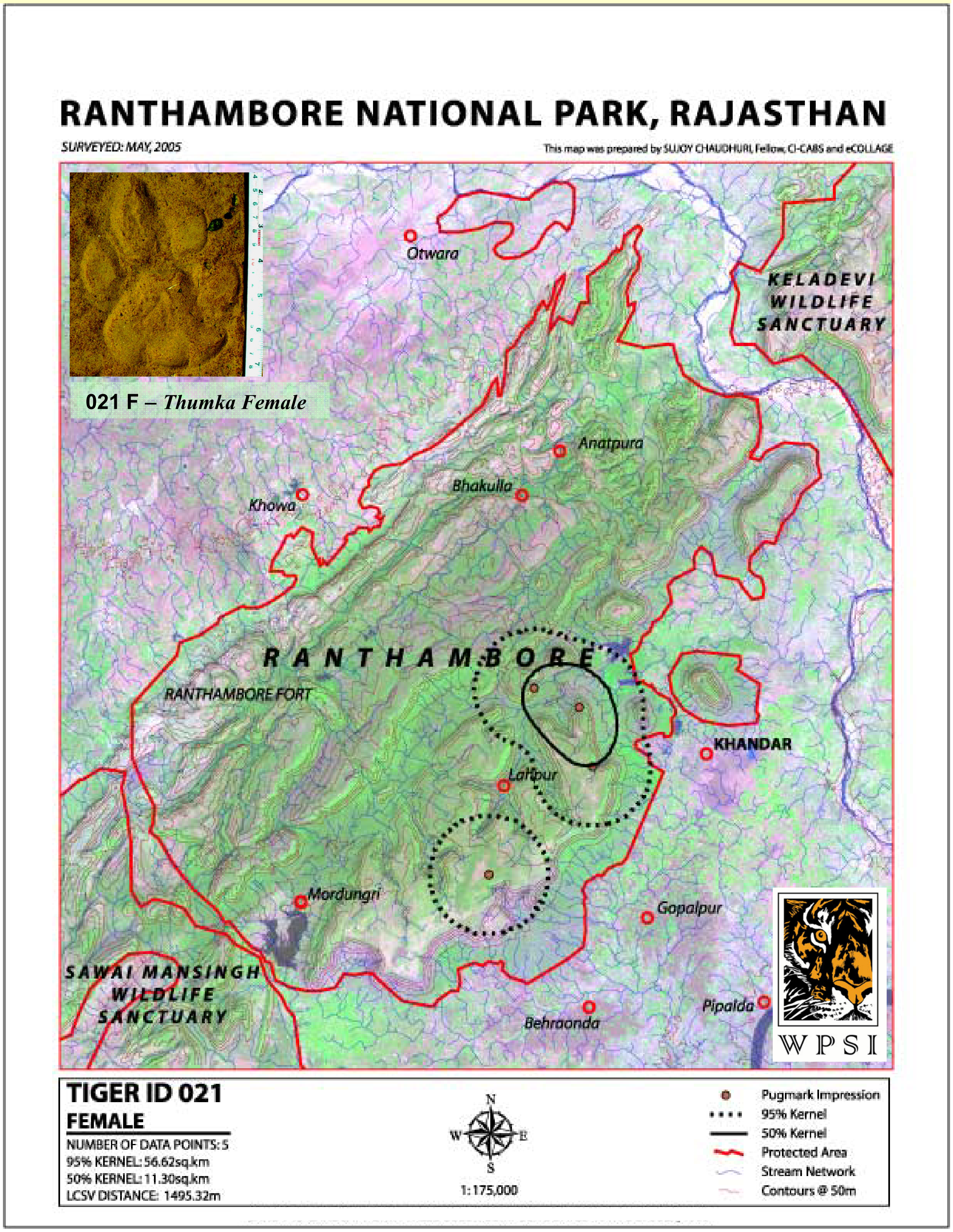


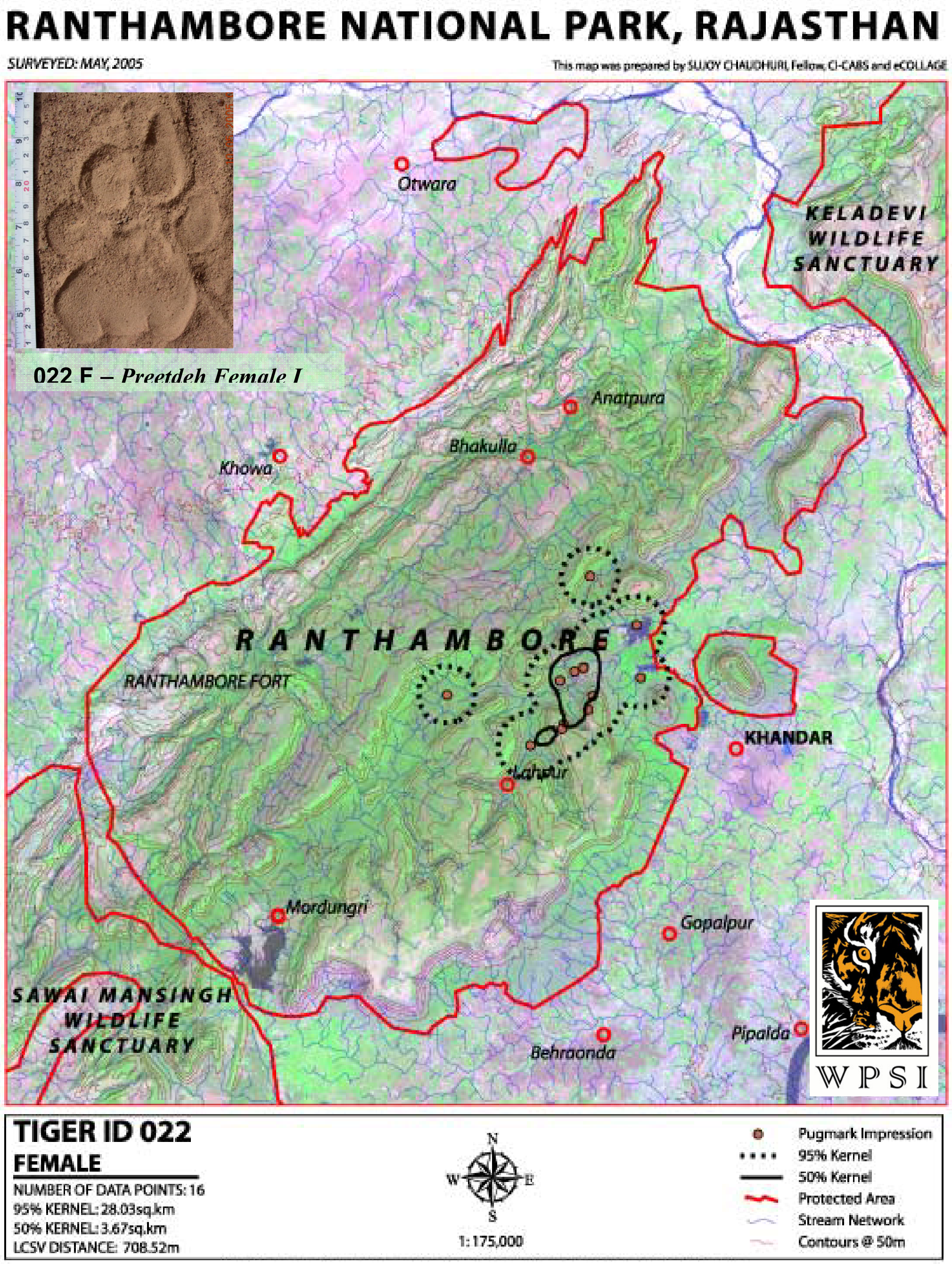
RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
012 F – Jhalra Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 012, 013, 014
FEMALE (12) WITH TWO CUBS
NUMBER OF DATA POINTS: 5
95% KERNEL: 3.68sq.km
50% KERNEL: 0.54sq.km.
LCSV DISTANCE: 375.51m
N
W
E
S
1:175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

