EVALUATING TIGER (*Panthera tigris*) POPULATION ESTIMATION APPROACHES IN A HIGH DENSITY AREA IN KANHA TIGER RESERVE.

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RISHI KUMAR SHARMA
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UNDER THE SUPERVISION OF

Dr. YADVENDRADEV V. JHALA

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

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भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE

This is to certify that *Mr. Rishi Kumar Sharma* of the Wildlife Institute of India has carried out original research titled "Evaluating tiger (*Panthera tigris*) population estimation approaches in a high density area in Kanha Tiger Reserve" for the partial fulfillment of the Master of Science (Wildlife Science) degree from Saurashtra University, Rajkot, India. These investigations were carried out under my supervision from November 2004 to June 2005. I also certify that this research has not been submitted for any other degree to any University.

Date: 22nd June 2005
Place: Dehradun

Jhala

Dr. Yadvendradev. V. Jhala
Head of Animal Ecology and
Conservation Biology
Wildlife Institute of India.

Post Box No. 18, Chandrabani, Dehradun - 248001. India
EPBAX : +91-135-2640111 to 2640115, 2640990 , FAX : 2640117 GRAM : WILDLIFE,
E-Mail : wii@wii.gov.in

Nature abhors a vacuum, and if I can only walk with sufficient carelessness I am sure to be filled.

- Henry David Thoreau

CONTENTS

LIST OF TABLES i

LIST OF FIGURES ii

ACKNOWLDGEMENT iv

SUMMARY viii

CHAPTER 1. INTRODUCTION 1

Current Conservation Status 2

Why is it Important to Estimate Numbers and Monitor Population Trends 3

Literature review 7

Importance of a Reliable Population Estimation Technique 7

Problems in population estimation of large carnivores 7

Use of Capture-recapture Approach 8

Use of camera traps within mark-recapture framework 9

Objectives of the study 10

Hypotheses 10

CHAPTER 2. STUDY AREA 11

Location 11

Climate 12

Vegetation 12

Fauna 13

Intensive study area 14

CHAPTER 3. METHODOLOGY 15

Field methods 15

Reconnaissance survey 15

Camera trapping 16

Intensive search method 19

Analytical methods 21

Camera trapping 21

Mark-recapture approach 21

Jackknife and bootstrap estimation 24
Intensive search effort 25
Mark-recapture approach using photographic
capture-recapture sampling 26
Jackknife and bootstrap estimation 26

CHAPTER 4. RESULTS 28
Camera trapping 28
Photographic capture of tigers 28
Sampling design 29
Inter-trap distance 29
Number of sessions 30
Increased camera spacing coupled with reduced sampling effort 31
Significance of a good reconnaissance survey 31
Activity pattern of tigers 31
Individual Heterogeneity in capture and trap shyness 32
Success rate of photo captures using camera traps 33
Test for population closure, model selection,
capture probabilities and population size 34
Estimates of effectively sampled area and tiger densities 36
Population estimate using Jackknife estimator 36
Population estimation using Bootstrap estimator 37
Intensive search effort 38
Capture-recapture or sight-resight of tigers 38
Test for population closure, model selection,
capture probabilities and population size 39
Estimates of effectively sampled area and tiger densities 39
Effect of pooling days of sessions on the accuracy and
Precision of population estimate using program MARK 40
Population estimate using Jackknife estimator 41
Population estimate using Bootstrap estimator 41
Effect of pooling days of sampling occasions on the accuracy and precision of
population estimate using jackknife and bootstrap estimators 42
Results for jackknife estimator (For intensive search effort) 43

Results for bootstrap estimator (For intensive search effort) 45

Comparing "camera trap" method with
"intensive search effort" method. 48

CHAPTER 5. DISCUSSION 49

Sampling design 49

Importance of a good reconnaissance survey 52

Activity patterns of tigers 53

Individual heterogeneity of capture and trap shyness 54

Use of camera traps for estimating population density of species that are not individually identified 55

Estimates generated by capture-recapture, jackknife and bootstrap estimators 56

Camera trapping versus intensive search effort 56

CHAPTER 6. CONCLUSIONS 58

LITERATURE CITED 60

LIST OF PLATES

Plate 1. Map of Kanha Tiger Reserve showing the intensive study area with camera trap locations.

Plate 2. Camera trap locations with the Minimum Convex Polygon, buffered with half the average distance between same tiger captures. A 95% kernel fitted to camera locations is also shown.

Plate 3. Map of Kanha Tiger Reserve showing the spatial distribution of individual tigers located by intensive search. A buffered Minimum Convex Polygon is fitted to the tiger locations to estimate the area sampled.

Plate 4. Spatial capture histories of individual tigers recorded by intensive search, with a buffered Minimum Convex polygon and 90% Kernel fitted to tiger locations.

Plate 5. Setting camera trap unit in field.

Plate 6. Self portrait of a tigress taken by a remote camera trap showing the unique stripe pattern on her left and right side. Note the track plot for recording details of the tiger pugmark sets.

APPENDICES

Appendix I Sampling schedule for camera trapping.

Appendix II Camera trap locations in the study area.

Appendix III Tiger intensive search effort matrix.

LIST OF TABLES

Table 1	Capture histories of 12 individual tigers "captured" in Kanha Tiger Reserve on 10 sampling occasions (30 days) during April 2005 to May 2005	**18**
Table 2	Capture histories of 12 individual tigers "captured" in Kanha Tiger Reserve on 17 sampling occasions (considering three days as one sampling occasion)	**20**
Table 3	Results from program CAPTURE showing model selection and population estimates generated by different models	**35**
Table 4	Effect of pooling days to generate variable number of sessions on the accuracy and precision of population estimate using program MARK	**40**

LIST OF FIGURES

Fig. 1	Map of the Kanha Tiger Reserve, showing the intensive study area in orange eclipse.	**14**
Fig. 2	Cumulative number of tiger photographs, indicating the number of individual tigers captured with increasing sampling occasions.	**28**
Fig. 3	Population estimates (with standard error) and number of individuals captured plotted against increasing inter-trap distance.	**29**
Fig. 4	Number of tiger photo captures, number of unique individuals, population estimate and standard error with decrease in the number of sessions from 10 to 4.	**30**
Fig. 5	Nocturnal activity pattern of tigers based on camera trap photo captures.	**32**
Fig. 6	Percent captures of individual tigers captured by camera trapping.	**33**
Fig. 7	Frequency of capture of different animal species using camera traps.	**34**
Fig. 8	Individual accumulation curve using jackknife estimator along with associated standard error.	**37**
Fig. 9	Individual accumulation curve using bootstrap estimator along with associated standard error.	**37**
Fig. 10	Frequency of sighting of individual tigers during intensive search effort.	**38**
Fig. 11	Decline in the number of "captures" and increase in standard error with decrease in the number of sessions (increasing the number of days per session).	**40**
Fig. 12	Individual accumulation curve using jackknife estimator along with associated standard error for intensive search effort.	**41**
Fig. 13	Individual accumulation curve using bootstrap estimator along with associated standard error for intensive search effort.	**42**
Fig. 14	Individual accumulation curve for 17 (three days each) sampling occasions.	**43**
Fig. 15	Individual accumulation curve for 10 (five days each) sampling occasions.	**43**
Fig. 16	Individual accumulation curve for 7 (seven days each) sampling occasions.	**44**
Fig. 17	Individual accumulation curve for 10 (ten days each) sampling occasion	**44**

Fig. 18	Individual accumulation curve for 17 (three days each) sampling occasions	**45**
Fig. 19	Individual accumulation curve 10 (five days each) sampling occasions	**45**
Fig. 20	Individual accumulation curve 7 (seven days each) sampling occasions	**46**
Fig. 21	Individual accumulation curve 10 (five days each) sampling occasions	**46**
Fig. 22	Comparing affect of pooling days on jackknife estimates	**47**
Fig. 23	Comparing affect of pooling days on Bootstrap estimates	**47**
Fig. 24	Comparison between tiger density estimates by "camera trapping" and "intensive search" effort across various estimators.	**48**

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SUMMARY

Reliable estimates of status and population trends are critical for the conservation of large terrestrial carnivores as they play an important role in evaluating effectiveness of conservation efforts and also provide benchmark data for future management decisions. Camera trapping technique have been widely used for population estimation of cryptic carnivores including tigers, but the issues regarding sampling design and effort required to effectively sample an area have been paid less attention.

An attempt was made to deal with these issues in the present study. The use of intensive search effort for tiger density estimation was also evaluated. Over a 30-day survey period, 33 camera trap sites were sampled in Kanha meadows of the Kanha Tiger Reserve. A total sampling effort of 330 trap nights yielded 39 photo-captures of 12 individual tigers over 10 sampling occasions that effectively covered a 111-km^2 area. The model M(o) fitted the capture history data well. The estimated capture probability/sample, p-hat = 0.22, resulted in an estimated population size and standard error ($N(SE\ N)$) of 13 (1.19), and a density ($D(SE\ D)$) of 11.71 (1.74)/100 km^2.

Camera spacing was found to considerably influence the population estimation. An increase in camera spacing from 1.5 to 2.5 km resulted in a loss of 35% (n=7) of photo captures which consequently decreased the precision of the estimates, though accuracy was not affected. A reduction in the trapping effort in terms of reduced trap nights resulted in lower level of precision though the accuracy of estimates was not affected.

Increase in the camera spacing from 1 to 2 km with a decrease in the number of sampling occasions (six) resulted in the loss of 42% of photo captures (n=12) and

loss of 25% of individual tigers ((M_{t+1}=9) thus underestimating the true tiger population by 16% (($N(SE\ N)$) being 10(1.84)

The data also suggests that the photo-captures are not likely to generate abundance index for species other than tigers, since the cameras are placed to maximize tiger captures in space and time.

My results suggest that a thorough reconnaissance survey is of utmost importance for camera trapping studies as it can help to maximize the capture probability of tigers and circumvent the sampling problems.

The different statistical estimator's viz. capture-recapture, jackknife and bootstrap did not show significant differences in the population estimation. Bootstrap estimator performed better than jackknife in terms of greater precision.

The differences between the density estimates generated by "camera trapping" (D=11.71/100 km^2, S.E.=1.74) and "intensive search effort" (D=12.74/100 km^2, S.E.=2.27) for tigers were not significantly different. Our results suggest that "intensive search effort" for tigers if used within capture-recapture framework can be used to arrive at reliable population estimates.

CHAPTER 1

INTRODUCTION

Reliable estimates of status and population trends are critical for the conservation of large terrestrial carnivores as they play an important role in evaluating the effectiveness of conservation efforts and provide benchmark data for future management decisions. However, the population estimation of large carnivores has always been controversial. Several methods have been employed to estimate tiger populations in India; "The Pugmark" based expert system (Choudhary, 1970, 1971, 1972; Sawarkar, 1987) and "Camera Trapping" in a mark-recapture framework (Karanth, 1995; Karanth & Nichols, 1998; Karanth *et.al.,* 2004) being the most widely used. However, methods used for population estimation of large carnivores have always been marred with one or the other problem because of low numbers and poor detection probability of large carnivores, which makes it extremely difficult to arrive at reliable estimates. In addition, reliable estimates of status and population trend of large carnivores are lacking due to high cost of sampling across large geographical areas (Smallwood & Fitzhugh, 1995). Methods for censusing endangered carnivores need to be practical and cost effective with regard to the prevailing socioeconomic conditions of the region.

The tiger serves as a flagship and umbrella species for conservation efforts in the Indian subcontinent (Jhala & Qureshi, 2004). It is the largest obligate terrestrial carnivore in all the mammalian assemblages in which it occurs in Asia (Seidensteicker *et. al.*, 1999). The charisma and awe associated with tiger has made it a hallmark for conservation efforts and this sentiment has been tapped to conserve overall biodiversity in several Asian countries. Since the tiger is at the apex of the food chain, saving the tiger means saving the complex ecosystems and habitats that lie within the tigers domain. The fate of the tiger is a good indicator of the conservation status of India's natural habitats and wildlife (Panwar, 1987). The importance of conserving this charismatic carnivore in terms of its ecological, aesthetic and ecological value cannot be overemphasized (Jhala & Qureshi, 2004). Humans have always looked at tigers with awe and suspicion. The tiger has been admired for its beauty and elegance on one hand and have invoked fear owing to its massive power and secretive nature on the other hand. The tiger have evolved in Asia and remained here tied to its close habitats (Seidensticker *et al.*, 1999). The people of Asia have lived with tigers and the tiger is very much alive in their consciousness, in their folklores and in their dances and their worships (Seidensticker *et al.*, 1999). It is essential that tiger survives not only in the consciousness of people but also in its real domain the Asian continent.

Current Conservation Status

The tiger once had the widest geographical distribution among large felids, stretching originally from almost 10 latitude south of the equator to (Java and Bali) to more than 60 north (the Russian Far East) and through more than 100 longitude (Nowell & Jackson, 1996). But owing to threats to its survival due to widespread over hunting of its prey, poaching of the tigers for commercial reasons and from habitat destruction (Seidensticker, 1986; Karanth, 1995), the conservation of this endangered cat have suffered several setbacks. The tiger is critically endangered; three of the eight putative subspecies are extinct and a fourth is close to extinction in the wild (Nowell & Jackson, 1996). All the populations are under severe pressure from loss of habitat and prey, hunting for their fur and for their use in traditional Chinese medicine (Kitchner, 1999). Over the last century, tiger's landscape has changed dramatically and tigers, their habitat and their prey have experienced increasing pressure due to expanding human population (Sunquist *et al.,* 1999). The degradation and fragmentation of the tiger's habitat has reduced ungulate abundance and distribution, which has caused decline in tiger numbers. For a once continuous distribution throughout southern and eastern Asia, there are now about 160 distinct and fragmented populations of tigers (Kitchner, 1999). The number of tigers have been decimated by 95% during this century (Jackson & Kemf, 1996) and remaining populations are in general small and fragmented (Wentzel, 1999). The entire subspecies from Bali, Java and areas adjacent to Caspian Sea have not survived and the South China tiger if not already extirpated from the wild, is down to a few individuals and is slipping away (Tilson *et al.,* 1999). The current tiger crisis in India in which the entire tiger population has been wiped out from Sariska Tiger Reserve and many known individuals went missing from other prominent reserves is also a pointer to the harsh fact that the tigers are not going to survive if immediate steps are not taken to conserve them.

Why is it Important to Estimate Numbers and Monitor Population Trends.

Reliable estimates of status and population trends are critical for the conservation of large terrestrial carnivores (Smallwood & Fitzhugh, 1995) as they play an important role in evaluating the effectiveness of conservation efforts and contribute baseline data for future management decisions. Several efforts have been made in the past to estimate tiger numbers using various methods including "Pugmark Method" (Choudhary, 1970, 1971, 1972; Sawarkar, 1987; McDougal, 1977, 1999; Smallwood & Fitzhugh, 1993; Grigione *et al.*, 1999) and "Camera Trap Method" (Karanth, 1995, Karanth & Nichols, 1998; Karanth *et al.*, 2004; Kawanishi & Sunquist, 2004). Though individual scientists, ecologists and scientific organizations may develop effective monitoring schemes for individual tiger reserves, or tiger population estimation methods, these would serve only an academic cause and contribute little to the tiger conservation unless they become institutionalized within the system responsible for implementing tiger conservation (Jhala & Qureshi, 2004). It need not be overemphasized that it is essential to monitor tigers to evaluate the management interventions and to have scientific information to react adaptively and solve problems (Karanth *et al.*, 2002). Scientific monitoring of tigers is also essential to generate data that can meet statistical rigour for analysis and appropriate inferences. The information generated thus can be readily made available to the managers, scientists and policymakers enabling them to make decisions on actual facts available from the field and not only on educated guesses, unreliable information or expert systems (Jhala & Qureshi, 2004). But do we know:

1. How many tigers are there in the wild?
2. Whether the population of tigers are increasing or declining in our protected areas?
3. The annual survival, recruitment and population change of tigers on a long term basis.