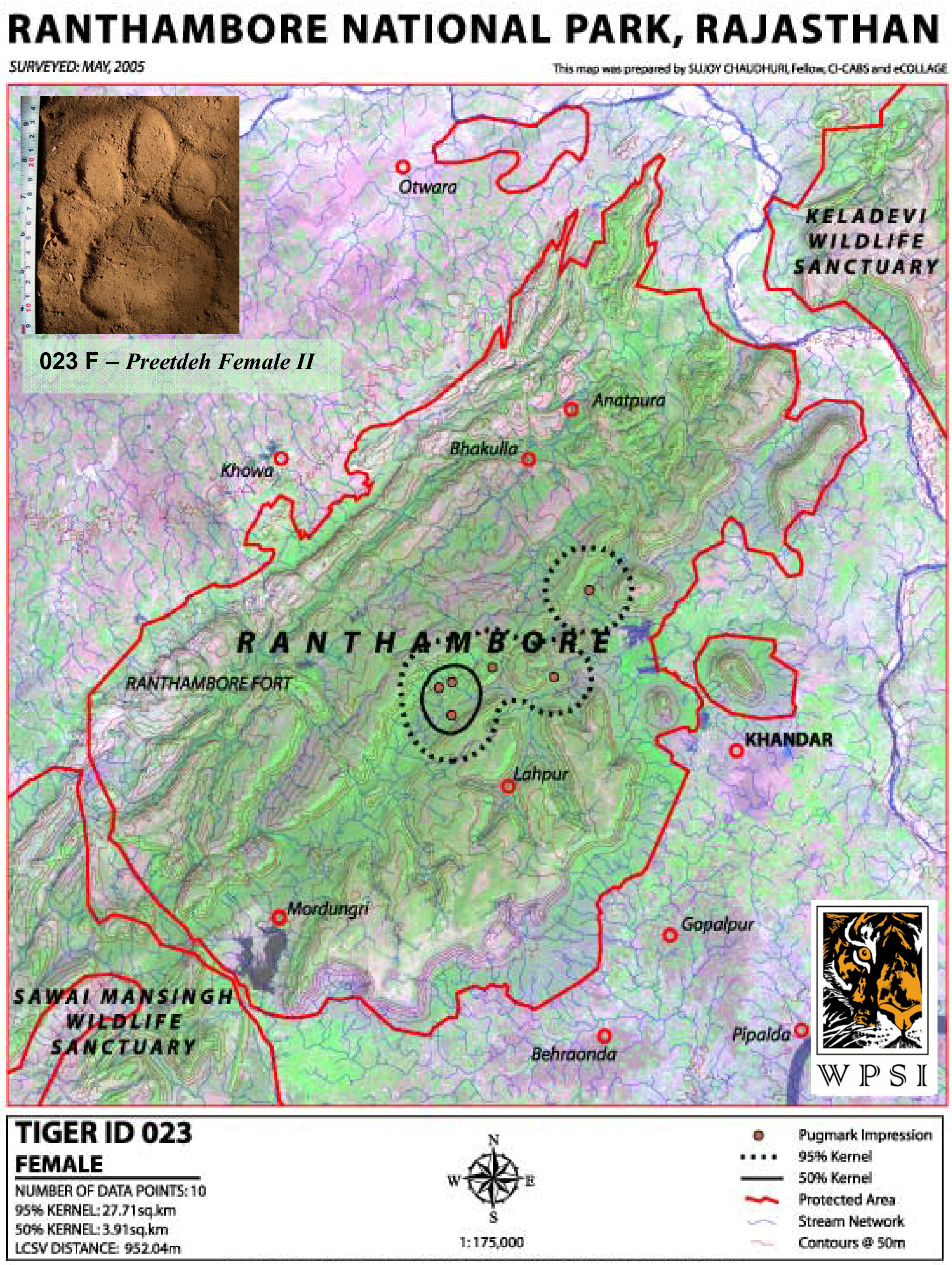

RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
015 F – Guda Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 015, 016, 017
FEMALE (15) WITH TWO CUBS
NUMBER OF DATA POINTS: 6
95% KERNEL: NA
50% KERNEL: NA
LCSV DISTANCE: NA
N
W
E
S
1:175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

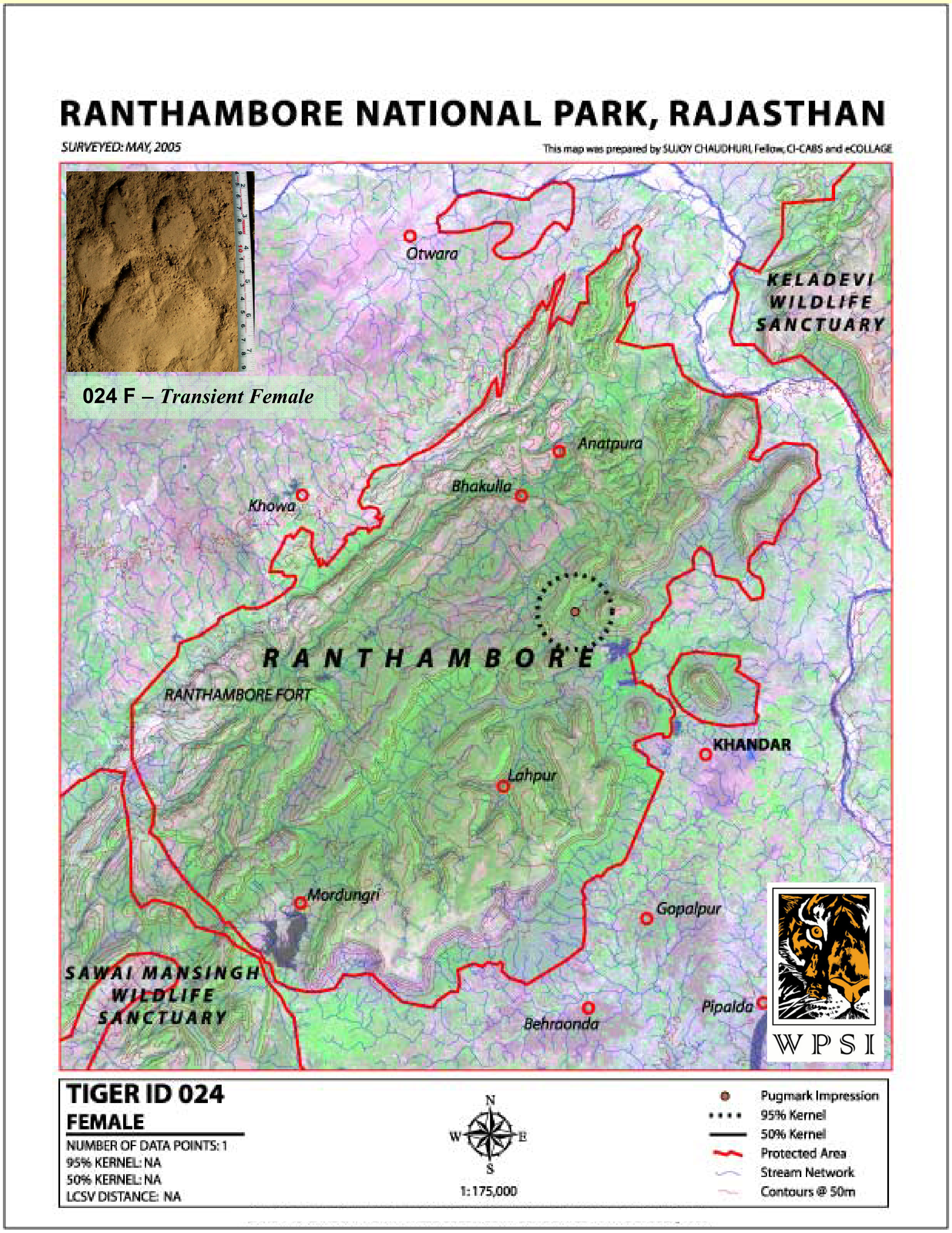

RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
018 F – Sultanpur Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 018, 019
FEMALE (18) WITH 1 CUB
NUMBER OF DATA POINTS: 2
95% KERNEL: NA
50% KERNEL: NA
LCSV DISTANCE: NA
N
W
E
S
1: 175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

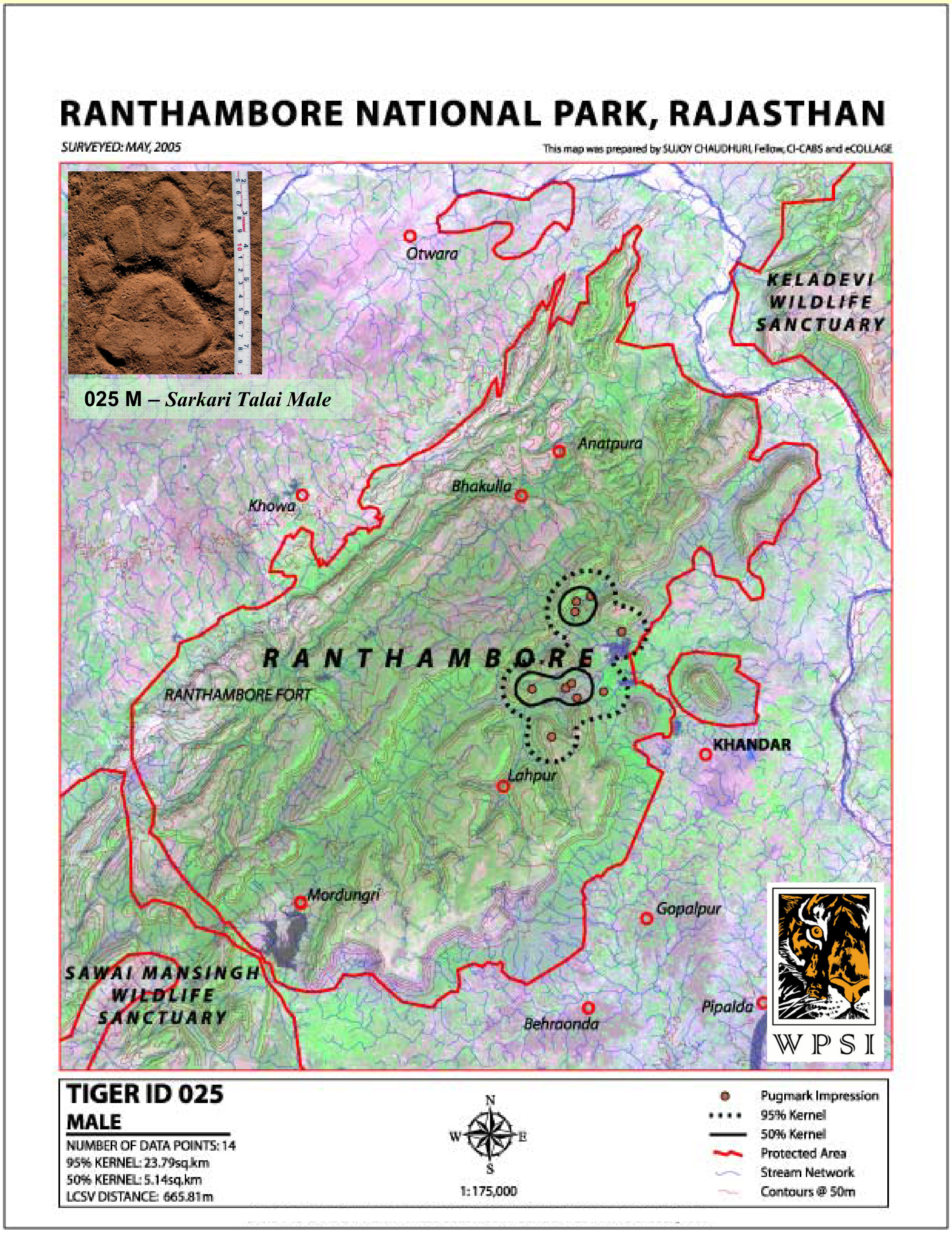

RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
020 F – Tambakhan Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 020
FEMALE
NUMBER OF DATA POINTS: 3
95% KERNEL: 5.45sq.km
50% KERNEL: 1.13sq.km
LCSV DISTANCE: 518.40m
N
W
E
S
1: 175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