It is indeed surprising that we do not have even the basic information for many of our protected areas. The gloomy predictions of the tiger's future by the concerned experts have lead to several proposals to save the tigers from immediate as well as the future threats to ensure its survival in the wild. But there are no hard statistics concerning the tiger status compiled in any central database, no reliable index of the trend in tiger numbers, available habitat or available prey or even a catalogue of conservation activities underway (Seidensticker, 1999).

Though there are other important questions concerning the ecology and behaviour of tiger, but we have to accept that there is no escape from the number game. In general following techniques have been used for the population estimation of tigers:

1. Snow track counts of Russian Far East (Miquelle *et al.*, 1996).
2. Pugmark Counts in Nepal (Mc Dougal, 1977).
3. Pugmark Census in India (Choudhary, 1970, 1971, 1972; Sawarkar, 1987).
4. Pugmark analysis using multivariate statistics approach for individual I.D. (Sharma S., 2001; Sharma *et al.*, 2005).
5. Camera trapping. (Karanth, 1995; Karanth & Nichols, 1998; Karanth *et al.*, 2002).
6. Scat based DNA profile, which is an emerging technique.

Of the above-mentioned techniques, pugmark census and camera trapping have been extensively employed for population estimation of tigers in India. Both techniques have their pros and cons. Pugmark technique though simple and easy to execute have been severely criticized because of the subjectivity involved in the technique (Schaller, 1967; Singh, 1972; Karanth, 1987, 1995 & 1999; Karanth & Nichols, 2000). It has also invited criticism as it attempts to arrive at total population estimation without employing a formal statistical framework (Karanth *et al.,* 2003). The shape and size of the individual tigers pugmark is also supposed to change with variation over different substratum, soil texture, soil moisture and soil depth.

Similarly, camera trap based mark-recapture technique has also been criticized on account of being expensive, chances of theft of camera equipment and limitations in precise population estimation in low-density populations (Karanth, 1987, 1999). It have also been emphasized that individual tigers could be incorrectly identified by photographic capture records due to apparent changes in stripe patterns associated with the gait of the tiger and the angle of the camera (Goyal & Johnsingh, 1996). Froyland (1998) in his camera trapping study in Royal Bardia National Park in Nepal suggested that tigers might become trap shy after they had once been photographed by flash. Camera trapping study in a high-density area in Royal Bardia National Park in lowland Nepal showed that distance between the trapping stations and number of trapping nights can considerably influence the results (Wegge *et. al.,* 2004). The authors also suggest stratified sub sampling in larger protected areas to circumvent the problem of trap shyness.

LITERATURE REVIEW

Importance of a Reliable Population Estimation Technique.

Reliable estimates of numbers of animals in a population are of special importance in the conservation of big cats, not only for the formulation of conservation strategy but also for political reasons, for allocating resources for conservation efforts, and for evaluating success of conservation programs (Nowell & Jackson, 1996; Karanth, 2003). Felids are notoriously difficult to count (Bertram, 1979). The traditional population estimation techniques, such as transect count, waterhole count etc. cannot be applied for density estimation of cats, especially tigers (*Panthera tigris*), due to their unique ecological attributes like territoriality, low density, nocturnal and cryptic behaviour (Bertram 1979; Karanth & Nichols, 1998, 2000). Therefore, in this case one is left with no choice but to rely on indirect methods of population estimation.

Problems in population estimation of large carnivores.

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

Cats especially are notoriously difficult to count (Bertram, 1979). The traditional census techniques, such as transect count, waterhole count etc. cannot be applied for density estimation of cats, because of their irregular, individualized and cryptic behaviour and movements. The cats seem to defy the basic assumptions required for traditional density estimation methods.

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

The combination of above said ecological factors i.e. extensive spatio-temporal distribution, secretive life, wide ranging behaviour, low detectability and low densities, makes the task of monitoring tiger populations an extremely difficult one.

Use of Capture-recapture Approach.

The estimation of tiger numbers have always been controversial but with the increase in the understanding of the tiger ecology in the recent years, the concepts and methodologies in tiger population estimation have also been refined (Grigione *et al.,* 1999; Karanth, 1995). Though there have been a remarkable progress in the population assessment methodologies (Seber, 1982; Pollock, 1990; Nichols, 1992), monitoring of tigers remains a serious challenge. This is because tigers by their very nature are very shy and elusive animals. Their preference for dense cover and nocturnal ranging patterns make it difficult to observe them during surveys (Karanth & Chundawat, 2002). The direct census of tigers is not a very good preposition as it has several inherent biological and statistical weaknesses. Therefore, it becomes important to have a sampling based, model driven, formal framework with a sound theoretical basis for the estimation of animal, population densities. Capture-recapture framework is one such option having a sound theoretical basis and excellent analytical software (Program MARK- Cooch & White, 1995). Capture-recapture studies have been extensively used in the past for population estimation of rodents, fish, birds etc. The capture-recapture models have been frequently reviewed and refined (Otis *et al.,* 1978, Pollock *et al.,* 1990, Seber, 1982, Nichols, 1992) and rest on a sound theoretical basis. Capture-recapture models have been used to estimate population size, mortality emigration rate and birth immigration rate though not all the models permit estimation of all the three quantities. Traditionally, long-term capture-recapture data from studies that include natality, immigration, mortality and emigration have been analyzed using the Jolly-Seber (JS) method or some variant of it (Pollock *et.al.*, 1990). Alternatively, a closed-population capture-recapture study, where multiple samples are taken over a sufficiently short period to assume closure requires another set of methods for estimating abundance.

Use of camera traps within capture-recapture framework.

Karanth (1995) initiated the use of camera traps within mark-recapture framework to estimate the densities of tiger. Following this, the camera trapping was widely used as a tool to monitor uniquely identifiable animals which are difficult to monitor using traditional approaches of population estimation. Camera trap surveys have been widely used to estimate population of cryptic and endangered felids such as Tigers, Leopards and Jaguars (Karanth 1995; Karanth & Nichols 1998; Karanth *et al.,* 2004; Kawanishi & Sunquist, 2004; Kostyria *et al.,* 2003; Silver *et al.,* 2004). Carbone *et al.* (2001) proposed the use of photographic rates to estimate the densities of tigers and other cryptic mammals. They also emphasized the use of the technique proposed by them in arriving at abundance estimates of animals that do not have a unique identification. However Jenelle *et al.* (2002) pointed out the shortcomings of this approach and concluded that when individuals can be identified, the best value of camera trapping technique is to use it within the mark-recapture framework. For the species that cannot be uniquely identified, the approach may be used at best to detect the presence absence of the species from the sampled area. Although the camera trapping technique was used very widely, issues regarding sampling design received less attention. Wegge *et al.* (2004) in their study in Royal Bardia National Park in Nepal showed the effects of trapping effort and trap shyness on estimates of tiger abundance from camera trapping studies.

Objectives of the study:

The present study has following objectives:

1. To evaluate experimental designs for capture-recapture estimation of tiger densities using camera traps.

2. To estimate the sampling effort in terms of camera spacing (camera densities) and trap nights needed for obtaining precise and accurate population estimates of tigers in a high density tiger population.

3. To explore the use of "intensive search" for tigers for density estimation.

Hypothesis:

I. As sampling effort declines (reduction in the number of camera trap nights), precision of estimates should decline, however accuracy of estimates should remain unaffected.

II. When camera densities decrease and trap distances increase, there should be loss of precision and accuracy of estimates if individual tigers have a probability of not being sampled.

CHAPTER 2

STUDY AREA

Located in the Maikal hills of Satpura, Kanha Tiger Reserve is internationally acclaimed for its rich floral and faunal attributes. The Reserve is an excellent interspersion of the Dadars (flat hill tops), grassy expanses, dense forests and riverine forests. The reserve is a typical geo-physiographical representative of the Central Indian Highlands. As per the biogeographic classification of India (Rodger & Panwar, 2000), the area lays in zone-6-E - Deccan Peninsula - Central highlands. Nestled slightly east of the Centre of the highlands, it occupies for the most part, the northern slopes of the main Maikal ridge in the Satpuras, and the valley encompassed by the spurs of varying elevations extending from the main hill ranges. The reserve prides itself in successfully conserving two most endangered species viz: the tiger (*Panthera tigris*) and the Central Indian Barasingha (*Cervus duvaucelli branderi*).

LOCATION

Kanha Tiger Reserve sprawls across the central highlands of Madhya Pradesh from West to East, and is renowned for its anthropological and natural attributes. Falling in the districts of Mandla and Balaghat, the tiger reserve lies within the Maikal hills, situated within the Mahadeo hills of Pachmari and Chota Nagpur at the following geographical coordinates:

Longitude **80^0-26'-10" to 81^0-4'-40"**

Latitude **22^0-1'-5" to 22^0-27'-48"**

CLIMATE

There are three distinct seasons in Kanha Tiger Reserve (Gopal & Shukla, 2001) viz.

Summer: March to mid June (the hottest period extends from late April to the first week of June).

Monsoon: Mid June to late September (July and August are the wettest months, and the average annual rainfall is around 1200 mm.).

Winter: November to February (with night temperature dropping to -20C at times during December and January).

VEGETATION

Champion and Seth (1968) have identified following forest types in Kanha.

1) Moist Peninsular Sal Forests(3C/C2)
    a) High level sal (3C/C2 ci).
    b) Low level sal (3C/C2 cii).
    c) Valley sal (3C/C2 ciii).
2)
    A) Southern Tropical Moist Deciduous Forest (3A/C2 a).
    B) Southern Tropical Dry Mixed Deciduous Forest (5 A/c-3).

The floral diversity comprises of 609 species and 10 varieties of angiosperms belonging to 386 genera and 104 families, and 17 species of pteridophytes belonging to 11 genera and 9 families. The flora if reserve also includes around 50 species of aquatic plants and 18 species of rare plants (Lal *et al.*, 1986).

The major tree species are Sal (*Shorea robusta*) Saja (*Terminalia alata*), Lendia (Lagerstroemia parviflora), Dhawa(*Anogeissus latifolia*), Tendu (*Diospyrus melanoxylon*), Palash (*Butea monosperma*), Bija (*Pterocarpus marsupium*), Mahua(*Madhuca indica*), Aonla (*Emblica officianalis*), Achar *(Bruguira spp.)* and Bamboo (*Dandrocalamus strictus*) etc. Besides there are many species of climbers, forbs and grasses.

FAUNA

Mammals:

Chital (*Axis axis*) , Sambar (*Cervus unicolor*), Barasingha (*Cervus duvaucelli branderi*), Barking deer (*Muntiacus muntjak*) , Chousingha (*Tetracerus quadricorni)*, Gaur(*Bos gaurus*) , Langur (*Semnopithecus enetellus*) , Wild pig (*Sus scrofa*) , Jackal (*Canis aureus*), Sloth bear(*Ursus ursinus*), Wild dog (*Cuon alpinus*), Leopard (*Panthera pardus*), Tiger(*Panthera tigris tigris*) .

Reptiles:

Python (*Python molurus*), Indian Cobra (*Naja naja*), Russell's Viper(*Vipera russeli*), Indian Krait (*Bungarus caeruleus*), Common Rat Snake (*Ptyas mucosus*), Indian Monitor(*Varanus bengalensis*), Fan Throated Lizard (*Sitana ponticeriana)* and Indian Garden Lizard (*Calotes versicolor*) etc.

Birds:

The Reserve supports around 300 species of birds.

INTENSIVE STUDY AREA

The present study was limited to a small area of the Kanha Tiger Reserve. The intensive study area covered the Kanha and Kisli ranges of the Reserve, covering an effective area of approximately 175 square k.m. out of the odd 940 square k.m. of core zone of the Reserve. The total area of Reserve is 1945 square k.m. The choice of the study area was based on the relatively high density of tigers in the twin ranges of Kanha and Kisli as compared to other ranges of the reserve.

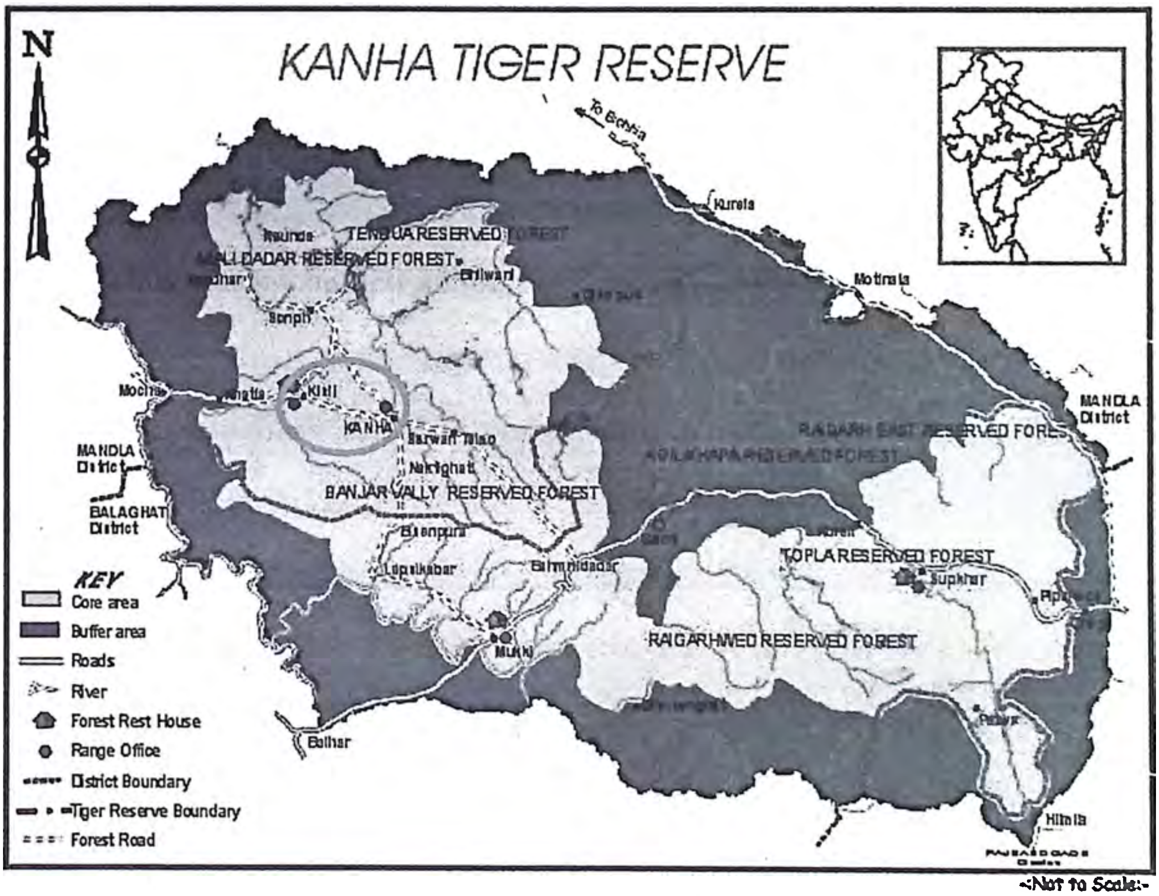


Figure 1. Map of the Kanha Tiger Reserve, showing the intensive study area in orange eclipse.

CHAPTER 3

METHODOLOGY

The study methods have been broadly classified into two categories.

(a) Field methods involving camera trapping tigers and identifying tigers through intensive photography through tiger shows and opportunistic sampling.

(b) Quantitative analysis of camera trapping data and intensive photography data.

FIELD METHODS

Reconnaissance survey

Reconnaissance survey was carried out in the month of November and December to locate and select suitable trap sites for deploying camera traps. The trap sites were selected based on cues of the use of the sites by the tiger such as scats, scrapes, scent marking, claw marks, pugmarks etc. The forest guards of the respective beats within the sampling area were also consulted to get a cue of the most extensively used trails such as those near the source of water. This was verified by walking on these trails to a distance of 0.5 to 1 k.m. to look for the signs of tiger presence. Initial survey yielded 40 potential trap sites which were marked using a hand held Global Positioning System These locations were overlaid on the map of the study area to determine the spatial spread of the trap sites and coverage of the area especially to detect large gaps without trap sites. Finally 33 trap sites were selected as required by the sampling design.