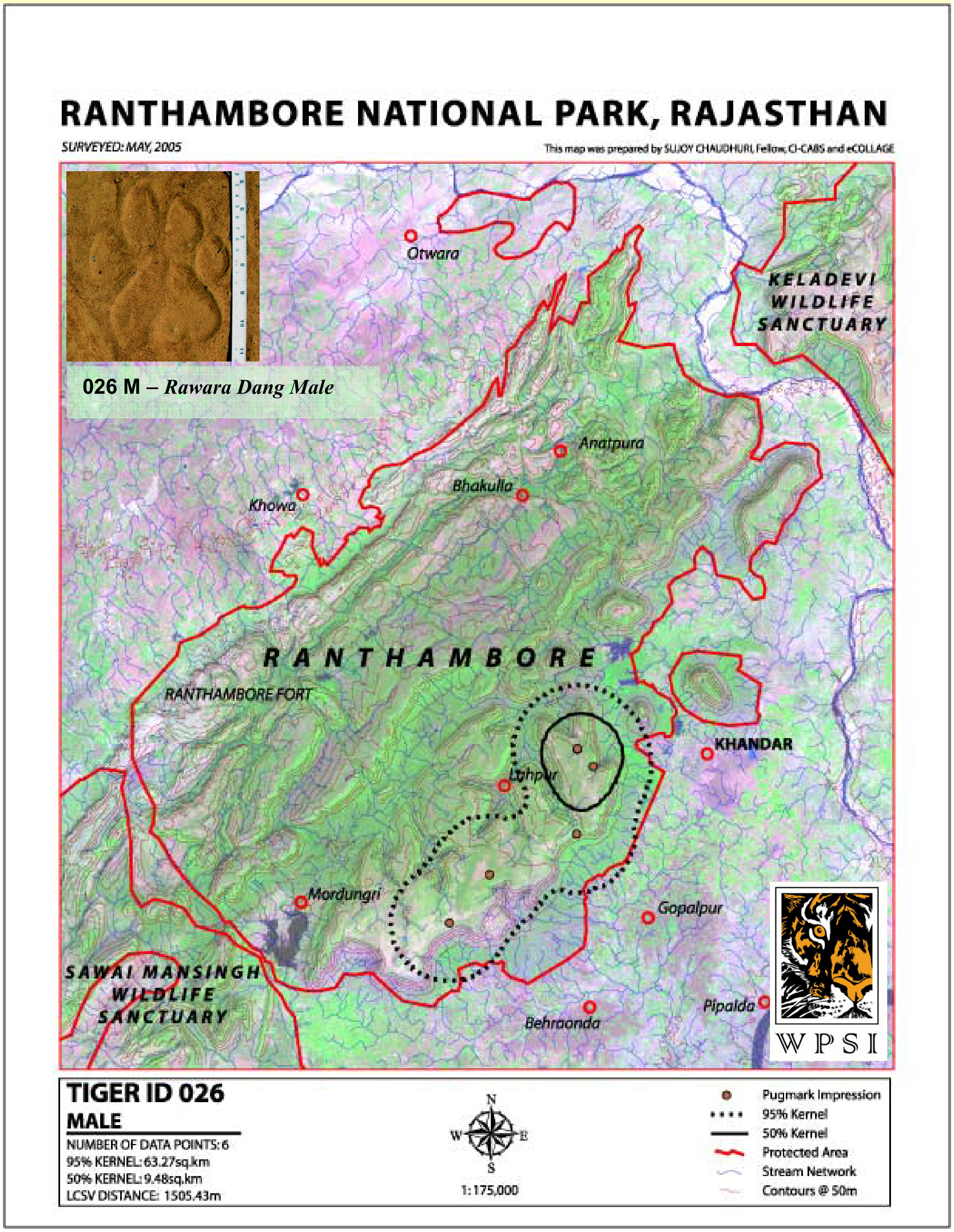

RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
021 F – Thumka Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 021
FEMALE
NUMBER OF DATA POINTS: 5
95% KERNEL: 56.62sq.km
50% KERNEL: 11.30sq.km
LCSV DISTANCE: 1495.32m
N
W
E
S
1: 175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
022 F – Preetdeh Female I
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 022
FEMALE
NUMBER OF DATA POINTS: 16
95% KERNEL: 28.03sq.km
50% KERNEL: 3.67sq.km
LCSV DISTANCE: 708.52m
N
W
E
S
1: 175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
023 F – Preetdeh Female II
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Pipalda
Behraonda
WPSI
TIGER ID 023
FEMALE
NUMBER OF DATA POINTS: 10
95% KERNEL: 27.71sq.km
50% KERNEL: 3.91sq.km
LCSV DISTANCE: 952.04m
N
W
E
S
1:175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
024 F – Transient Female
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 024
FEMALE
NUMBER OF DATA POINTS: 1
95% KERNEL: NA
50% KERNEL: NA
LCSV DISTANCE: NA
N
W
E
S
1: 175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
025 M – Sarkari Talai Male
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Lahpur
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 025
MALE
NUMBER OF DATA POINTS: 14
95% KERNEL: 23.79sq.km
50% KERNEL: 5.14sq.km
LCSV DISTANCE: 665.81m
N
W
E
S
1:175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m


RANTHAMBORE NATIONAL PARK, RAJASTHAN
SURVEYED: MAY, 2005
This map was prepared by SUJOY CHAUDHURI, Fellow, CI-CABS and eCOLLAGE
026 M – Rawara Dang Male
Otwara
KELADEVI WILDLIFE SANCTUARY
Anatpura
Bhakulla
Khowa
RANTHAMBORE
RANTHAMBORE FORT
KHANDAR
Mordungri
Gopalpur
SAWAI MANSINGH WILDLIFE SANCTUARY
Behraonda
Pipalda
WPSI
TIGER ID 026
MALE
NUMBER OF DATA POINTS: 6
95% KERNEL: 63.27sq.km
50% KERNEL: 9.48sq.km
LCSV DISTANCE: 1505.43m
N
W
E
S
1:175,000
Pugmark Impression
95% Kernel
50% Kernel
Protected Area
Stream Network
Contours @ 50m

## Observations & Limitations

*Terrain:*

The best pugmarks are found on dry, fine, level soil. Ranthambhore National Park provided ideal conditions and it is also small in size, which made it possible to obtain a precise estimate of the tiger population. A prerequisite of the Digital Pugmark technique is good pugmark sets and this method may only be feasible in a few areas. The technique may need modification if it is used over a larger area and, of course, it cannot be used in areas with high rainfall (e.g. Namdapha) or mangroves (e.g. Sunderbans).

*Baseline Data Collection:*

If the census area is fairly large and well populated by big cats, the initial collection of base-line data will be time-consuming and arduous. However, it is important to collect and analyse exhaustive field data as this will give the most comprehensive results. The Digital Pugmark technique cannot be used on plaster casts of pugmarks.

*Tiger Movement:*

Due to the unpredictable movement pattern of tigers, that often walk long distances, many pugmarks trails will be found on some days, while other days there might be none. However, over a census period of 15 days and if the PIPs have been strategically placed, enough pugmark trails should be found to make data collection and statistical analysis possible.

*Tiger Gender:*

The gender of a tiger can only be accurately characterised using adult pugmark sets.

*Infrastructure:*

A good infrastructure – mobility and wireless communication – is essential. Forest Guards on foot patrols equipped with wireless handsets should immediately send a message to the camera team when they find a fresh track of pugmarks. Thanks to the cooperation of the Forest Department and the infrastructure in Ranthambhore, a swift response was possible allowing the teams to record as many 21 pugmark sets in a single day. A Forest official familiar with the area accompanied each team.

*Digital Photography:*

It is not possible to take usable photographs of pugmarks in strong, direct sunlight, or when shadows are minimal. The best time to take photographs is early morning when the sunlight is angled. By the evening, pugmarks often get obscured by other animal tracks.

*Personnel:*

A digital pugmark monitoring exercise should be carried out by personnel trained in such data collection since the readings have to be very precise. It might be difficult for most Forest Guards to carry out the procedure. Depending on the area that is being monitored there should be from 5 to 12 camera teams of 1 to 2 people each, and the data should be collected for a minimum of 15 days. Ranthambhore National Park provided ideal conditions and 5 trained teams were adequate to cover the Park.

*Equipment:*

Essential equipment includes a good laptop computer (with at least 256 MB Ram plus a USB port, CDR/RW, 40 GB hard disk and a memory card reader), digital cameras (with a minimum of 4 megapixels – we used Nikon Coolpix 4100), GPS units, small rulers and steel retractable measuring tapes, prescribed data sheets, and good transport and wireless communication.

*Analysis:*

Last but not least, analysis can only be carried out by an experienced computer operator with trained analytic skills. More robust population estimates can be obtained using the tiger identities in a mark-recapture framework.

## Acknowledgements

The huge amount of data was collected by an extraordinary group of individuals: Nitin Desai (team leader and Director, WPSI Central India), Onkuri Majumdar (Legal Programme, WPSI), Chandramohan Khare (WPSI, Central India), Keya Chaturvedi and Payal Narain (Project Officers, WPSI), Trishna Dutta (field biologist), Tito Joseph (Database Officer, WPSI), and S. Guruvayurappan (WPSI, South India). Based in the field for 15 days, and without electricity in the searing heat of a Rajasthan summer, they were cheerful at all times and never missed a day of data collection. Trishna Dutta also untiringly assisted with the data analysis.

The purchase of the equipment and some of the costs were covered by a generous and timely donation from The Fund for the Tiger, USA. We would particularly like to thank the Chairman, Mr Brian Weirum.