ESTIMATION OF TIGER DENSITIES USING PHTOGRAPHIC CAPTURE-RECAPTURE SAMPLING

CAMERA TRAPPING

A detailed overview of camera trapping tigers for the purpose of estimating abundance is given by Karanth (1995) and Karanth & Nichols (1998). The underlying concept is to lay the camera traps in the area of interest in a manner to maximize the chances of photographing the resident tigers. The main concern is to cover the area fairly completely, in the sense that it would be difficult for a tiger in the sampled area to travel about and not encounter at least one camera trap (Nichols & Karanth, 2002). The sampling design was modified to suit the needs of sampling strategy. We used a total of 11 *Trailmasters*™ (TM 1550) active infrared trail monitoring system which uses an invisible infrared beam across the trail between the transmitter and receiver. Each *Trailmasters*™ unit was connected to two cameras (Canon A1 Mini DX) using a multitrigger device which simultaneously fired both the cameras to take the picture of both the flanks of the animal. The cameras were placed at a distance of 5 meters on both sides from the centre of the trail so as to get the full frame pictures of the tigers. The camera delay was kept at minimum (so as not to miss a mating pair or a mother with cubs) and the pulse rate was kept at 5 based on our initial trial and error approach and taking into consideration the gait and the size of the study animal.

The study area was divided into three sampling blocks so as to divide our sampling effort equally across the entire sampling area. Each sampling block consisted of 11 trap sites, covering an area of 17, 13 and 12 sq. kms. respectively. *Trailmasters*™ unit along with the cameras was deployed in one block everyday on rotation basis so as to cover the entire study area in three days time. Thus each sampling occasion (Otis *et al.*, 1978) combined captures from three days of trapping (one day drawn from each block). There were 10 sampling occasions during the 30 days of trapping involving a total of 330 trap nights.

Each camera unit was given a unit identification number (I, II, III.....XI) and each roll was also uniquely marked (e.g. I/A1, II/B1, III/C1) thus enabling us to correctly match the time, location and picture resulting from each capture, thereby enabling accurate identification of individual tigers. To remove any ambiguity, all the 11 traps were monitored on a daily basis and resulting data recorded in a standard format. Since we had pugmark impression pads along with the camera units, we could correctly predict the number of tiger captures along with the captures of the other animals even before developing the camera trap rolls.

Every photo captured tiger was given a unique identification number (e.g. Tiger A, Tiger B etc) after carefully examining the position and shape of stripes on the flanks, limbs, forequarters and even tail (Schaller, 1967; McDougal, 1977; Karanth, 1995; Franklin *et al.,* 1999). I could also ascertain the sex of all the captured animals based on camera trap photographs.

Table 1. Capture histories of 12 individual tigers "captured" in Kanha Tiger Reserve on 10 sampling occasions (30 days) during April 2005 to May 2005.

Individual	Sampling occasion									
Identifications	1	2	3	4	5	6	7	8	9	10
A	1	1	1	0	1	0	0	0	0	0
B	0	0	0	1	1	1	1	0	1	0
C	0	0	1	1	0	0	0	0	0	0
D	0	0	0	1	0	0	1	0	0	1
E	0	1	1	0	0	0	0	0	0	0
F	1	0	0	0	0	0	1	1	0	0
G	0	1	0	0	0	1	0	0	0	0
H	0	1	1	0	0	1	0	0	0	0
I	1	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	1	0	0	0
K	0	0	0	0	0	0	1	0	0	0
M	0	0	0	0	0	1	0	0	0	0

Note- "1" signifies that the animal was photo captured on a particular occasion while "0" signifies that the animal was not photo captured on a particular occasion.

Plate 1. Map of Kanha Tiger Reserve showing the intensive study area with Camera Trap locations. The different symbols represent 3 blocks that were identified for ease of systematic sampling.

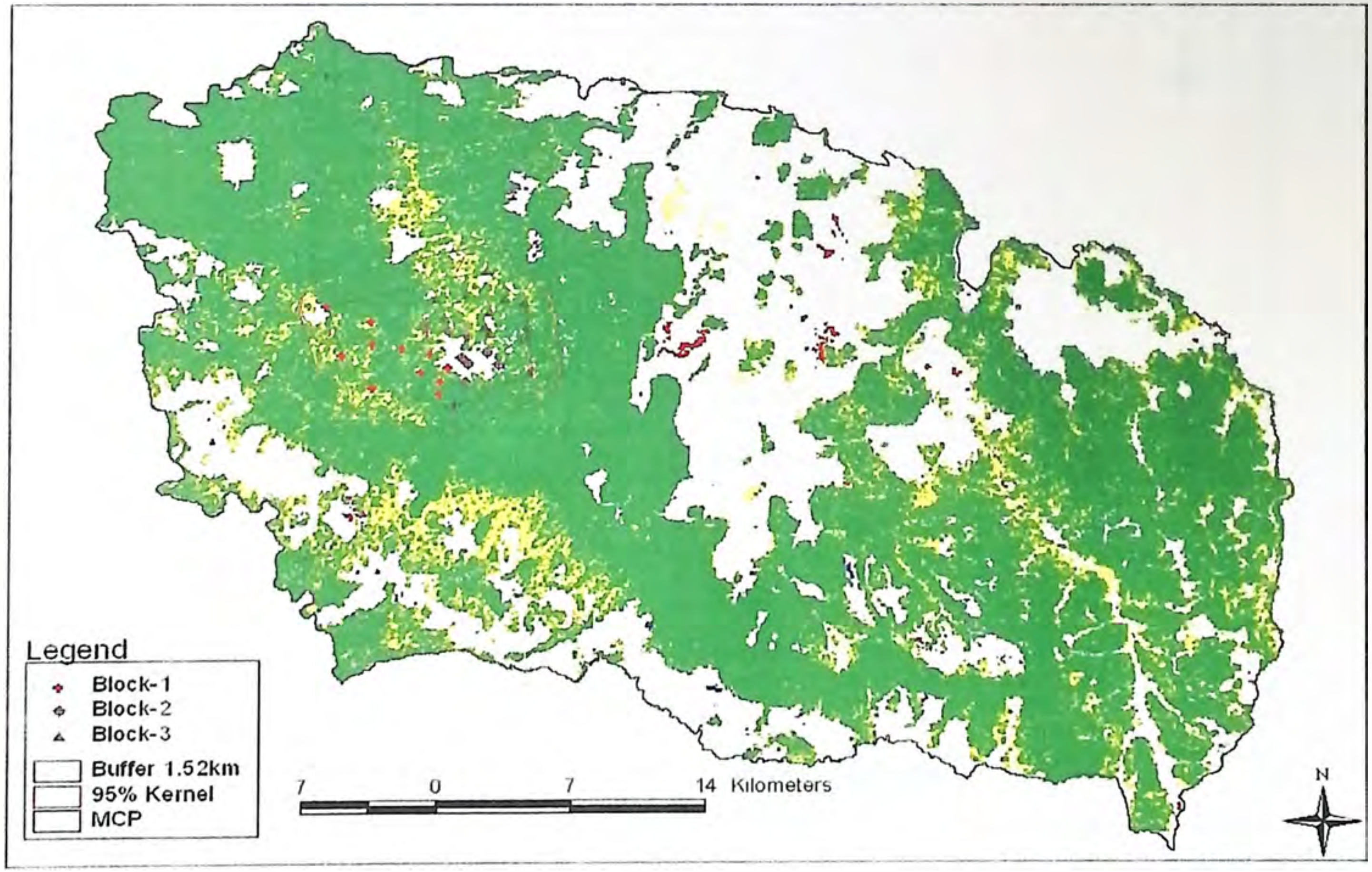
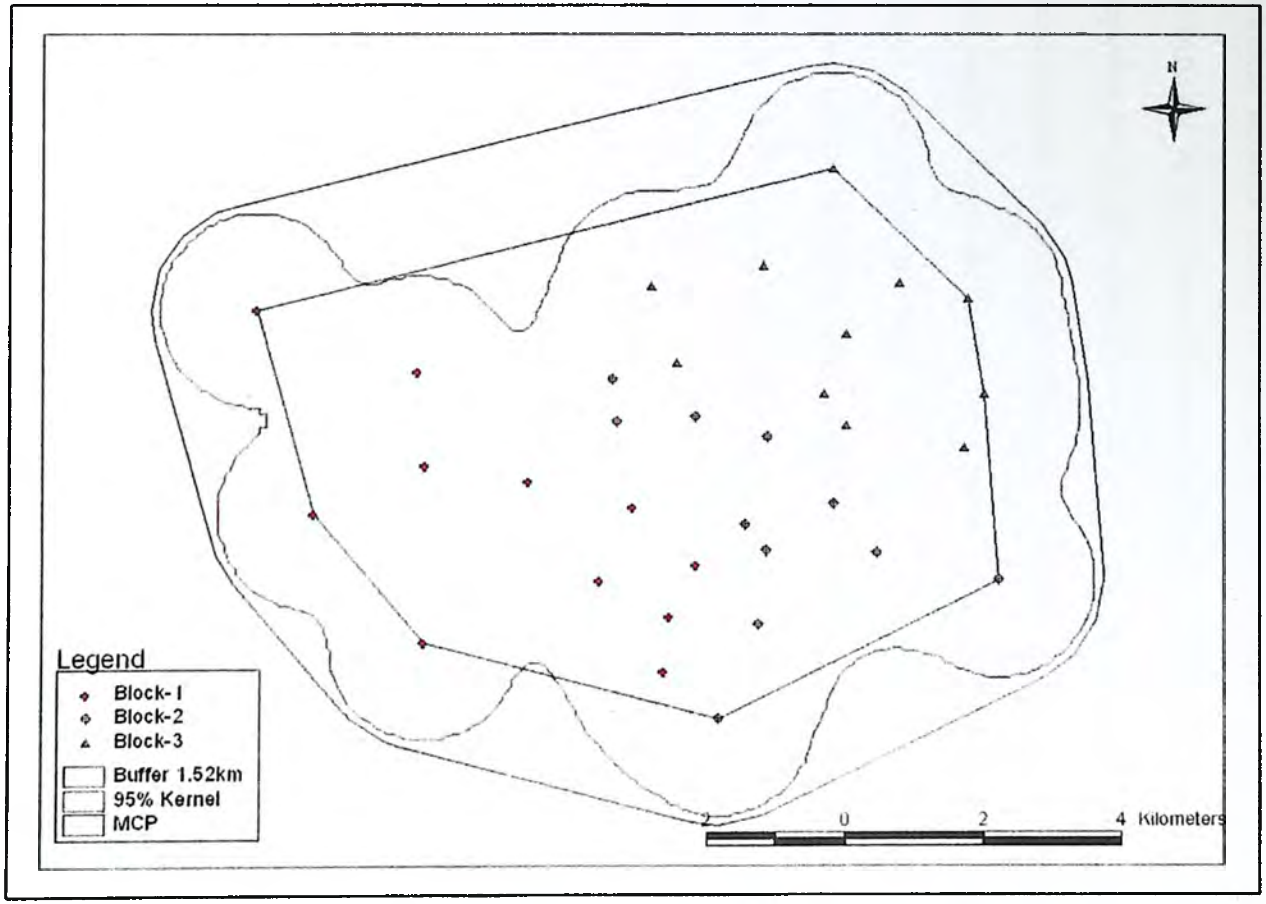


Plate 2. Camera Trap locations within the Minimum Convex Polygon, Buffered with half the average distance between same tiger captures. A 95% Kernel fitted to camera locations is also shown.



INTENSIVE SEARCH METHOD

An attempt was made to photograph as many tigers as possible in the study area besides camera trapping using the intensive search method. I had at my disposal, excellent wireless network facility of the Kanha Tiger Reserve. Forest guards, other researchers working in the Reserve, naturalists, park guides and elephant mahouts promptly reported any tiger sighting. All the tigers thus reported were photographed whenever possible using a Nikon F-65 camera with 80-300 mm zoom lens. Attempt was made to take picture of both the flanks, face and two to three full frame pictures from different angles. The individual tiger was closely observed with a Nikon 8x-40x binocular to find out any unique markings, injury, special facial patterns etc. In case the animal being too far for photography, sketches of prominent features were drawn. The animals which could not be identified with 100 percent surety were rejected. The GPS. location of each sighting was also recorded using a hand held GPS. Approximate age, sex and unique markings if any were also recorded. Over a period of time, an album of photographs of all the known individuals was developed with a brief description (approximate age, sex, unique markings, any other relevant information e.g. mating, association with other animals etc) of each individual tiger which was then used as a ready reference. The aforesaid information was meticulously recorded as it can provide a crude estimate of ranging patterns, mortality, survival, recruitment and other demographics parameters (Jhala pers. comm.). A total of eighty tiger sightings were recorded in the study area. I could successfully identify and sex all the individual tigers recorded through the intensive photography effort.

Table 2. Capture histories of 12 individual tigers "captured" in Kanha Tiger Reserve on 17 sampling occasions (considering three days as one sampling occasion).

Individual I.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0
C	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0
D	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
E	0	0	1	1	1	0	0	0	1	0	1	0	1	1	1	1	0
F	0	0	0	1	1	0	1	1	1	1	1	0	0	0	1	0	0
G	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
H	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
I	0	0	0	0	0	1	0	1	0	1	1	0	0	1	0	0	1
J	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1
K	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Note- "1" signifies that the animal was photo captured on a particular occasion while "0" signifies that the animal was not photo captured on a particular occasion.

Plate 3. **Map of Kanha Tiger Reserve showing the spatial distribution of individual tigers located by intensive search. A buffered Minimum Convex Polygon is fitted to the tiger locations to estimate the area sampled.**

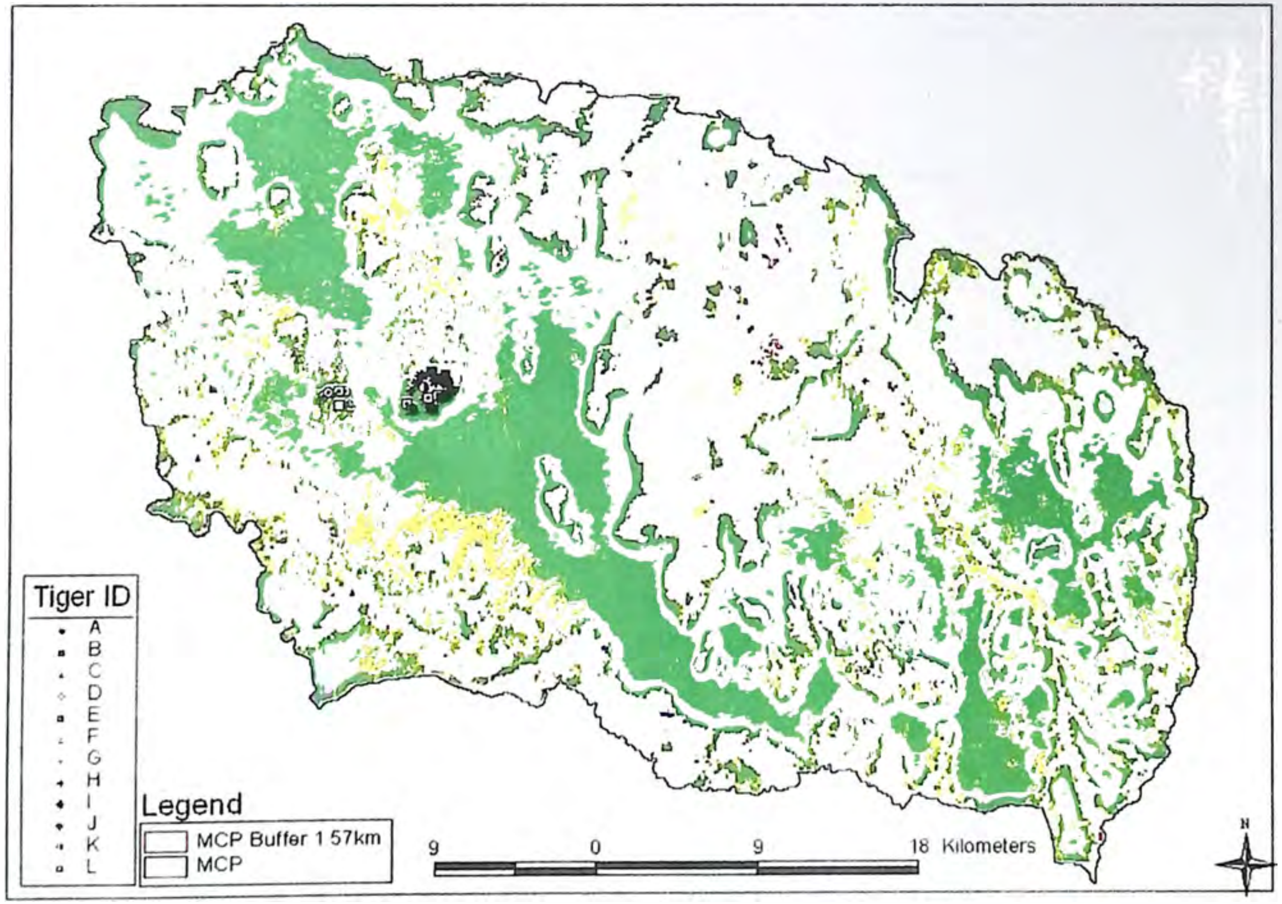
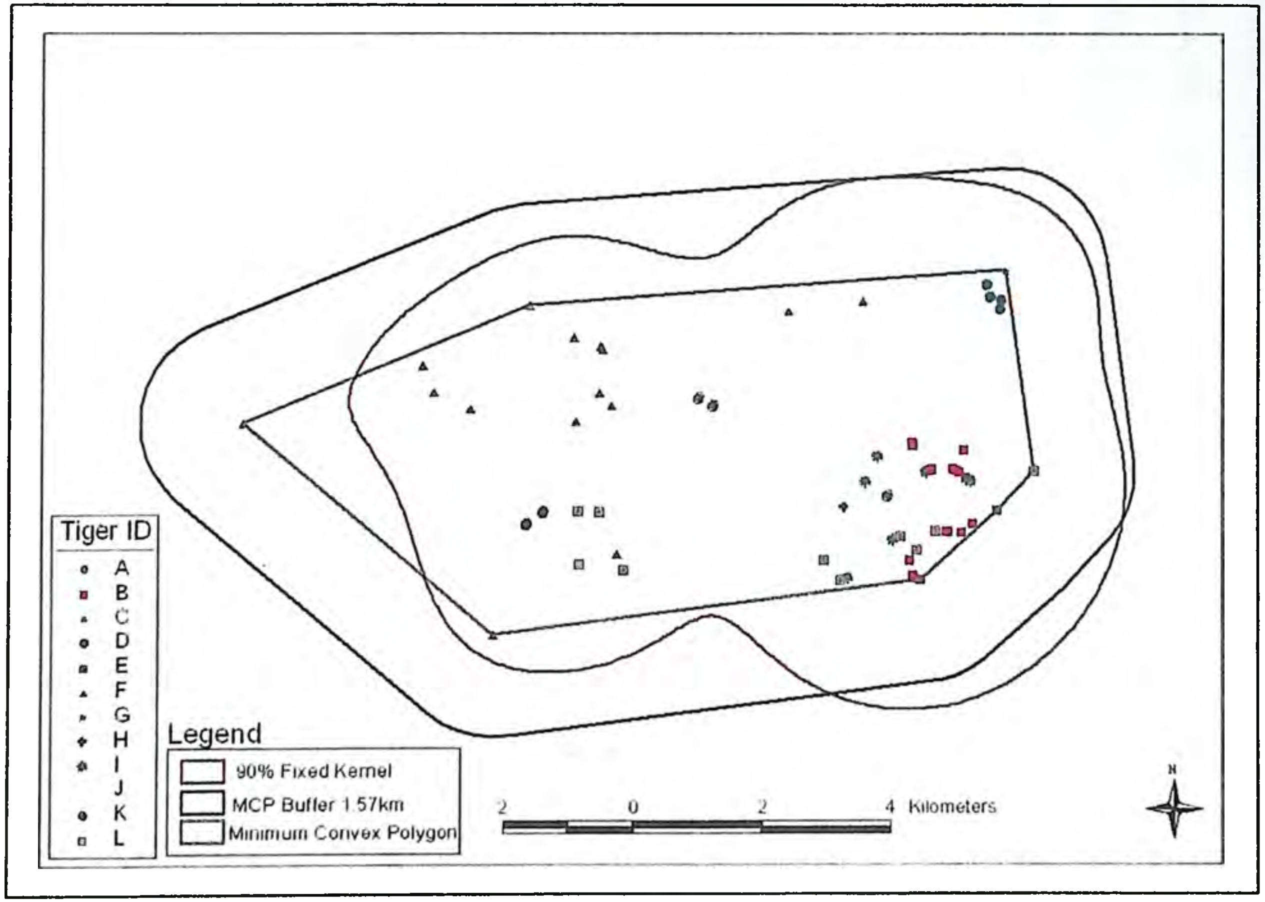


Plate 4. Spatial capture histories of individual tigers recorded by intensive search, with a buffered minimum convex polygon and a 90% Kernel fitted to tiger locations.



ANALYTICAL METHODS

Camera trapping

Mark-recapture approach

Individual capture histories for the identified tigers were constructed using a standard 'X-matrix format' (Otis *et al.*, 1978; Nichols, 1992), in which '1' indicates capture of a particular animal during a particular sampling occasion, while '0' indicates that the animal was not captured during that occasion. The capture history for animal *i* consists of a row vector of *t* entries, where *t* denoted the number of sampling occasions for the study site. Each entry, denoted as X_{ij} for individual *i* on occasion *j* assumed a value of either '1' or '0' depending on whether the animal was captured or not captured during that particular sampling occasion. For example a capture history of 0111001000 indicates that the particular individual tiger was captured only on second, third, fourth and seventh sampling occasion in a survey comprising of ten sampling occasions.

Because tigers are long lived animals (Sunquist, 1981; Smith, 1993), and sampling was carried out only for 30 days, it was assumed that the sampled population was demographically closed (Otis *et al.*, 1978; Karanth, 1995; Karanth & Nichols, 1998, Karanth *et al.,* 2004). To validate the closure assumption, the capture history data was analyzed using program CAPTURE (Rextad & Burnham, 1991) freeware from http://www.mbr-pwrc.usgs.gov/software.html. The program CAPTURE provides a statistical test for the assumption of population closure. The program also facilitates the objective comparison of several probabilistic models of the underlying capture-recapture process that are likely have to generated the observed capture histories (Otis *et al.*, 1978; Nichols, 1992). But I used program MARK (Cooch & White, 1995) for the population estimation. The closed captures models allow the modeling of the initial capture probability (*p*) and the recapture probability (*c*) to estimate population size (*N*). This data type is the same as is analyzed with Program CAPTURE (White *et al.*, 1982). All the likelihood models in CAPTURE can be duplicated in MARK. However, MARK allows additional models not available in CAPTURE, plus comparisons between groups and the incorporation of time-specific and/or group-specific covariates into the model.

Individual Covariates cannot be used with the closed captures data type because animals that were never captured (and hence, whose individual covariates could never be measured) are incorporated into the likelihood as part of the estimate of population size (*N*). Models that can incorporate individual covariates existing in the literature (Huggins 1989, 1991) have been implemented in MARK. Estimates of population size are given for the Huggins' models, but these estimates are not quite as efficient as the closed captures data type where the statistical models are equivalent to those in Program CAPTURE. However, the ability to incorporate individual covariates makes the Huggins' models more appropriate if individual heterogeneity exists in the data. Further, the Huggins models seem to provide more reasonable estimates of *N* when nearly all the population has been captured. The Huggins models provide the population size as a derived parameter, and MARK allows these derived parameters to be used in model averaging and variance components analyses.

In addition, the Pledger (2001) models using mixtures of *p* values to model individual heterogeneity have been incorporated into all the closed capture models available in MARK. The analysis of capture-history data involves the comparison between various possible capture-recapture models using a series of hypothesis tests and the results of an overall discriminant function test, in order to select the most appropriate abundance estimation model for a given data set (Karanth *et al.,* 2004). The various capture-recapture models offered in the program MARK consider the potential effects of the behavioral response of tiger to camera trapping (e.g. trap shyness or trap avoidance), time specific variation (e.g. weather changes) and heterogeneity between individual animals (resultant of a multitude of factors such as individuals territorial status, movement patterns, trap access etc.), on capture probabilities.

The following models (Otis *et al.*, 1978; Nichols, 1992) incorporated in MARK were considered in the analysis:

M_o: capture probability is same for all the tigers and is not influenced by behavioural response, time or individual heterogeneity.

M_h: capture probabilities are heterogeneous for each individual tiger, but not affected by trap response or time.

M_b: capture probabilities differ between previously captured and uncaptured tigers due to trap response behaviour, but are not influenced by heterogeneity or time.

M_t: capture probability is the same for all individual tigers, but varies during sampling only due to time specific factors.

The model selection procedure of program MARK also takes into consideration an array of more complex models such as $M_{(bh)}$, $M_{(th)}$, $M_{(tb)}$ and $M_{(tbh)}$, which incorporate the effect of heterogeneity, trap response and time in various combinations. The overall model selection function (*Otis et al.*, 1978) ranks potential models on a scale of 0.0-1.0, wherein the higher score indicates a better relative fit of the data to the specific capture-history data generated by the sampling. For each model the program MARK estimated capture probabilities per sample (*p-hat*) and the tiger population size, *N* (i.e. the number of tigers in the sampled area, including tigers that were not photo captured at all).

To evaluate the effect of camera trap spacing on accuracy and precision of density estimates, I systematically omitted data from 5, 10, 15 and 20 trap station spaced at 1.75 k.m., 2.0 k.m., 2.10 k.m. and 2.5 k.m. This was done to look at the effect of varied sampling designs on the precision of estimates. Next I varied the number of sessions for the study area, systematically decreasing the sessions from 10 to 4, to look at the effect of reduced sampling effort on the precision of population estimation. I also analyzed the effect of increased inter-trap distance coupled with a decrease in the sampling effort in terms of reduced number of sessions.

To study the importance of reconnaissance survey and its possible implications on study design, I omitted trap locations having poor or zero captures based on tiger presence data generated from one month monitoring of track plots laid at the trapping locations prior to camera trap sampling.

Jackknife and bootstrap estimation

I wanted to test the efficacy of species abundance models in predicting the number of individual tigers from abundance data generated through camera trapping. This was done because unlike mark recapture, where the input for population estimation is in the form of incidence (presence absence) data, the species accumulation models incorporate all the information from the data set as the estimate is generated from the abundances of individual tigers. The camera trapping data was subjected to Jackknife estimator to arrive at individual accumulation using program *Estimate S 7.50* (Colwell, 2005). Assuming each of my camera trap sessions to be a sample, I generated an individual tiger abundance matrix. The standard data format called as incidence or abundance matrix (N_{ij}) consists of a row vector of t entries, where t denoted the number of sampling occasions. Each entry denoted as N_{ij} for individual i on occasion j assumed an abundance value indicating the number of times it was captured on that occasion. This was done to capture maximum information instead of using just presence-absence (incidence) data. *Estimate S 7.50* computes expected species accumulation curves (sample based rarefaction curves) with 95 percent confidence intervals (Gotelli & Colwell, 2001) using analytical formulas of Colwell *et. al.,* (2004). Another advantage of Jackknife estimation using *Estimate S* is that unlike rarefaction curves that estimate richness using sub samples, jackknife estimator estimates richness including individuals that are not present in any sample.

I also used Bootstrap estimator to arrive at individual accumulation using program Estimate S 7.50 (Colwell, 2005).

Intensive search effort

The tiger intensive photography data was subjected to two different analytical approaches. Though this data can be used to ascertain the minimum number of unique individual tigers present in the study area by just counting the unique individuals seen or photographed using this approach, I subjected the data to a formal statistical analysis. This was done to see if this kind of data can yield reliable population estimates as compared to the most widely used technique of capture-recapture using camera traps.

Capture-recapture approach using photographic capture-recapture sampling.

The Individual capture histories for the identified tigers were constructed using a standard 'X-matrix format' (Otis *et al.*, 1978; Nichols, 1992), in which '1' indicates capture of a particular animal during a particular sampling occasion, while '0' indicates that the animal was not captured during that occasion. I had a 50 day sampling effort for tiger intensive photography spread over the study area. This was divided into sessions, each session comprising three days. This was done because only one block (out of a total of three blocks) of the study area was intensively sampled everyday, thus covering the whole study area in three days.

Assuming the three day session as a standard, I also analyzed sessions comprising varying number of days. I structured the 50 day sight-resight data into 17, 10, 7 and 5 sessions by pooling the number of days sampled in each session. Thus 17 sessions comprised of 3 days each, 10 sessions comprised of 5 days each, 7 sessions comprised of 7 days each and 10 sessions comprised of 10 days each. This was done to test the effect of pooling data on the accuracy and precision of population estimate, since in capture-recapture studies, an individual irrespective of the number of times it is captured in a. particular session is counted as one event.

Jackknife and bootstrap estimation.

Jackknife estimator was used to arrive at individual accumulation using program *Estimate S 7.50* (Colwell, 2005) as described earlier. For jackknife estimation also, the data was analyzed for varying number of sampling occasions. This was done by pooling varied number of days viz. 3, 5, 7 and 10 into a single sampling occasion. Thus I had 17, 10, 7 and 5 sampling occasions respectively for a sampling effort of 50 days.

The "intensive search" data was subjected to bootstrap estimator as well using program *Estimate S 7.50* (Colwell, 2005).

CHAPTER 4

RESULTS

CAMERA TRAPPING

Photographic capture of tigers:

During 30 days of trapping (April 2005 to May 2005), the three sampling blocks were sampled ten times each (Table 2). The total sampling effort amounted to 330 nights of trap effort documenting a total of 39 tiger photographs of 12 individual tigers (4 males and 8 females) over an area of 111 km^2. Though the number of individual tigers captured seems to stabilize at the VI^{th} session (Figure 1) or the 20^{th} day of sampling effort, the possibility of capturing more individuals with an increased sampling effort cannot be ruled out.

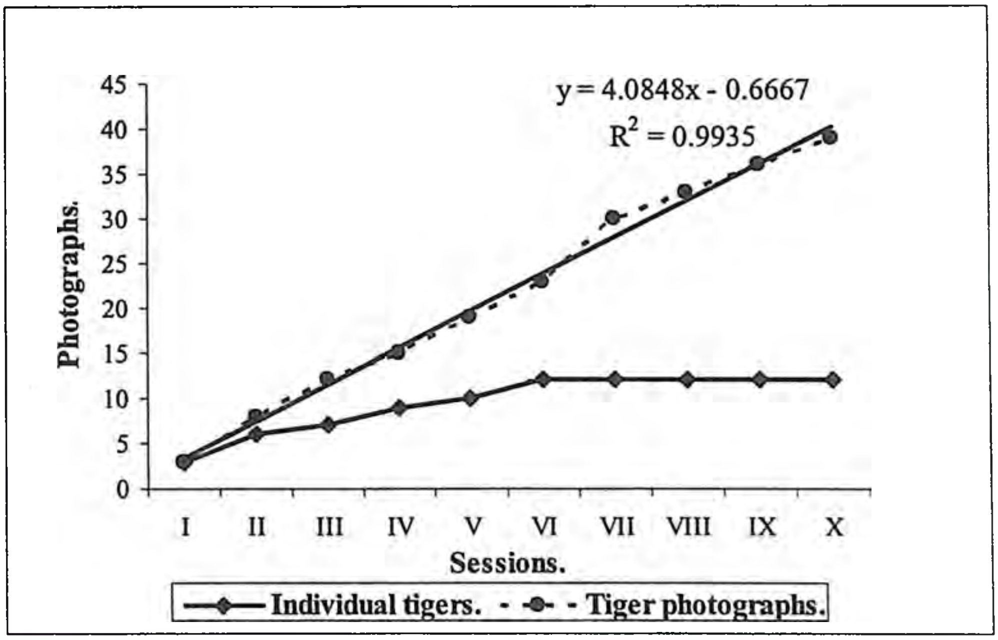


Figure 2. Cumulative number of tiger photographs, indicating the number of individual tigers captured with increasing sampling occasions.