We are indebted to Sujoy Chaudhuri and eCollage who generously offered to prepare the maps.

**Guru & Tito with the Lahpur Forest staff**

We are extremely grateful to the Ranthambhore National Park authorities for their extraordinary support, particularly with vehicles and communications, and in particular the Field Director Shri Shafaat Husain, DCF Shri G.S. Bhardwaj, ACF Shri Sudarshan Sharma and Range Officers Shri J.S. Hada, Shri R.S. Bhandari, and Shri S. Yadav. Numerous companionable Foresters and Forest Guards went out of their way to assist us. We would especially like to thank Shri Rathore, Nawal Singh, Brijmohan, Hansraj, Sualal, Prakash, Balkishan, Ghanshyam, Phoolchand and Gaffar, and drivers Ranjit, Manoj and Syed. Four of the camera teams were generously hosted by the Forest staff at Anatpur (Kundera Range) and Lahpur (Khandar Range).

And lastly, none of this would have been possible without the unstinting support of the Members of the Empowered Committee on Forest and Wildlife Management, and in particular the Chairman Shri V.P. Singh and the Member Secretary Shri R.P. Kapoor (PCCF, Government of Rajasthan).

*Sandeep Sharma*
*Belinda Wright*
*New Delhi June 2005*

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9. Sharma, S. (in prep.). *PUGMARK 1.0 - A software and database management system for population monitoring of tigers and other large felids.*


**Tigress in Ranthambhore, May 2005**

**Sharma et.al.** (*in press*): Identification of individual tigers from their pugmarks.
**Journal of Zoology**

# IDENTIFICATION OF INDIVIDUAL TIGERS FROM THEIR PUGMARKS

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RH: Identifying Individual Tigers ● *Sharma et al.*

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E-mail: san_cobra@rediffmail.com

***Abstract:*** Pugmarks have been used for identifying individual tigers (*Panthera tigris*) in India since *shikar* days; though the reliability of tiger population estimates based on pugmark-census has been questioned. Here we develop an objective multivariate technique to identify individual tigers from their pugmarks. Tracings and photographs of hind pugmarks were obtained from 23 pugmark-sets of 19 individually known tigers (17 wild and 2 captive tigers). These 23 pugmark-sets were then divided into two groups, one of 15 pugmark-sets for model building and another of 8 pugmark-sets for model testing and validation. A total of 93 measurements were taken from each pugmark along with 3 gait measurements. We used maximum CV ratio, maximum ***F***-ratio and removed highly correlated variables to finally select 11 variables from these 93 variables. These 11 variables did not differ between left and right pugmarks. Stepwise Discriminant Function Analysis (DFA) based on these 11 variables correctly classified pugmark sets to individual tigers. A realistic population estimation exercise was simulated using the validation data set. The algorithms developed here correctly allocated each pugmark set to the correct individual tiger. We also tested the effect of extraneous factors, i.e. soil depth and multiple tracers, and compared pugmark tracings with pugmark photographs. We recommend collecting pugmarks from soil depth ranging between 0.5-1 cm and advocate the use of pugmark photographs in lieu of pugmark tracings to eliminate the chance of obtaining substandard data from untrained tracers. Our study suggests that tigers can be individually identified from their pugmarks with a high level of accuracy and pugmark sets could be used for population estimation of tigers within a statistically designed mark-recapture framework.

**Key words*:*** footprints, individual identification, multivariate analysis, *Panthera tigris,* pugmark, spoor, tiger, tracks.

The estimation of number of individuals of a species in a population is a key question in the field of ecology and wildlife conservation (Caughley 1977, Seber 1992). Population estimates of any species are required for formulation of a conservation strategy, prioritization and allocation of resources, evaluating the success of conservation programs, and also for political reasons (Nowell & Jackson 1996, Karanth 2003). The tiger (*Panthera tigris*) is considered as an icon for conservation in all ecosystems wherever it occurs. Due to its endangered, umbrella, and flagship status, accurate and reliable population estimates are critical for implementation and assessment of conservation measures and management practices (Nowell & Jackson 1996). Felids are notoriously difficult to count (Bertram 1979). Population estimation of tigers is difficult due to their low densities, territoriality, nocturnal & cryptic behavior (Karanth & Nichols 1998, 2000).

Currently three methods are being used for population monitoring of tigers.

(i) Total count based on *expert* identification of tiger pugmarks to individual tigers in India (Panwar 1979a, Choudhary 1970, 1972, Karanth *et al*. 2003) Nepal (McDougal 1977, 1999) and Bangladesh.

(ii) The snow track encounter rate indices calibrated to tiger densities used in the Russian Far East (Miquelle *et al*. 1996, Hayward *et al*. 2002).

(iii) Mark-recapture technique based on tiger photographs obtained using camera-traps in a few selected tiger reserves (Karanth & Nichols 2000, Kawanishi & Sunquist 2004).

Of the above method used for population estimation of tigers, the camera trap technique using the mark-recapture framework is statistically most robust. However, for estimating population of any endangered species it is essential that the estimates are accurate as well as precise. The mark-recapture based population estimates of tigers using camera traps suffers from problems like high cost of equipment, risk of camera theft and low precision of density estimates especially in areas of low tiger density (Karanth & Nichols 2000) because the technique relies on sampling tigers only at a few predetermined locations (where camera traps are set).

However, we propose to use pugmark sets for identifying individual tigers in a statistical framework and then using them for tiger population estimates in a mark-recapture framework.

**Use of tracks for identifying individual animals**

Attempts have been made to identify individuals of a species based on its tracks. Researchers and field managers could distinguish between individual mountain lions (*Felis concolor*) by using deformations and gross differences in size and shapes (Currier, Sheriff & Russel 1977, Kutilek *et al*. 1983, Fitzhugh & Gorenzel 1985, Van Dyke, Brocke & Shaw 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, Lewison & Galentine 2000), in combination with radio-telemetry locations and distances between track sets (Currier *et al*. 1977, Shaw 1983, Fitzhugh & Gorenzel 1985,Van Dyke *et al*. 1986, Neal, Steger& Bertram 1987), and by morphometric analysis of pad shape (Grigione & Burman 2000). Successful attempts have also been made in identifying individuals of other species from their tracks e.g. Asian rhinos (Strickland 1967, Schenkel & Schenkel-Hullinger 1969, Kurt 1970, Borner 1970, Flynn & Abdullah 1983, Van Strien 1985), black rhino (*Diceros bicornis*) (Jewell, Alibhai & Law 2001), mountain tapir (*Tapirus pinchaque*) (Lizcano & Cavelier 2000), pine marten (*Martes martes*) (Zalewski 1999), snow leopard (*Uncia uncia*) (Riordan 1998), and jaguar (*Panthera onca*) (Marcelo Aranda & Carolyn Miller Personal Communication).

Tracking tigers for hunting was a tradition among Indian hunters, which flourished under royal patronage (Sankhla 1978, Singh 1999). Champion (1929) and Brander (1930) were the first observers to publish about characteristics of tiger pugmarks. It was claimed that gender, age, physical condition and also the individual identity of a tiger could be determined from its tracks (Corbett 1944, Choudhury 1970, 1971, 1972, Sankhla 1978, Panwar 1979 a,b; Jayarajan, 1983a,b; Sawarkar 1987, Basappanavar 1988, Gogate *et al*. 1989, Rishi 1997, Singh 1999).

**Use of pugmarks for monitoring tiger populations**

The first attempt to enumerate tigers from their pugmarks was done by W.J. Nicholson of Imperial Forest Service in Palamau district, Bihar in 1934, which gave him a figure of 32 tigers for an area of 299 $km^2$ (Jayarajan, 1983a). A systematic methodological approach for recording pugmarks for individual tiger identification and their *census*, from their pugmarks was formally conceptualized and advocated by S. R. Choudhury (1970, 1971). He introduced the ‘tiger tracer’ and developed the methodology of pugmark based census. This method was again fine-tuned by Panwar, (1979a), Sawarkar (1987), and Singh (1999). The basic premise of the methodology is that experienced persons can identify each individual tiger from their pugmark tracing (Panwar 1979a,b; Sale &

Berkmuller 1988, Sharma 2001). McDougal (1977, 1999) also identified a few resident individual tigers from their pugmarks in Chitwan national park, Nepal.

The reliability of the pugmark census technique has often been questioned due to its subjectivity and lack of validation on populations of known free ranging tigers (Schaller 1967, Singh 1972, 1984, S.D. Ripley quoted in Sankhla 1978: Pages 190-191; Karanth 1987, 1993, 1995,1999, 2003, Karanth & Nichols 2000, Karanth *et al*. 2003). Critics of the technique believed that an individual tiger's pugmark changes in shape and size over different substrate (soil texture, moisture and depth). Another source of variability is the variation between different tracer's ability to trace the features of the pugmark over the tracing sheet (Karanth 1987).

The currently used technique of tiger population estimation based on pugmark is believed to suffer from the following drawbacks (Karanth *et al.* 2003).

i. Poor data quality: Pugmark tracings and plaster casts obtained by several field personnel are often inconsistent and of poor quality.
ii. Individual tigers are believed to be identifiable from these substandard data by supervisory officials.
iii. The method assumes total enumeration of tigers by obtaining pugmarks of all tigers that are subsequently identified to individuals.

Attempts have been made to quantitatively and objectively assess the pugmark based individual identification of tigers (Gogate *et al*. 1989, Gore *et al*. 1993, Das & Sanyal 1995, Riordan 1998). These studies suggest that pugmarks do possess quantifiable information that could permit individual identification. However, due to limitations of an experimental design and lack of appropriate sample size of pugmark data from known tigers, these studies were not conclusive. Recent more definitive studies on tracks of mountain lions (Smallwood & Fitzhugh 1993, Grigione *et al*. 1999, Lewison, Fitzhugh & Galentine 2001) black rhinos (Jewel *et al*. 2001), mountain tapirs (Lizcano & Cavelier 2000), snow leopards and tigers (Riordan 1998), jaguars (Carolyn Miller Personal Communication) and pine martens (Zalewaski 1999) used a quantitative approach for discriminating amongst individuals on the basis of a group of track sets.