Sampling design:

Inter-trap distance.

Since the minimum inter-trap distance used for the purpose of population estimation is 1.5 km, that will be considered as a standard to compare against the varying inter-trap distances. Increasing the regular spacing to 1.70 km does not result in loss of any individual. But increasing spacing further to 2.0 km results in loss of one individual. Increasing regular spacing further to 2.10 and 2.50 km respectively resulted in loss of two individuals each. There is a loss of 35% of photo captures at 2.5 km spacing. The population estimation also registered a decline, while the standard error on the population estimate also increased with the increase in camera spacing. This highlights the importance of a robust study design in camera trap studies using mark-recapture framework.

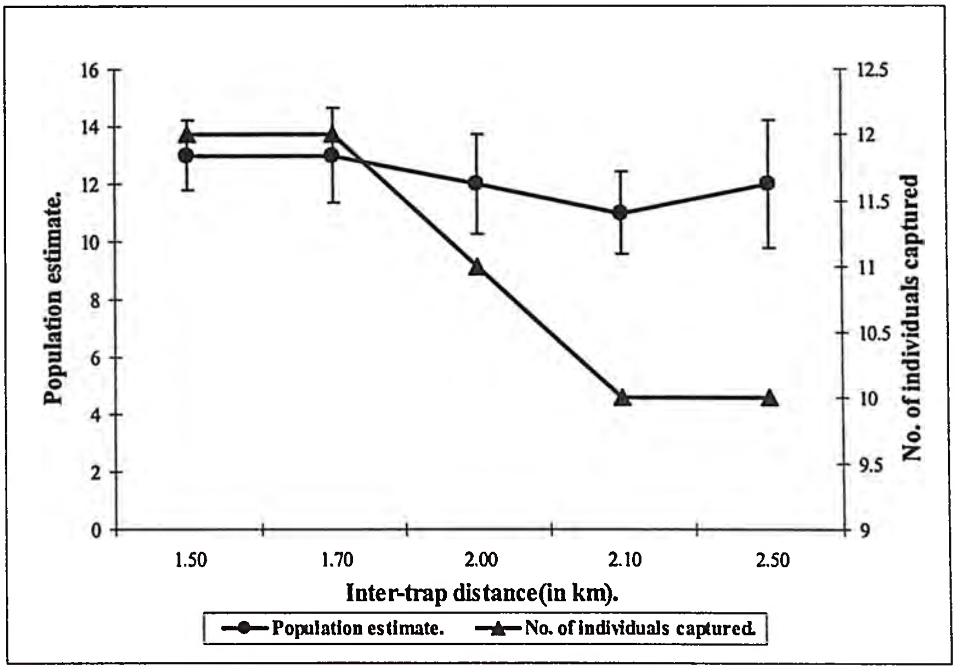


Figure 3. Population estimates (with standard error) and number of individuals captured plotted against increasing inter-trap distance.

Number of sessions.

A reduction in the sampling effort by systematically dropping the number of sampling occasions (sessions) resulted in a gradual decline in the number of photographic captures. The number of captures registered a rapid decline, when more than three sessions were dropped. The number of unique individuals captured also showed a similar declining trend with the reduced sampling effort. As long as the number of unique individuals (M_{t+1}=12) captured remains constant, the population estimate (N=13) also remains constant although the standard error on the population estimate goes on increasing with a decrease in the sampling effort. Reducing the number of sessions to six results in the loss of two individual (M_{t+1}=10) and a consequent decline in population estimate (N=11). The results show that a minimum of seven sessions (21 nights) would be required to arrive at an accurate albeit less precise population estimates.

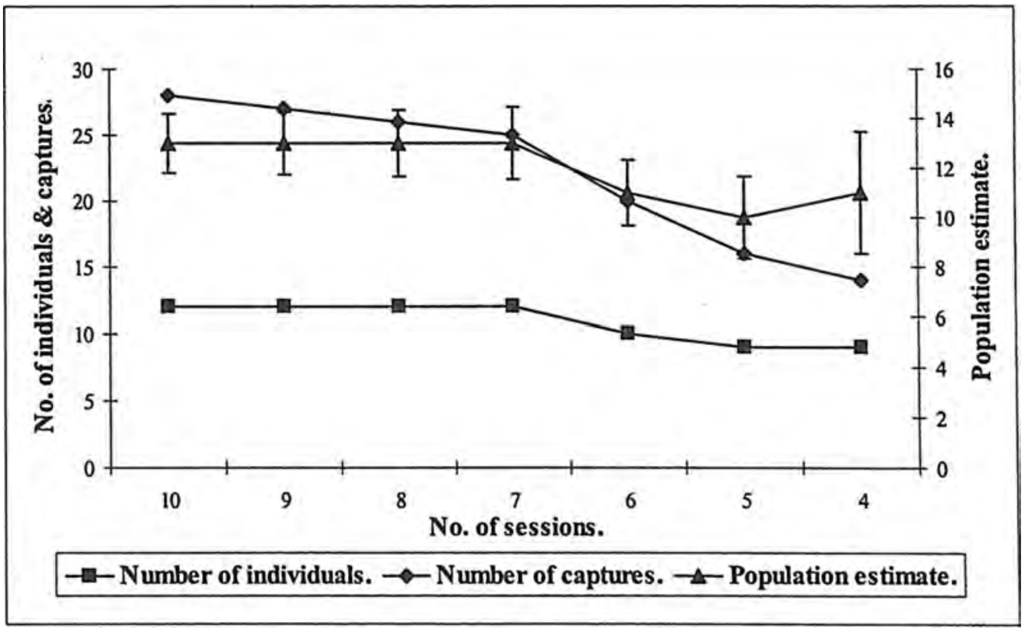


Figure 4. Number of tiger photo captures, number of unique individuals, population estimate and standard error with decrease in the number of sessions from 10 to 4.

Increased camera spacing coupled with reduced sampling effort.

Increasing camera spacing to 2.10 km with a restricted sampling for only six sessions resulted in loss of 42% captures(n=16). This resulted in a loss of 25% of unique photo captured individuals (M_{t+1}=9). The population estimation using program MARK (Cooch & White, 1995- http://www.phidot.org/software/mark/docs/book/) resulted in an underestimate of 16% (*N*=10) with a standard error 1.84. This highlights the importance of a good study design in terms of camera spacing and sampling effort.

Significance of a good reconnaissance survey.

I monitored track plots at all the 33 camera trap sites one month prior to camera trap survey. Based on the frequency of occurrence of tigers on these track plots, I excluded 9 trap sites having poor or no occurrence of tigers for population estimation through camera traps. The results recorded no loss of number of unique individual tigers captured (M_{t+1}=12), though there was a loss of 12% of captures (n=25). The population estimate *N* was 13 with a standard error of 1.63. Thus it resulted in accurate population estimate with a marginally high standard error as compared with population estimate derived at by using all the 33 trap sites (*N*=13, S.E.=1.19). However when data from randomly selected 24 rap stations was analyzed, then population estimate *N* was 16 with a standard error of 4.38.

Activity pattern of tigers.

Assuming that there is a direct correlation between frequency of tiger "captures" in specific time of the night and activity, I simulated a 14-hour (6 p.m.-8 a.m.) activity curve. This was done by dividing the 14 hours into 7 periods (2 hours in each). Then the number of tiger "captures" for each period was counted. As expected, a midnight peak was obtained as the maximum numbers of captures were recorded between 12 midnight to 2 a.m. Though the activity pattern graph shows a trimodal peak depicting heightened activity at 8 p.m. to 10 p.m. and subsequently at 4 a.m. to 6 a.m., the data is insufficient to make any definitive conclusions.

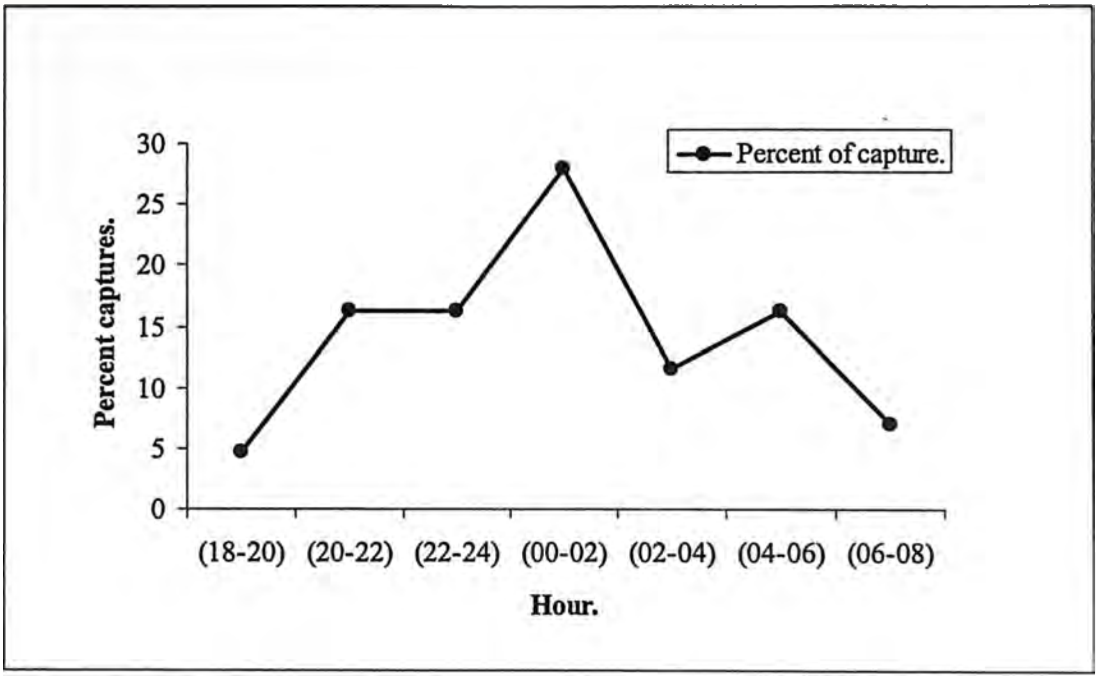


Figure 5. Nocturnal activity pattern of tigers based on camera trap photo captures.

Individual Heterogeneity in capture and trap shyness.

Out of a total of 12 tigers captured in the study area, four were captured only once. On at least three different occasions, clear instances of trap avoidance were seen. In first instance, the tiger was observed to have completely abandoned the trail having camera trap, while in two other instances, the tiger was observed (from pugmarks) to circumvent the camera trap site. Individual tigers showed considerable variability in captures as is evident from the figure below.

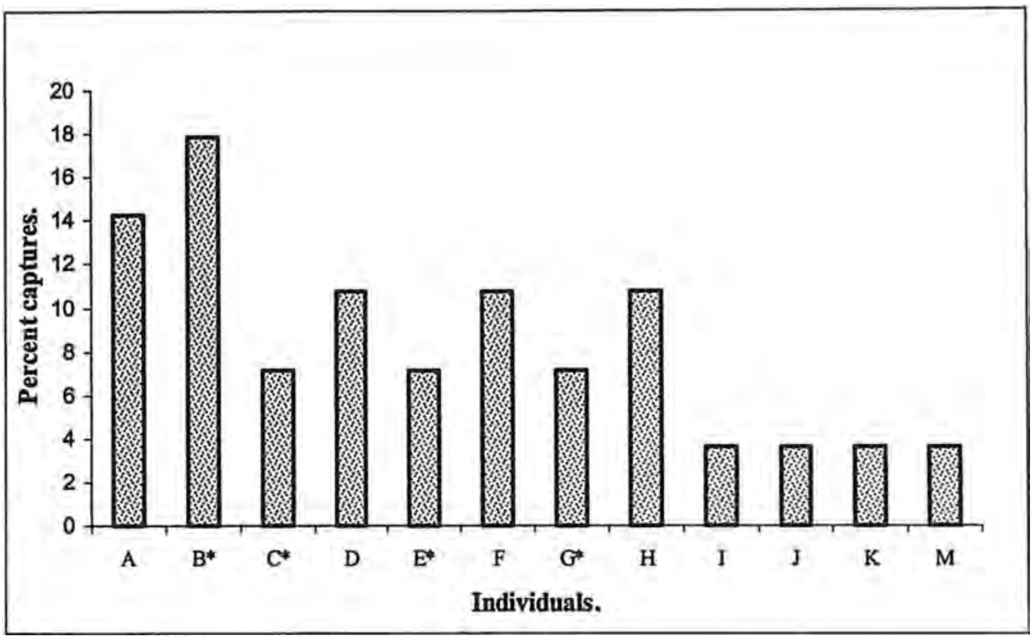


Figure 6. Percent captures of individual tigers n=29. Note * indicates males.

Success rate of photo captures using camera traps.

Carbone *et. al.,* (2001) suggest use of camera traps as a method of surveying abundance. Based on computer simulations and an analysis of the rates of camera trap capture from 19 study sites of tiger across the species range, they show that the number of camera days per tiger photograph correlate with independent estimates of tiger densities. They further go on to suggest that since this statistic do not rely on individual identity, it can be particularly useful for estimating the population density of species that are not individually identified. However one should keep in mind that the frequency of captures of animals in photo captures may not truly correlate to their abundance. This is because the basic sampling design for photo capturing tigers (maximizing the number of captures) is different from the usual sampling approaches adopted for the population estimation of other large mammals. For photo-capturing tigers, cameras are deployed at locations having maximum probability of capturing them and not randomly across space.

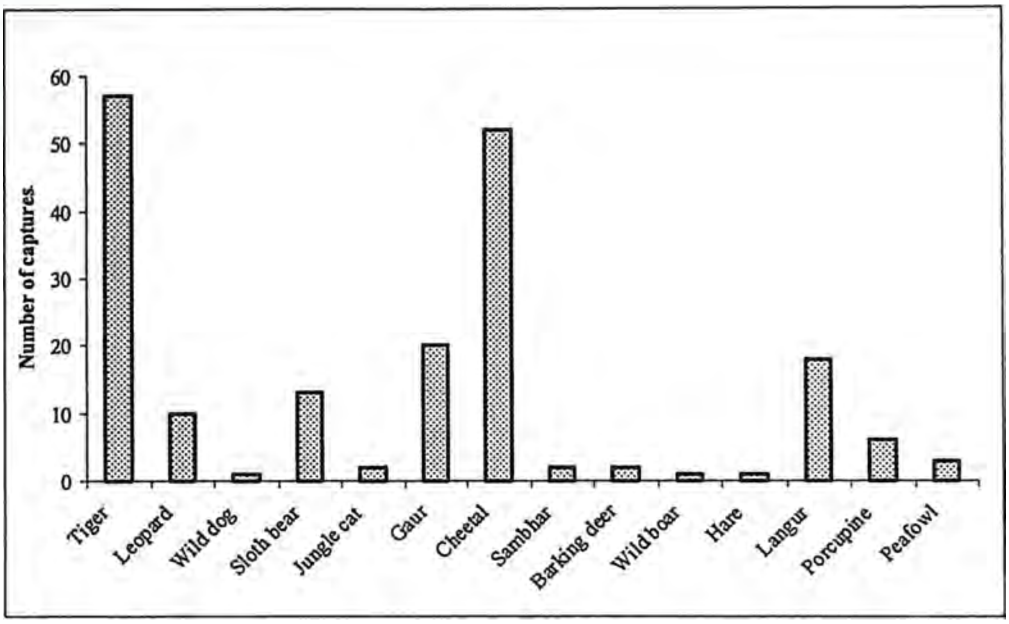


Figure 7. Frequency of capture of different animal species using camera traps.