In the present study, we propose an objective approach for identifying individual tigers from their pugmark sets that has potential for use in population estimation and monitoring. We develop a multivariate model based on 9 variables from tiger pugmarks and two gait variables using Discriminant Function Analysis (DFA) that permits individual identification of tigers. Once individual identity of a tiger is ascertained, we propose to use this information in a mark-recapture framework (Pollock *et al*. 1990) for population estimation and monitoring.

## STUDY AREA AND STUDY DESIGN

To achieve the objective of this study we wanted to have a population of tiger pugmark sets with reasonable pugmark replicates from definitively known individual tigers. This was achieved by sampling tiger pugmark-sets from different tiger reserves and zoos in India (Table 1). Tracings or photographs of right and / or left hind pugmarks from a pugmark-set was collected if >5 replicates of of the same known tiger were found from a fresh pugmark trail. We ensured that individual pugmark-sets that were sampled within a tiger reserve were from different tigers, primarily by direct sighting of tigers (n=10 tigers). In few cases pugmark sets that were separated by distances > 50 km and formed within the past 12 hours were considered to be from two different tigers. Most of the pugmark-sets were collected from a long series of pugmarks, where the tiger had walked in normal gait. The gait was judged as normal after examining the pugmark trail for consistency in stride length and pattern of foot-fall (Sawarkar 1987).

Pugmarks from well-beaten dirt roads having finely pulverized soil depth of 0.5 to 1 cm, over flat terrain were traced on acetate sheets using indelible ink pen following the standard pugmark tracing technique (Choudhury 1971, Panwar 1979a, Fjelline & Mansfield 1989, Sharma, Jhala & Sawarkar 2003) and also photographed from a fixed height using a pugmark-photography stand (Sharma *et al.* 2003) by the first author (SS). Five to ten samples of gait variables i.e. stride, straddle and step, were also measured for each pugmark set recorded (Singh 1999, Zielinski & Kucera 1995) (Figure 1).

**Assessing tracer's variability and substratum effect**

The major sources of variability likely to influence individual identification from pugmarks were:

(a) The variability in pugmark shape and size due to soil depth.

(b) Variability associated with the different tracers and their tracing skills.

Pugmark sets of a known solitary tigress in Keoladeo National Park, Bharatpur (Rajasthan) were traced and photographed at three different soil depths of < 0.5 cm, 0.5 -1 cm and 2 cm respectively, over a period of 3 days.

To address the issue of multiple tracers' variability, three of us (SS, YVJ, VBS) traced the same 28 pugmarks from the pugmark sets of one male and one female tiger at the National Zoological Garden, New Delhi.

**Image analysis of pugmark tracings and photographs**

The pugmark tracings and photographs were scanned using flatbed scanner to convert them to digital images for further analysis. A 5 cm line was introduced in every tracing during the scanning for calibrating various measurements obtained from the pugmark. Assignment of centroids and morphometric measurements were obtained using Arc Info 8.0.2 (Environmental Systems Research Institute, Inc., Redlands, CA, USA), Arc View 3 (Environmental Systems Research Institute, Inc., Redlands, CA, USA) and Sigma Scan Pro 4 (SPSS Inc.) software.

A total of 93 measurements that were likely to cover most aspects of the geometry of a pugmark were measured from left as well as the right pugmarks. The reason for measuring a large number of variables was to extract maximum possible information from the pugmark and to determine which measurements likely had the maximum discriminating power between tigers. We used many of the same variables that earlier studies (Gogate *et al.* 1989, Gore at al. 1993, Das & Sanyal 1995) had identified as being useful. Out of the 93 variables measured, 47 were linear, 7 were area, 11 were angle, 18 were ratio and 10 were shape variables.

**Comparison of tracings and photographs of the pugmark**

To assess the use of pugmark photographs in place of pugmark tracings, we took photographs and tracings of three different pugmark-sets and performed statistical comparisons.

**Statistical methods**

The 23 pugmark-sets were divided into two groups, set 1 (n=15 pugmark-sets) for variable selection and model building and set 2 (n= 8 pugmark-sets) for model testing and validation. SPSS 8.0 (SPSS Inc.) was used for all statistical analysis. Since variables were of different scales, all were converted to their Z-scores before subjecting them to further statistical analysis (Zar 1984).

*Variable selection.--*

The objective of this exercise was to reduce the data dimensionality, so as to achieve maximum discrimination with a parsimonious model containing few robust variables. We used Maximum Coefficient of Variation (CV) ratio method and Maximum ***F***-ratio method as criteria to select variables.

In the maximum CV ratio method, the Coefficient of Variation (CV) for each measured variable of a pugmark set was computed for individual tigers ($CV_t$). A grand coefficient of variation ($CV_g$) was computed for the same variable from all pugmark sets of set 1 (tigers). $CV_g$ was then divided by the $CV_t$ for each variable to get maximum CV ratio ($CV_r = CV_g / CV_t$) . This procedure was repeated for all variables. A large value of $CV_r$ denotes that a particular variable has small variation within pugmark-sets relative to between the pugmark-sets (tigers). Such variables would have a greater capability to discriminate between individual tigers.

For maximum ***F***-ratio method we computed for each variable i) the sum of squared deviations of individual variable from their mean for each pugmark-set ($S_w^2$), ii) and the sum of squared deviations of group averages of each variable of each pugmark set from the grand mean obtained from all pugmark sets ($S_b^2$). The ***F***-ratio is $S_b^2 / S_w^2$ (Zar 1984). A large value of ***F***-ratio for a particular variable suggests that it is fairly consistent within the same pugmark-set but differs between the pugmark-sets of different tigers. Such variables would have better ability to discriminate between different tigers.

Though the left and right pugmarks of the same tiger were not mirror images of each other, it seemed likely that some of the variables we had measured were similar between the left and right hind foot. If some of these variables of the left and right pugmark could be pooled for the analysis, then the number of variables in the model would be reduced thereby giving a more parsimonious model. Along with these the samle size of pugmarks in a pugmark set will increase (left and right together) thereby increasing the discriminating power of the model (Johnson & Wichern 1992). The variables selected by the maximum CV, and F ratios were paired for left and right pugmarks of the same pugmark-set and tested by a paired ***t***-test (Zar 1984). Pearson's correlation coefficients were computed for those variables that were not statistically different between left and right pugmarks of the same tiger. Only one of a pair of highly correlated variables ($r > 0.8$, $p<0.05$) was selected for further analysis.

*Ability to Discriminate Individual tigers.--*

We used Multiple Group Stepwise DFA for discriminating between individual pugmark-sets (tigers). The Smallest F-ratio method with a probability of 0.05 for variable entry and 0.1 probability for variable removal from the model was selected.

*Validation of model for individual discrimination of tigers by pugmark-sets.--*

1. We validated the model by using the variables selected above in a predictive DFA to correctly assign unknown pugmark-sets to individually known tigers (Williams 1983, Johnson & Wichern 1992). For predictive DFA each pugmark set (set 1 &2, n=23 pugmark sets) of 19 tigers was divided

into two halves, by randomly picking 50% of the pugmarks from all pugmark-sets. The first half of this data set was used as the training data set to develop discriminant functions. The remaining data set of pugmarks was used as a test set. Class assignment pattern for each pugmark into their respective pugmark set was examined.

Since the entire pugmark set (a series of continuous pugmarks made by the same tiger) and not a single pugmark implies the identity of a tiger, it was the accuracy of correct classification of the pugmark sets and not the individual pugmark, which were of relevance. The decision rule for correct classification of a pugmark set was devised on the correct classification of more than 50% of pugmarks of that test set to the correct training pugmark set (tiger). Considering a rare event when 50% of the test set of pugmarks was classified into 2 or more training sets, then the training set which had the larger average probability of classification of each pugmark from the test set was considered to be the group assigned by the model.

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

*Estimating the sample size of pugmarks in a pugmark set for accurate identification.--*

To estimate the number of pugmarks in a pugmark set that would be needed to accurately predict the identity of an individual tiger; we used a data set of 10 tigers that had a minimum of 10 pugmarks each in their pugmark sets. We attempted to discriminate between these tigers by starting with 2 pugmarks in each pugmark set and thereon incrementing the pugmark set by 2 pugmarks for each run of predictive DFA. We plotted the average percent accuracy of individual identification versus the number of pugmarks in a pugmark set.

*Tiger population estimation exercise.--*

In the previous exercise, the actual number of tigers was known a priori and the model was tested to predict the correct grouping of each pugmark-set to individual tigers. However, in a field population estimation exercise several pugmark sets could be recorded without knowing the identity of the tiger. An analytical technique needs to be developed that permits recognition of a set of pugmarks as belonging to a 'new' tiger or assigning the pugmark-set to a tiger whose pugmarks have been recorded earlier. In a typical field situation it is likely that multiple pugmark-sets of the same tiger from different locations are obtained.

To address this problem, a population of pugmark sets of 15 known tigers (set 1, n of pugmarks in pugmark sets were 6-10) and 8 pugmark sets (set 2, n of pugmarks in pugmark sets were 10-14) from tigers whose identity needed to be ascertained was used,. The eight pugmark sets represented four new tigers and two pugmark sets of tigers that were already present in the population of the 15 known tigers. We tested if our model (built from set 1) could correctly classify these 8 pugmark sets to the already known individuals and identify the new tigers as addition to the simulated population to predict the correct number of tigers represented by these 23 pugmark sets.

Each of the 8 new pugmark sets was entered in the model for discrimination one at a time. Half of the data of each new pugmark set was randomly split into two groups. One of the groups was given the identity of the pugmark set (training set) and the other half left unassigned to any group (test set). This data (new pugmark set along with 15 known tiger pugmark sets) was then analyzed using variables selected by the earlier model developed from set 1 with DFA. We examined the predicted group membership and probability of group assignment for the new pugmark set. The pugmark set was considered as a new tiger in cases where all the pugmarks of an entire pugmark set were classified as a distinct group. However, if some of the pugmarks of the pugmark set were classified into 2 or more groups, then we examined the probability of group assignment for each pugmark into those groups.

*Assessing effect of soil depth, multiple tracers, and comparison between pugmark photographs & tracings.*--

We used DFA to discriminate between pugmark sets of 5 tigers whose pugmark size was similar to that of the tiger whose pugmark sets were traced from soil depths of <0.5, 0.5-1, and 2 cm (Comparison of 8 pugmark sets).

DFA was used to compare the classification of pugmark-sets from tracings and photographs of the same pugmark sets. Six pugmark sets of 2 known tigers traced by three different tracers were compared with pugmark tracings of 5 other tigers (comparison of 11 pugmark sets) by DFA

## RESULTS

### Variable selection

By using a combination of maximum CV ratio and maximum *F*-ratio, we selected 33 variables out of the 96 variables, that maximized information from a tiger's pugmark for discriminating between individuals. Variables that differed between left and right hind pugmarks (paired t-test, $p<0.05$) were removed from further analysis. After removing one of a pair of highly correlated variables ($r > 0.8$, $p<0.05$) from the remaining variables, we were left with 11 variables, which were used as predictor variables in the stepwise DFA (Figure 1). All of the 11 variables were found to contribute significantly to the discriminant functions which correctly classified all of the 15 pugmark sets to individual tigers.

### Model Validation

In all the five test runs of the model validation, the test data set was correctly classified to the individual tiger. DFA analysis of the entire dataset (19 tigers, set 1 &2) gave 11 significant ($p <0.05$) Standardized Canonical Discriminant functions that correctly discriminated between tigers (Table 2). Pugmarks from most of the pugmark sets had a very high probability of correct classification. The average probability of correct classification of pugmarks to the correct pugmark set was 0.92 (sd 0.083).

### Variability due to substratum and multiple tracers

The pugmark-sets of the same tiger taken from two different soil depths (< 0.5 cm, and 2 cm) showed a wide dispersion and mixing with pugmark sets from other tigers. However, the pugmark set of the same tiger from a soil depth of 0.5 to 1 cm formed a distinct cluster (Figure 2).

The DFA correctly classified 11 pugmark sets belonging to 7 different tigers where 6 pugmark sets from 2 known tigers were traced by 3 different observers (one set per tiger by each observer) (Figure 3).

### Variability between pugmark tracing and pugmark photos

The results of this analysis showed that DFA could not differentiate between tracings and photographs of pugmarks. On examining the classification table it was found that pugmark tracings and pugmark photographs for the same tiger were classified as a single group.

### Sample size of pugmarks in a pugmark set.

Accuracy of pugmark classification to the correct pugmark set (tiger) increased as sample size of pugmarks in the pugmark set increased (Figure 4). A sample of 10 pugmarks per pugmark set gave an average accuracy of 96.2% (se 7.9) of correct classification of pugmarks to the correct tiger (pugmark set), while using the 12 pugmarks per pugmark set gave 100% classification accuracy.

**Population estimation exercise**

After considering the predicted group memberships and the probabilities of group classification, all of the 8 pugmark sets (6 sets representing 4 new tigers and 2 sets belonging to already existing tigers within the simulated pugmark set population) were correctly classified either as new tigers or as belonging to the already existing tigers (represented by the 15 known tiger pugmark sets). In cases where the newly entered pugmark set belonged to a new tiger, the classification was unambiguous in our dataset. However, when a pugmark set that entered the model belonged to an already existing tiger within the data set, there was intermixing of the test set pugmarks with the training set and with the pugmark set of the same tiger in set 1. The average sum of probabilities of intermixing of pugmarks belonging to the same tiger but from different pugmark sets was 0.713 (SE 0.072 with a 95% lower bound of 0.64).

## DISCUSSION, CONCLUSIONS & MANAGEMENT IMPLICATIONS

Our dataset, though limited to 23 pugmark sets of 19 tigers, strongly suggests the potential of using pugmark and gait variables for identifying individual tigers. Individual identification would be the first step for population estimation and monitoring. Total counts of tigers based on this method may only be feasible in very small reserves with a few tigers. However, in an average tiger reserve with even a moderate density of tigers, total counts would be very difficult to obtain (Karanth 2003, Karanth *et al*. 2003). Models based on a mark-recapture framework (Pollock *et al*. 1990) could provide population estimates when coupled with identifying individual tigers from their pugmark sets.

In most tiger reserves in Central and Western India conditions are conducive for obtaining good pugmark set data. Sampling pugmark sets has several advantages compared to sighting-resighting based on camera traps. Sampling based on camera traps is limited to predetermined sites and therefore needs much more effort in achieving required sample sizes for precise estimates of abundance especially in areas of low tiger densities (Karanth 1999, Carbone *et al*. 2001). In contrast, due to the tiger's habit of using trails, obtaining pugmark-sets is relatively easy. Sufficient samples of pugmark sets could be obtained even from low-density areas by intensive search.

A prerequisite for the currently available mark-recapture models is that the identity of a captured animal is known with certainty. Within our limited data set, we had achieved this level of accuracy of identifying each tiger uniquely from its pugmark sets. However, we caution that this may not be the case for all pugmark set data. There may be some pugmark sets whose identity may not be known with certainty. Our data suggests that a minimum of 10 pugmarks per pugmark set should be recorded in order to determine the identity of a pugmark set with a high level of certainty in a pugmark set population of about 20.

Pugmarks from a pugmark set would be classified into a group with a probability ranging from 0 to 1. One approach would be to set cut-off bounds based on large data sets from known tigers. For this data set the average probability of a pugmark being correctly classified to its pugmark set group was 0.92 (sd 0.083). When two pugmark sets from same tigers were considered, the average sum of cross-classification probability was 0.71 with a 95% lower bound of 0.64. Thus, if a new entrant pugmark set gets mixed with a pre-existing pugmark set and the average sum of this probability (of intermixing) is greater then 0.64, then we could consider the two pugmark sets as belonging to the same tiger. In rare cases, a pugmark set may get dispersed into several groups with small probabilities of classification in these groups. However, we did not come across such a case in our data. An approach to incorporate the error probabilities of uncertain identification into the population estimation model as reported for genotyping errors in mark-recapture studies (Lukacs & Burnhum, In Press) would need to be developed. In the 8 pugmark sets we used for the population estimation exercise, each set had data ranging from 10-14 pugmarks. We believe that larger numbers of pugmarks (>10) recorded for each pugmark set would increase the probability of correct classification in the model. We used pugmark set data from 15 known tigers as training data to which a new entrant pugmark set was added for comparison and classification. It is essential to have a training data set of a minimum of 5-8 known tigers. Preferably, these pugmark sets should be from both genders and of varied sizes (age groups). Each time a new tiger is added, the training data set increases in size. When a pugmark set is classified as belonging to a pre-existing tiger (in the training data) then the new pugmark set gets the same identity as that of the pre-existing set, thereby increasing its sample of pugmarks.

It is likely that the accuracy of correct classification of pugmark sets may drop as the number of pugmark sets being compared becomes large. However, for any meaningful comparison, we believe that the number of pugmark sets that actually need to be compared would be between 10-35. It would be pointless to compare tiger pugmark sets separated in space by >40 kms and in time by <12 hrs. Even considering sample sizes for multiple mark-recapture sessions (Pollock *et al.* 1990) it is unlikely that comparisons within and between sessions would exceed 35 pugmark sets even in high tiger density areas (as is seen from camera trap data in tiger habitats (Karanth & Nichols 2000). Our data strongly suggests that a high level of accuracy is likely to be achieved in individual identification of tigers within these sample sizes. Studies such as this would need to be replicated to ensure that this level of accuracy is replicable with other tiger pugmark set data.

The availability of suitable substrate is a limiting factor for obtaining useful pugmark sets. Thus, the method can be used only in those areas where the substrate is conducive for the registration of pugmarks e.g. in tiger habitats of central and western India and not in tropical rainforests, *terai* floodplains or mangrove swamps. Even with our limited data we caution that pugmarks registered in soil depths > 1 cm were likely to give imprecise results.

Pugmark based population monitoring has potential for monitoring of other large carnivores including felids, canids and ursids. With intensive data-collection this method could also be used for studying the gross ranging pattern of individual tigers when more invasive and expensive technology like radio-telemetry is not feasible. The method has been effectively demonstrated for obtaining sex-ratio in a tiger population (Sharma *et al.* 2003) and can be further developed to provide information on stage based population structure. The technique for pugmark based individual identification has potential for application in identifying problem tigers.

The methodology for individual identification proposed in this paper uses the quantifiable information from hind feet pugmarks and gait variables. Unique information could also be extracted from measurements of front feet pugmarks as also observed in mountain lions (Smallwood and Fitzhugh 1993). However, obtaining front feet pugmarks of tigers is not always possible since the hind feet pugmarks overlap the impressions of the front feet, thereby obliterating the front feet pugmarks. It would also be possible to use non quantifiable information in the form of various permanent idiosyncratic features like seams and creases in the pad, irregular placement of toes, distinct shape of toes, etc. for individual identification. Amongst our data set we found that such irregularities were obvious in 11 out of the 19 tigers. Such information though not used in the current study could be used in a logical framework to stratify pugmark sets that should be compared statistically. Such an approach would likely increase precision of individual identification by limiting comparisons between truly ambiguous pugmark sets.

Pugmark-based population monitoring of tigers is cost-effective, non-invasive, rapid and a practical method in harmony with the traditional practice of the tiger *census* done by wildlife managers. Because of this, the method is likely to be acceptable and possibly implemented, thereby filling an important void for an objective tiger population monitoring system in Central and Western India.