Test for population closure, model selection, capture probabilities and population size.

The statistical test for population closure using program CAPTURE (Otis *et al.*, 1978; Rexstad & Burnham 1991) rejected the closure assumption for the sampled population ($z = -2.38$, $P = 0.0008$).

Goodness of fit test for model M(t) showed a reasonable fit ($\chi^2 = 11.497$, d.f. = 9, $P = 0.37$). This was followed by model M(b) ($\chi^2 = 9.645$, d.f. = 11, $P = 0.56$) and model M(h) ($\chi^2 = 9.00$, d.f. = 9, $P = 0.437$). Because of sample size constraints, the program

MARK (Cooch & White, 1995) could not test the fits of models M(t) and M(bh) against model M(o). But since none of models tested differs significantly from M(o), therefore the most parsimonious model M(o) is selected for the purpose of estimation.

Although the model selected was M(o) estimates derived from all models are reported (Table 3.).

Table 3. Results from program CAPTURE showing model selection and population estimates generated by different models.

M_{t+1}	n	closure test *z*	*P*	p – hat *(average)*	Model selection		N	SE[N]
12	28	-1.494	0.07	0.23446	M(o)	1.00	13	1.19
					M(h)	0.78	13	2.73
					M(b)	0.33	12	0.75
					M(bh)	0.71	12	0.75
					M(t)	0.00	13	0.61
					M(th)	0.50	14	2.71

The model M(0) was used for the purpose of population estimation, though the individual heterogeneity in captures suggests use of model M(h). This was done on the basis of the fact that Akaike criteria looks at the model fit in terms of log likelihood and number of parameters being estimated. The model fit is better with higher number of parameters. However with higher number of parameters, the model becomes less parsimonious. Akaike criteria weighs these two factors by positively considering model fit and penalizing the function for every parameter being included in the model (Cooch & White, 1995). Thus it strikes an optimal balance between model fit and model parsimony.

Estimates of effectively sampled area and tiger densities.

The polygon formed by outermost camera traps measured 59.207 km^2. The boundary strip width was calculated from "mean maximum distance moved" for tigers that were photo captured on more than one occasion. Using the above mentioned approach, I estimated a buffer width (W) of 1.52 km. and an effectively sampled area (A) of 111 km^2. I also calculated a 95% kernel on the trap sites which came out to be 90 km^2. This was done because 95% kernel appears to make more ecological sense and seems to provide a better estimate of effectively sampled area rather than a buffer on "minimum convex polygon".(See Plate 2).

Tiger density was obtained by dividing the estimated population size (*N*) by the effectively sampled area (A). The estimated density ((*D(SE)*)) for the study area was 11.71(1.74)/100 km^2 using buffer on "minimum convex polygon and 14.44/100 km^2 using 95% kernel.

Population estimate using Jackknife estimator.

The jackknife estimator estimated the population *N* to be 15 with a standard error 1.99. It should be noted that jackknife estimator considers the individuals that may have not been "captured" at all. The results are depicted in figure 8.

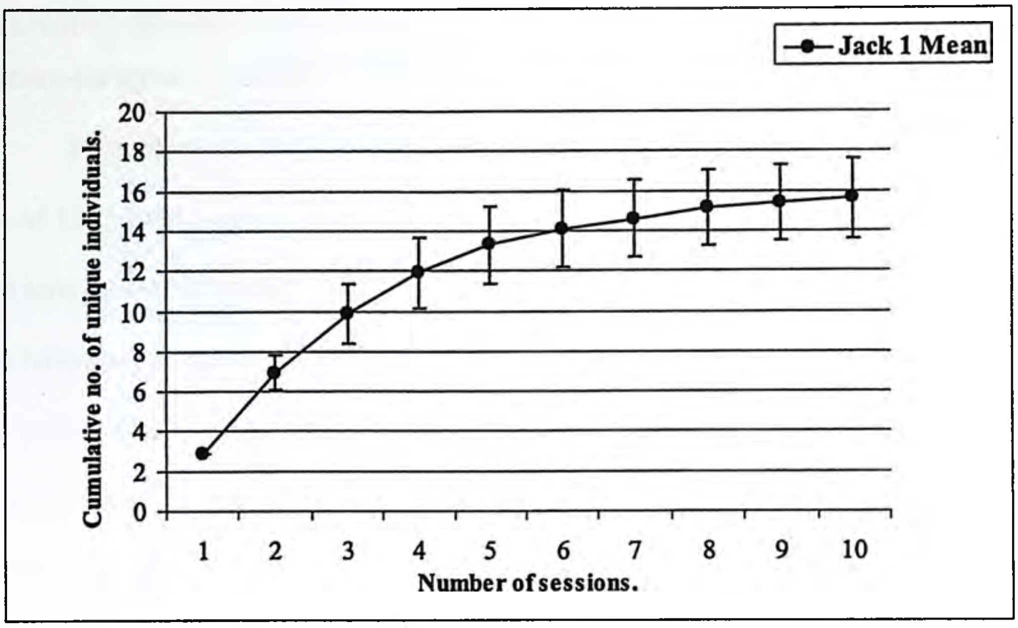


Figure 8. Individual accumulation curve using jackknife estimator along with associated standard error.

Population estimation using Bootstrap estimator.

The bootstrap estimator estimated the number of unique individuals to be 13.81 with no standard error on it.

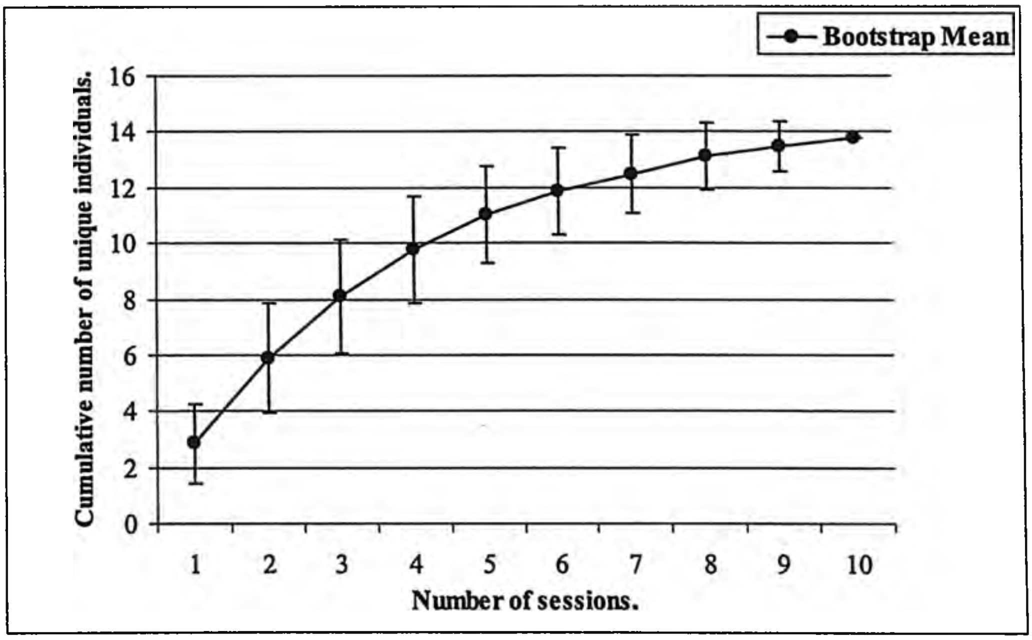


Figure 9. Individual accumulation curve using bootstrap estimator along with associated standard error.

INTENSIVE SEARCH EFFORT.

Capture-recapture or sight-resight of tigers.

Fifty days of intensive search effort resulted in 80 sightings of tigers. Out of a total of 12 individuals thus sighted, I recorded 5 males and 7 females. The cubs (< 1 yr) were seen on six occasions. Three cubs belonging to one litter were seen twice while two cubs belonging to another litter were seen on four occasions. Thus intensive search effort was better able to detect the cubs as compared to camera trapping. The frequency of sightings varied considerably among different individuals owing to individual behaviour of tigers. Tigers shy to humans and elephants were sighted less frequently.

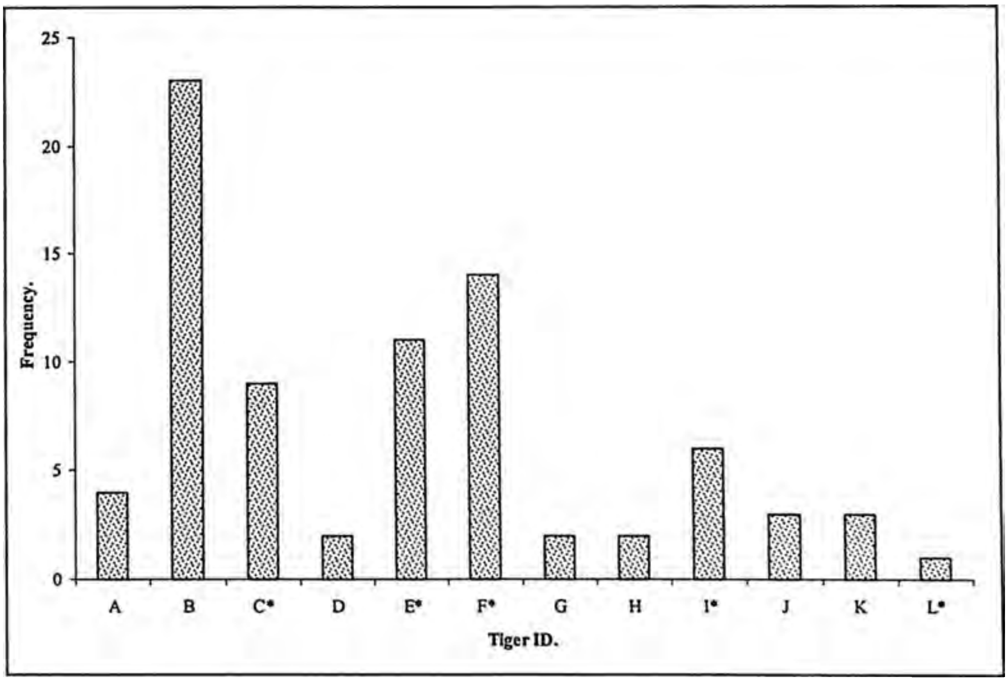


Figure 10. Frequency of sighting of individual tigers during intensive search effort. Note * indicates males.

Test for population closure, model selection, capture probabilities and population size.

The statistical test for population closure in CAPTURE (Otis *et al.,* 1978, Rexstad and Burnham 1991) did not support my assumption that the sampled population was closed for the study interval (z=-1.93, P=0.02). As the sample size was sufficiently large, the test for null hypothesis M(o) against M(h) resulted in χ^2=9.162, d.f.=2 and P=0.01023 Results of CAPTURE show reasonable fit for model M(h) with a goodness of fit value χ^2 =11.88, d.f.=16 and P=0.79774. Program MARK (Cooch and White, 1995) estimated the population to be N=13 with a standard error S.E. =1.9376 using model M(h).

Estimates of effectively sampled area and tiger densities.

The polygon formed by outermost sighting locations measured 47.76 km^2. The boundary strip width was calculated from "mean maximum distance moved" for tigers that were sighted on more than one occasion. Using the above mentioned approach, I estimated a buffer width W of 1.57 km. and an effectively sampled area of 101.80 km^2. I also calculated a 90% fixed kernel on the trap sites which came out to be 75 km^2. Tiger density was obtained by dividing the estimated population size (N) by the effectively sampled area (A). The estimated tiger density (D(SE D)) for the study area was 12.75(2.27) per 100 km^2 using buffer on "minimum convex polygon and 17.33 per 100 km^2 using 90% fixed kernel.

Effect of pooling days of sessions on the accuracy and precision of population estimate using program MARK.

Though accuracy of the population estimate (*N*=12) for model M(o) was not affected, there was a marked decrease in the precision as the standard error gradually increased as the number of sessions was reduced (Figure 11). Model M(o) also underestimated the true population (*N*=12, true estimate *N*=13).

Table 4. Effect of pooling days to generate variable number of sessions on the accuracy and precision of population estimate using program MARK.

		Estimates based on Mo				Estimates based on Mh			
		n	p	Mt+1	N(SE[N])	n	p	Mt+1	N(SE[N])
Interval	**Sessions.**								
3 day	**17**	57	0.2794	12.00	12(0.2169)	57	0.2579	12	13(1.9376)*
5 day	**10**	47	0.3917	12.00	12(0.2964)	47	0.3615	12	13(3.8248)*
7 day	**7**	39	0.4643	12.00	12(0.4085)	39	0.3980	12	14(2.0675)*
10 day	**5**	33	0.5500	12.00	12(0.5049)*	33	0.4714	12	14(1.7708)

Note: * indicates the best model selected by program MARK.

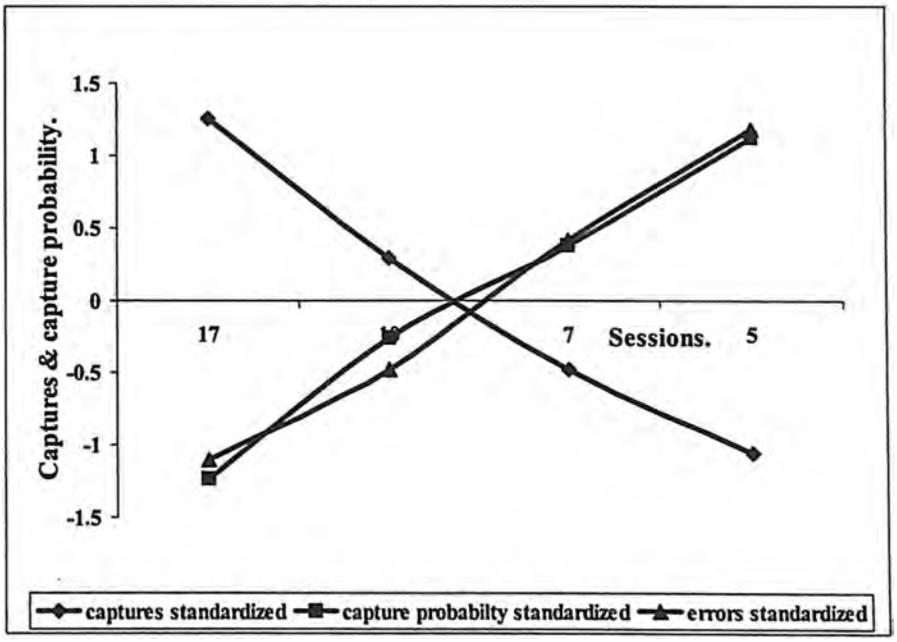


Figure 11. Decline in the number of "captures" and increase in standard error with decrease in the number of sessions (increasing the number of days per session).

Population estimate using Jackknife estimator.

I used 17 sampling occasions as used for capture-recapture (50 days) to estimate tiger population. The jackknife estimator estimated the population N to be 14.04 with a standard error of 1.47.