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**Table 1:** Details of the pugmark sets collected from individually known tigers from different study areas between Nov. 2000 to April 2001

| S.No. | Study Site | Number of Pugmark-Sets collected | Number of Individual Tigers represented by the pugmark-set | Number of Pugmark Collected | Average Number of Pugmarks per track-set (Range of Pugmarks) | Number of Pugmark photo-sets of Individual Tigers |
|---|---|---|---|---|---|---|
| 1 | **Keoladeo National Park**, Rajasthan | 3 | 1 | 22 | 7 ( 3-5 ) | 1 |
| 2 | **Ranthabhore Tiger Reserve**, Rajasthan | 8 | 8 | 80 | 10 (4-6) | 5 |
| 3 | **Kanha Tiger Reserve**, Madhya Pradesh | 7 | 6 | 78 | 11 (5-7) | 3 |
| 4 | **Bandhavgarh Tiger Reserve**, Madhya Pradesh | 2 | 2 | 16 | 8 (3-5) | 1 |
| 5 | **National Zoological Garden,** New Delhi | 6 | 2 | 33 | 11 ( 4- 18) | 2 |
| | **Total** | **26** | **19** | **229** | **10 (3-18)** | **12** |

**Table 2:** The Discriminant Function model coefficients and relevant statistics for the significant ($p<0.05$) Canonical Functions for a population of 19 known tigers.

| **Functions** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **AT3** | 0.321 | 0.003 | 0.692 | -0.318 | 0.325 |
| **MiT3** | -0.232 | 0.211 | -0.433 | -0.117 | -0.007 |
| **D23** | -0.222 | 0.037 | 0.728 | 0.548 | -0.546 |
| **LT'2** | 0.221 | 0.145 | -0.315 | 0.398 | 0.451 |
| **H** | 0.375 | 0.213 | 0.339 | -0.501 | -0.658 |
| **QT2T3** | -0.002 | -0.251 | 0.178 | 0.369 | 0.321 |
| **HLTL** | -0.338 | 0.012 | 0.187 | 0.144 | 0.359 |
| **DN1N2** | 0.192 | 0.209 | 0.179 | -0.096 | 0.114 |
| **Wpg** | 0.289 | -0.134 | -0.145 | -0.672 | 0.241 |
| **stride** | 0.373 | 0.917 | -0.299 | 0.238 | -0.235 |
| **stradle** | 0.788 | -0.579 | -0.148 | 0.277 | -0.050 |
| ***Eigenvalue*** | 18.68 | 10.36 | 2.18 | 1.81 | 1.33 |
| ***% of Variance*** | 51.94 | 28.82 | 6.05 | 5.03 | 3.69 |
| ***Cumulative %*** | 51.94 | 80.76 | 86.81 | 91.84 | 95.53 |
| ***Wilks' Lambda*** | 0.00 | 0.00 | 0.01 | 0.04 | 0.12 |
| ***Sig.*** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**FIGURE CAPTIONS**

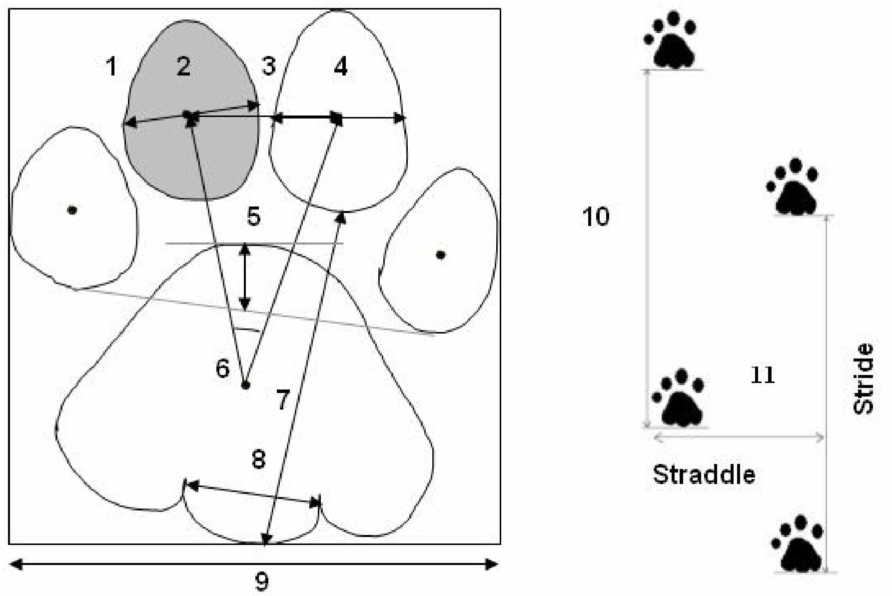
**Figure 1:** **11 final predictor variables used in the analysis, 9 measurements were taken from the pugmark while remaining 2 measurements were gait measurements taken form field.**

1. Area of toe no.3 (AT3)
2. Length of minor axis of toe no. 3 (MiT3)
3. Distance between toe no. 2 and toe no. 3 (DT2T3)
4. Length of minor axis of toe no. 2 (LT'2)
5. Distance between main pad top to toe base-line (H)
6. Angle between toe no. 2 and toe no. 3 (QT2T3)
7. Heel to lead toe length (HLTL)
8. Distance between notch 1 and notch 2 (DN1N2)
9. Width of the pugmark (Wpg)
10. Stride
11. Straddle

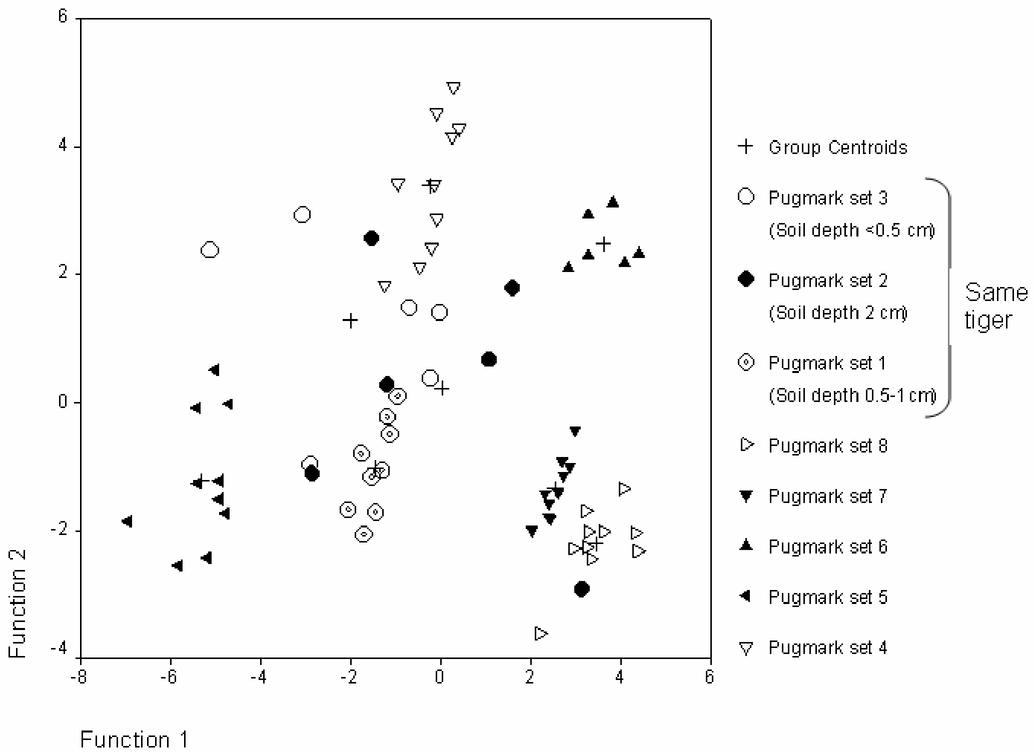
**Figure. 2.** Group centroids and pugmark clusters of eight pugmark sets on canonical function axis, using 11 variables. Pugmark sets no. 1, 2, and 3 are of same tiger traced from three different soil depths (<0.5, >2 and 0.5-1 cms.). Pugmarks of pugmark set 3 forms a single cluster, whereas pugmarks from pugmark set 1 and 2 are intermixed and dispersed in canonical space. Remaining five pugmark sets (Pugmark set no. 1, 2, 3, 4 and 5) are different tigers forming distinct clusters.

**Figure. 3.** Group centroids and pugmark clusters of 11 pugmark sets of 7 different tigers on canonical function axis, using 11 variables. Three different observers traced 6 pugmark sets of 2 different tigers. These are seen forming two distinct clusters here ascertaining that those 6 pugmark sets belongs to 2 distinct tigers. Rests of the 5 clusters are representing 5 different tigers.