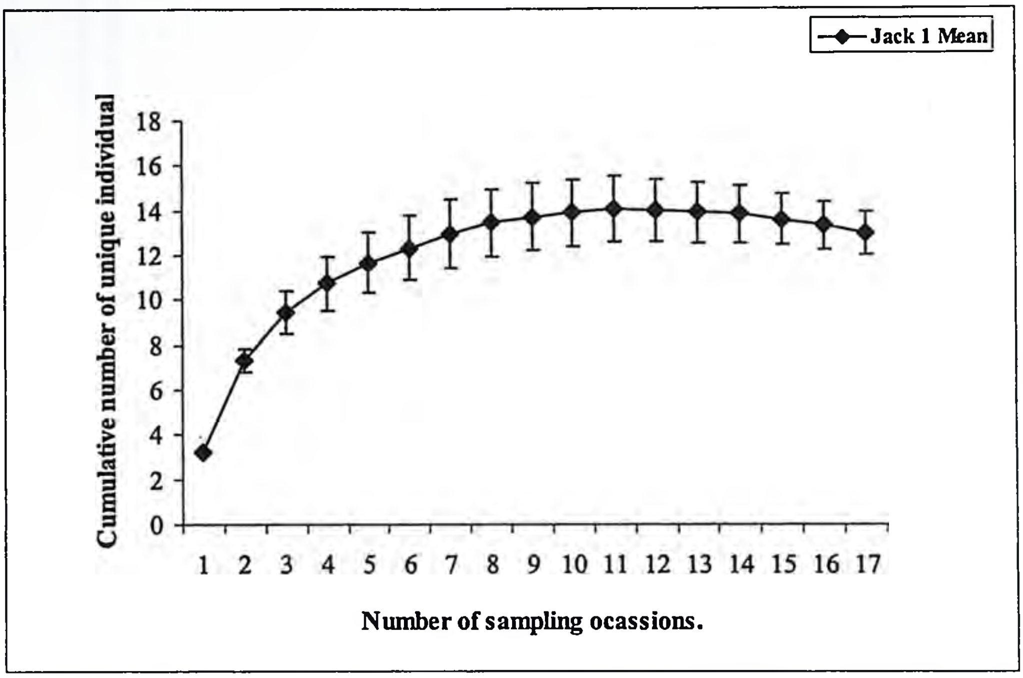


Figure 12. Individual accumulation curve using jackknife estimator along with associated standard error for intensive search effort.

Population estimate using Bootstrap estimator.

Bootstrap estimator estimated tiger population N to be 13 with a standard error of (0.51) which fares better than the population estimate arrived at by using capture-recapture statistic (N=13 with S.E.= 1.9376). The number of sampling occasions used for bootstrap estimation was also kept at a constant 17 to make objective comparison within different approaches. The results of bootstrap estimation are depicted in figure 13.

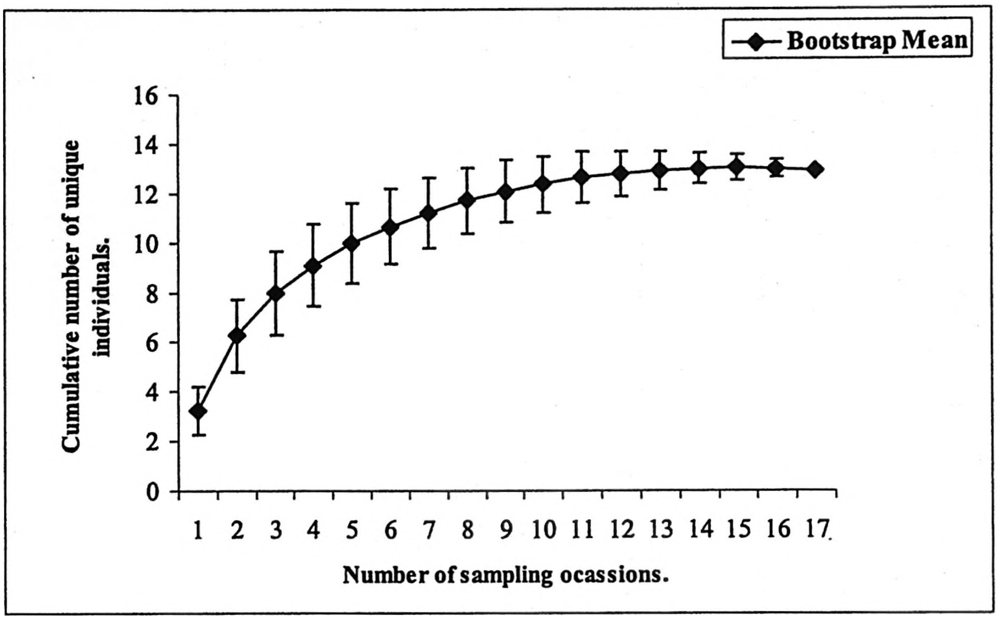


Figure 13. Individual accumulation curve using bootstrap estimator along with associated standard error for intensive search effort.

Effect of pooling days of sampling occasions on the accuracy and precision of population estimate using jackknife and bootstrap estimators.

The results show that both the estimators give consistent results irrespective of varying sampling occasions generated by pooling data over different days, thus reducing the length of sampling occasions. The pooling also did not result in any marked change in the standard errors of the estimates. The figures (Fig. 22. & Fig. 23.) clearly show that there is no affect on the accuracy of estimates for both the estimators, while precision appears to gradually increase for jackknife estimator while it appears to decrease for bootstrap estimator by pooling data.

Results for jackknife estimator (For intensive search effort).

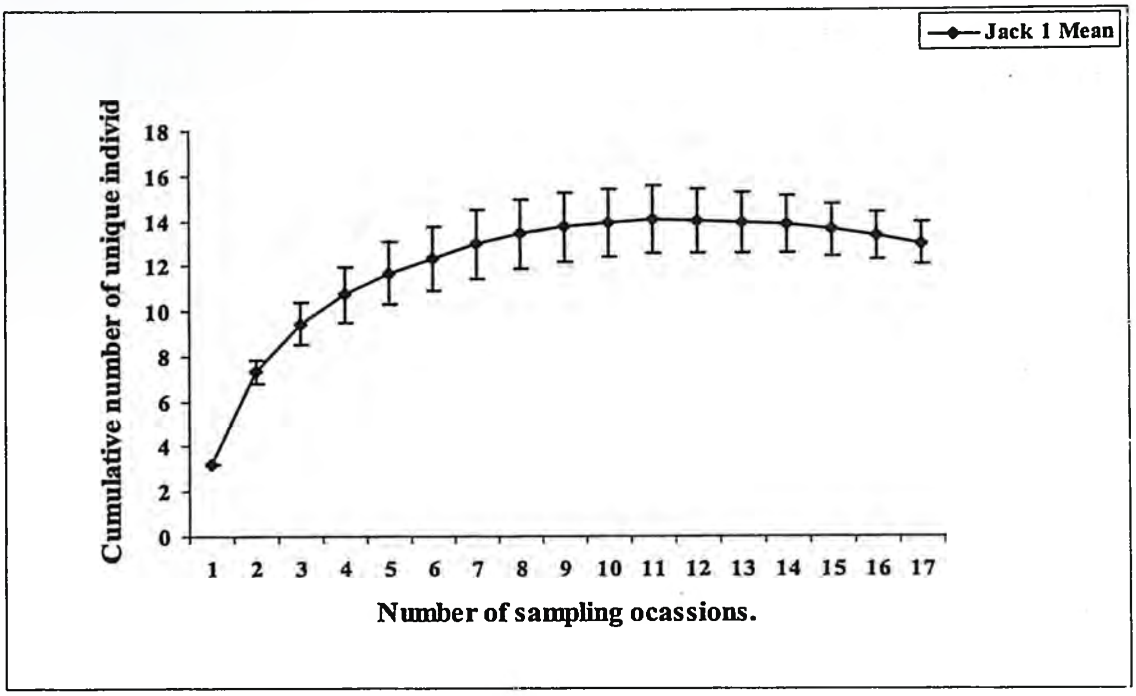


Figure 14. Individual accumulation curve for 17 (three days each) sampling occasions.

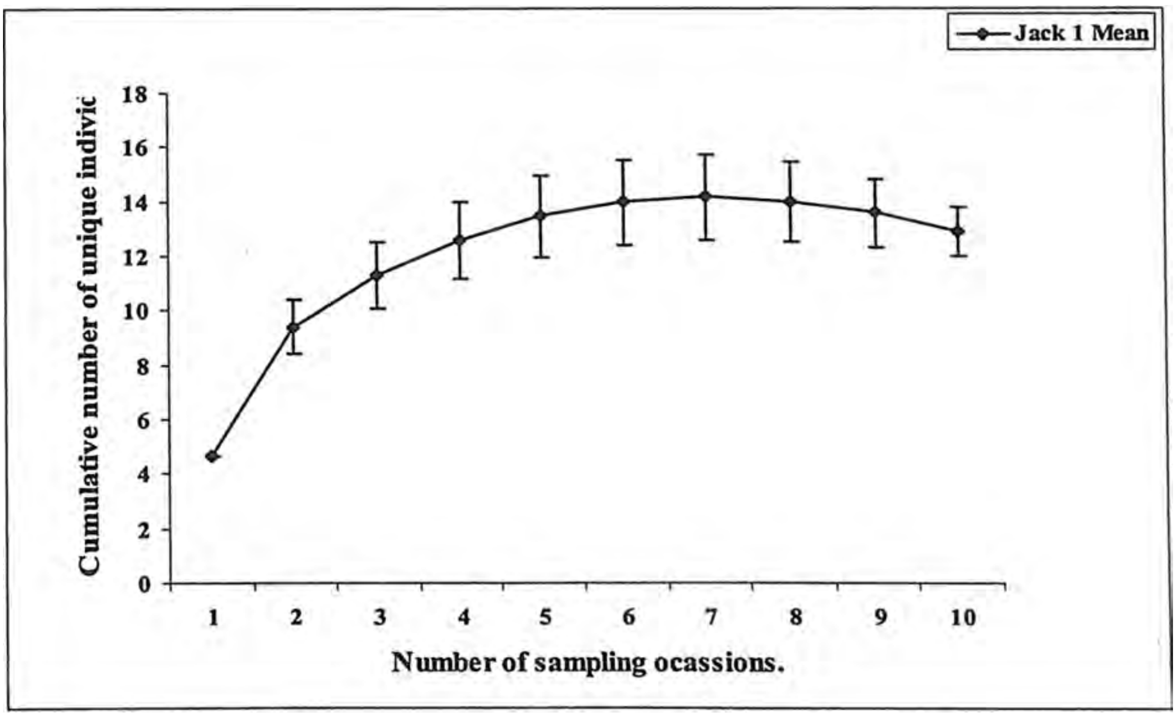


Figure 15. Individual accumulation curve for 10 (five days each) sampling occasions.

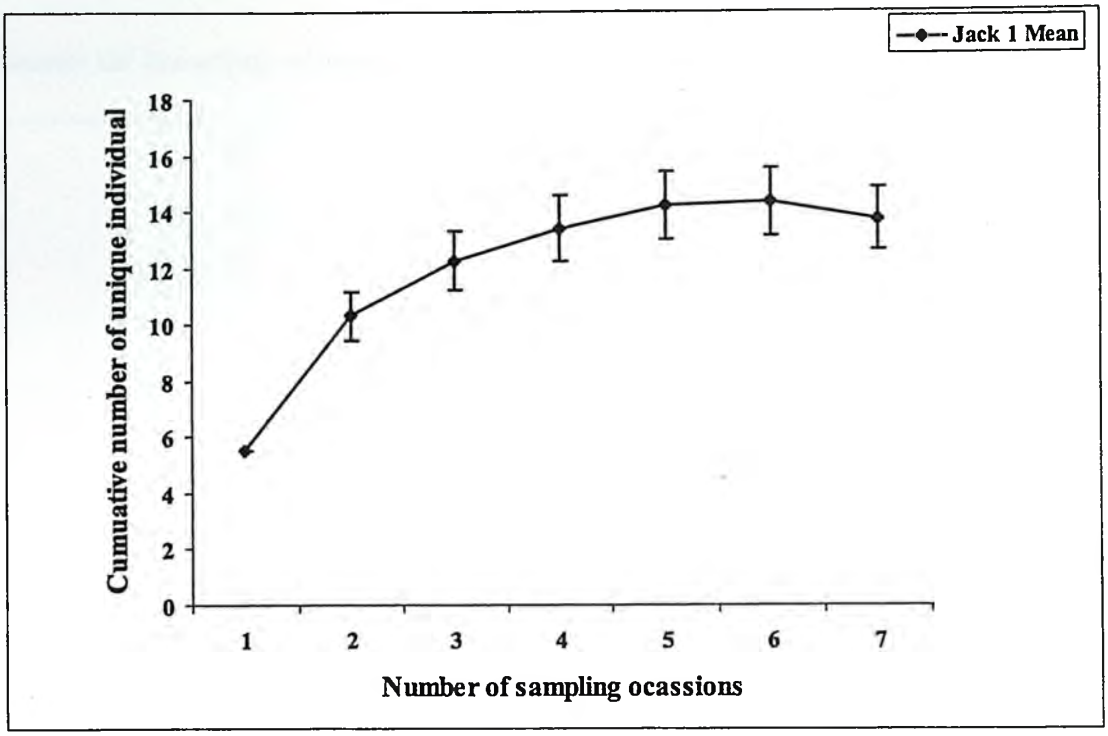


Figure 16. Individual accumulation curve for 7 (seven days each) sampling occasions.

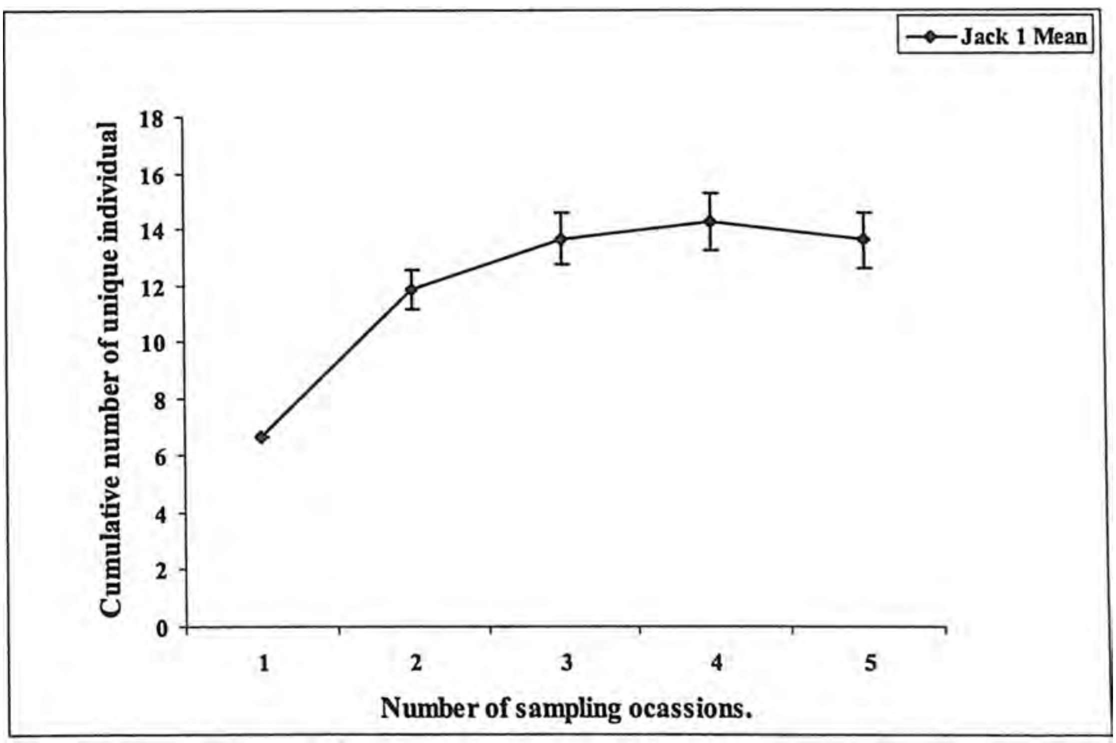


Figure 17. Individual accumulation curve for 10 (ten days each) sampling occasion.

Results for bootstrap estimator (For intensive search effort).