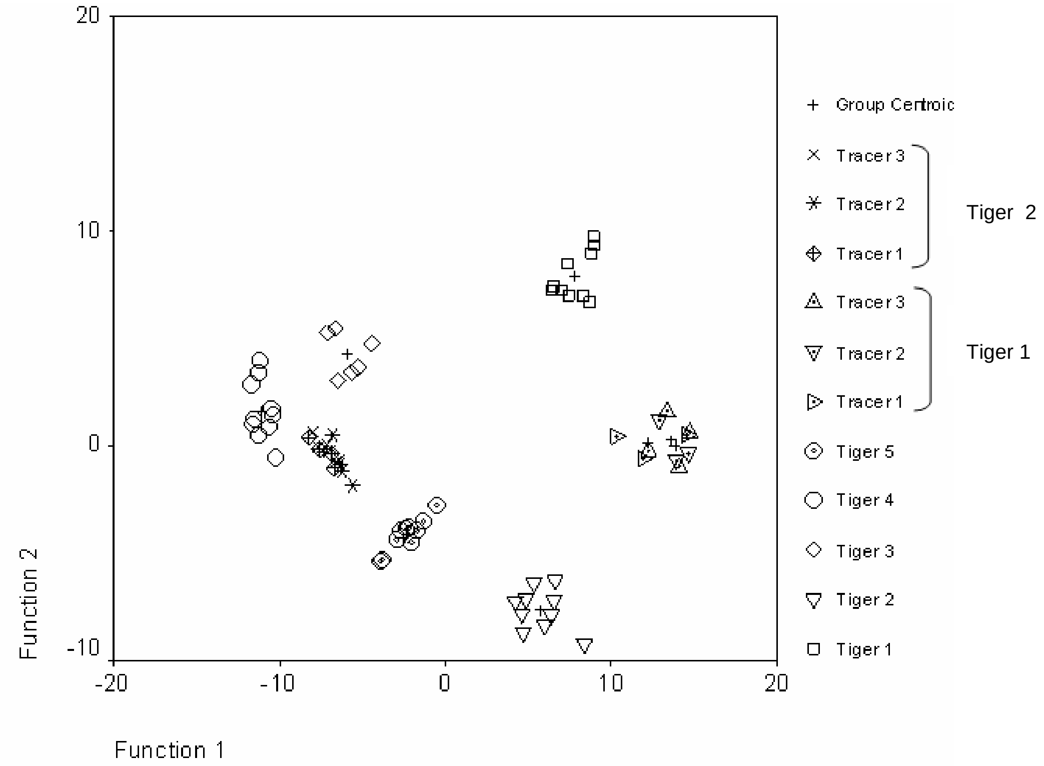
**Figure. 4.** Sample size estimation of number of pugmarks needed in a pugmark set for accurate classification. The error bars are standard errors.



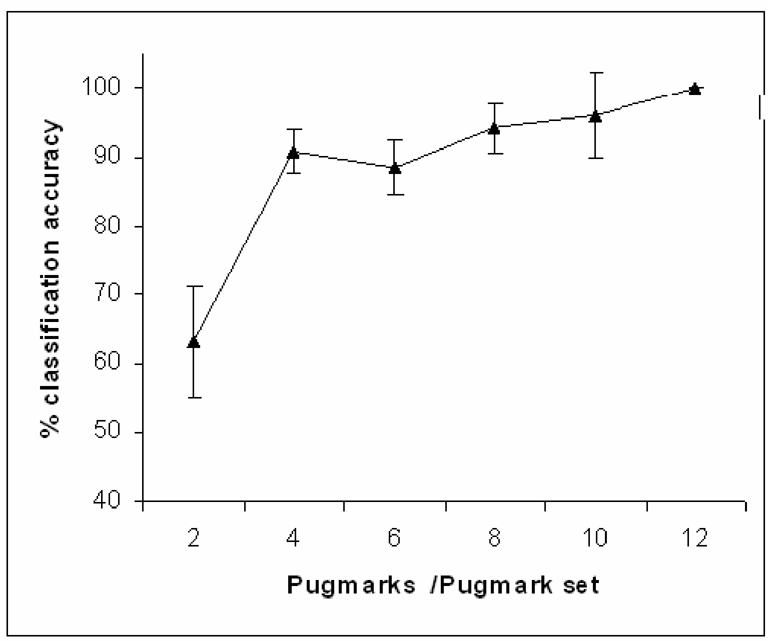
1
2
3
4
5
6
7
8
9
10
11
Stride
Straddle

Group Centroids
Pugmark set 3 (Soil depth <0.5 cm)
Pugmark set 2 (Soil depth 2 cm)
Pugmark set 1 (Soil depth 0.5-1 cm)
Same tiger
Pugmark set 8
Pugmark set 7
Pugmark set 6
Pugmark set 5
Pugmark set 4
Function 2
Function 1



20
10
0
-10
-20
-10
0
10
20
Function 2
Function 1
Group Centroid
Tracer 3
Tracer 2
Tracer 1
Tiger 2
Tracer 3
Tracer 2
Tracer 1
Tiger 1
Tiger 5
Tiger 4
Tiger 3
Tiger 2
Tiger 1

% classification accuracy
100
90
80
70
60
50
40
2
4
6
8
10
12
Pugmarks /Pugmark set

# Gender discrimination of tigers by using their pugmarks

***Sandeep Sharma, Yadvendradev Jhala, and Vishwas B. Sawarkar***

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

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

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

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

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

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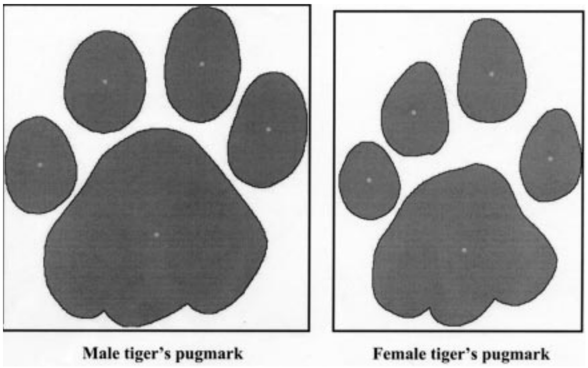


Figure 1: Hind pugmark of a male tiger and a female tiger showing the square-frame and rectangular-frame criterion for gender discrimination of tigers.

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

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

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

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

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

## Methods

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

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

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

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

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

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

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

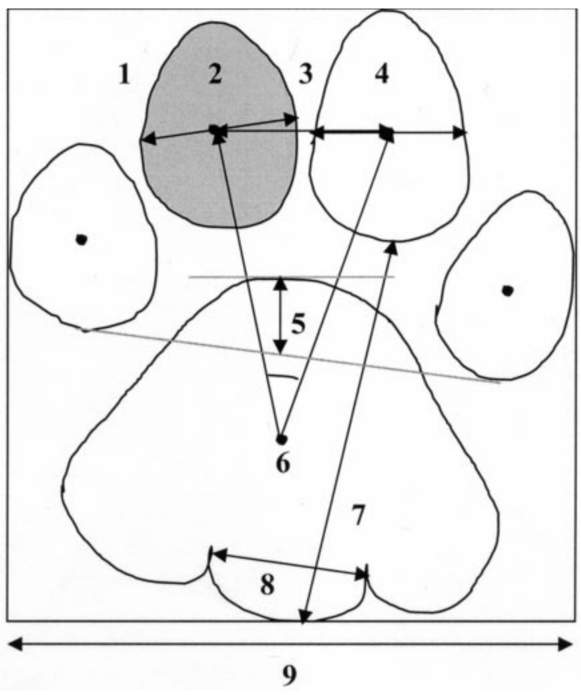


Figure 2. Nine pugmark variables measured from pugmark: (1) area of toe 3, (2) length of minor axis of toe 3, (3) distance between toe 2 and toe 3 (DT2T3), (4) length of minor axis of toe 2, (5) distance between main pad top to toe base-line (H), (6) angle between toe 2 and toe 3, (7) heel to lead toe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

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

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

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

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

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

## Results

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

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

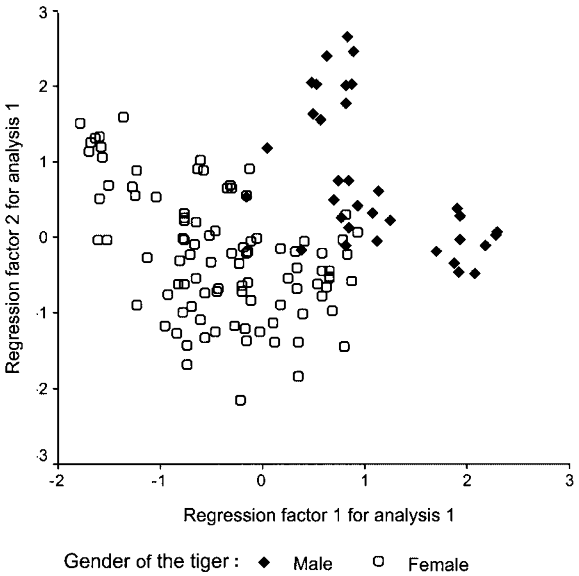


Figure 3. Scatterplot between PC1 and PC2 for 13 tigers of known gender, showing two distinct data populations of males and females, based on pugmark measurements.

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

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

For female tigers:

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

and for male tigers:

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

where,

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

and

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

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

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

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

For female tigers:

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

and for male tigers:

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

where

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

## Discussion

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

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

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

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

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

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

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

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

## Management and conservation implications

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

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

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

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

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

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

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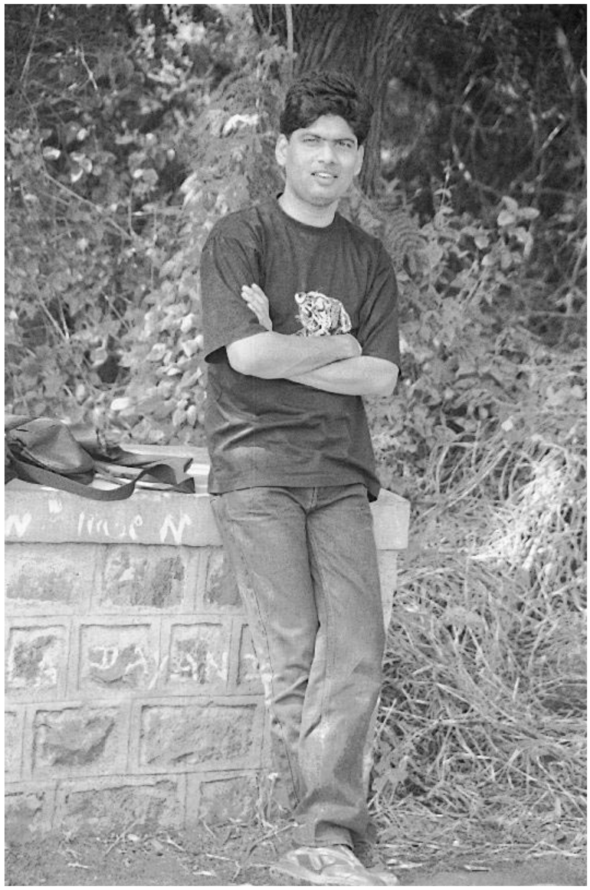

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