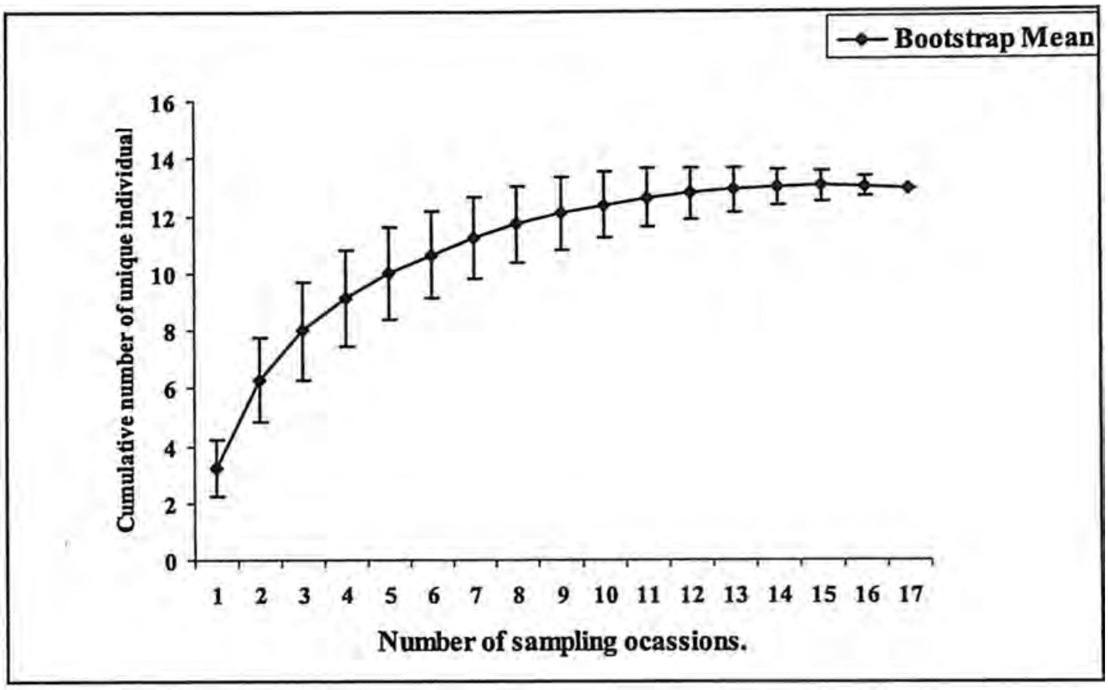


Figure 18. Individual accumulation curve for 17 (three days each) sampling occasions.

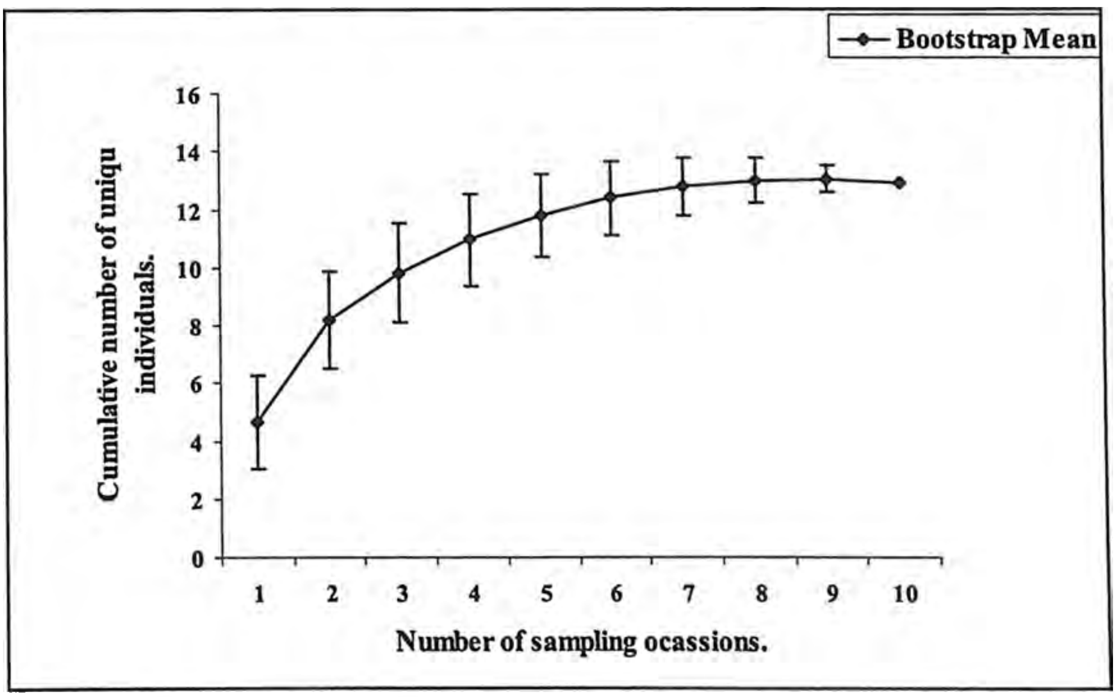


Figure 19. Individual accumulation curve 10 (five days each) sampling occasions.

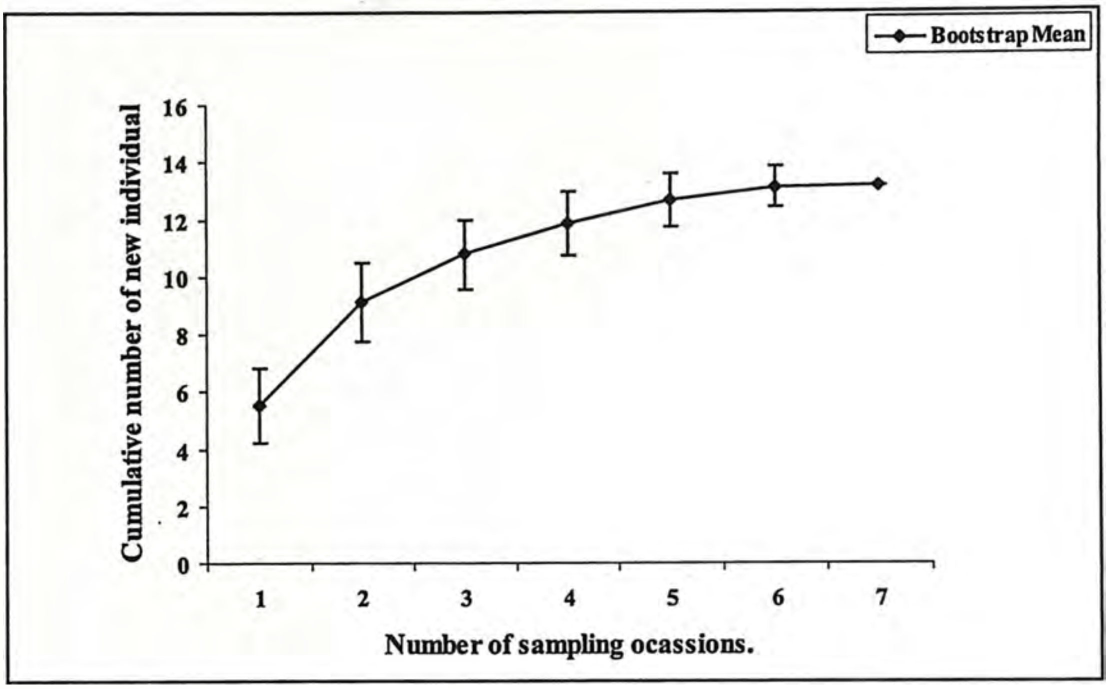


Figure 20. Individual accumulation curve 7 (seven days each) sampling occasions.

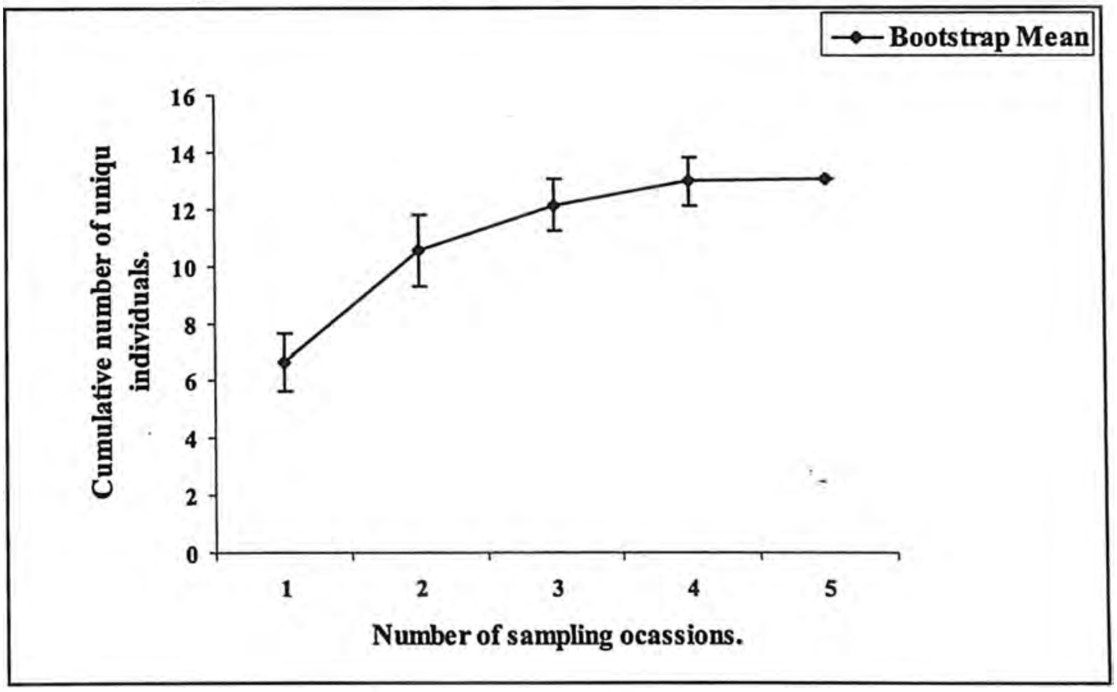


Figure 21. Individual accumulation curve 10 (five days each) sampling occasions.

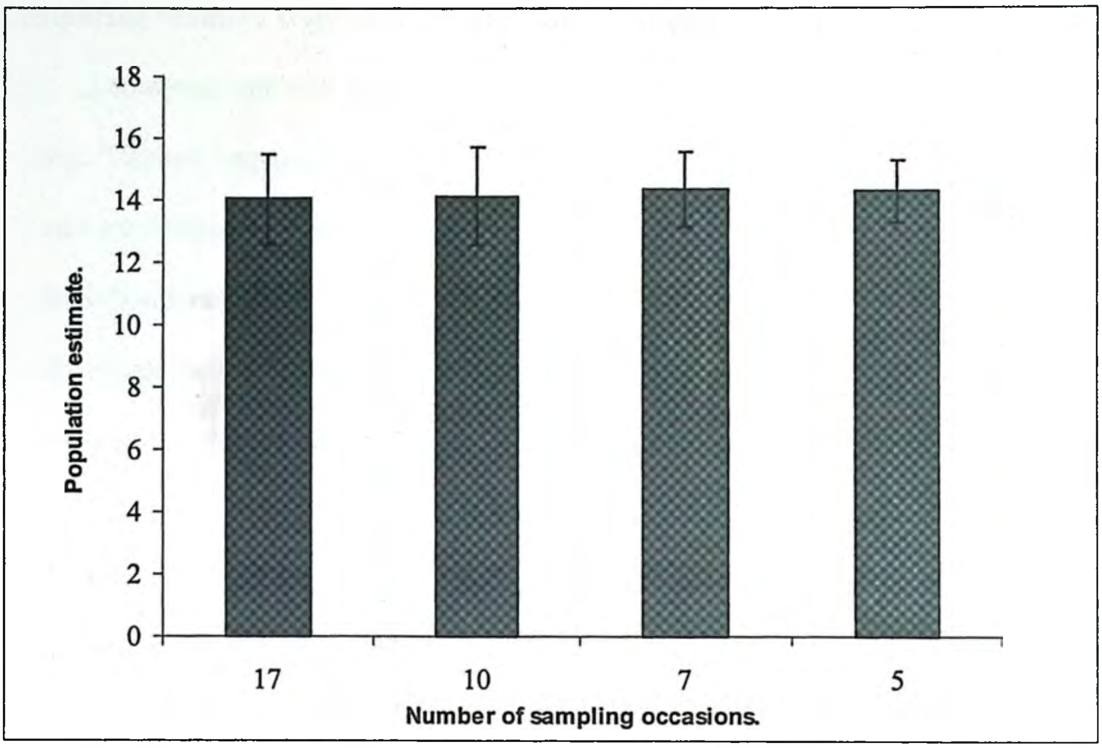


Figure 22. Comparing affect of pooling days on jackknife estimates.

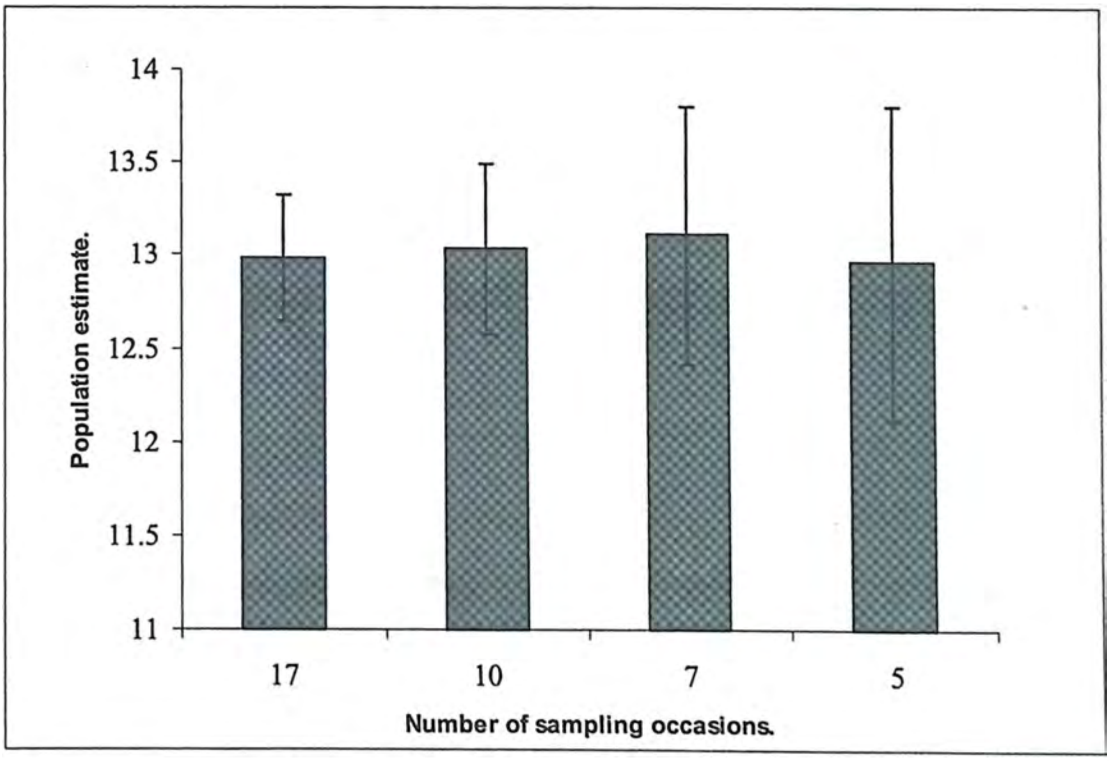


Figure 23. Comparing affect of pooling days on Bootstrap estimates.

Comparing "camera trap" method with "intensive search effort" method.

I compared the two population estimation approaches for tiger density estimation viz. "camera trapping" and "intensive search effort" across various estimators viz. capture-recapture, jackknife estimator and bootstrap estimator. The density estimates from "camera trap" data and the "intensive search effort" did not show any significant difference across any of the estimators. Tiger density (*D* (*SE D*)) using capture-recapture, jackknife and bootstrap estimators on camera trap data was found to be 11.71(1.74), 14.05(2.20) and 11.71(1.40) per 100 km^2 respectively.

Intensive search method of tiger density estimation yielded a tiger density (*D* (*SE D*)) of 12.75(2.27) using capture-recapture, 14.12(2.15) using jackknife estimator and 13.54(1.28) using bootstrap estimator.

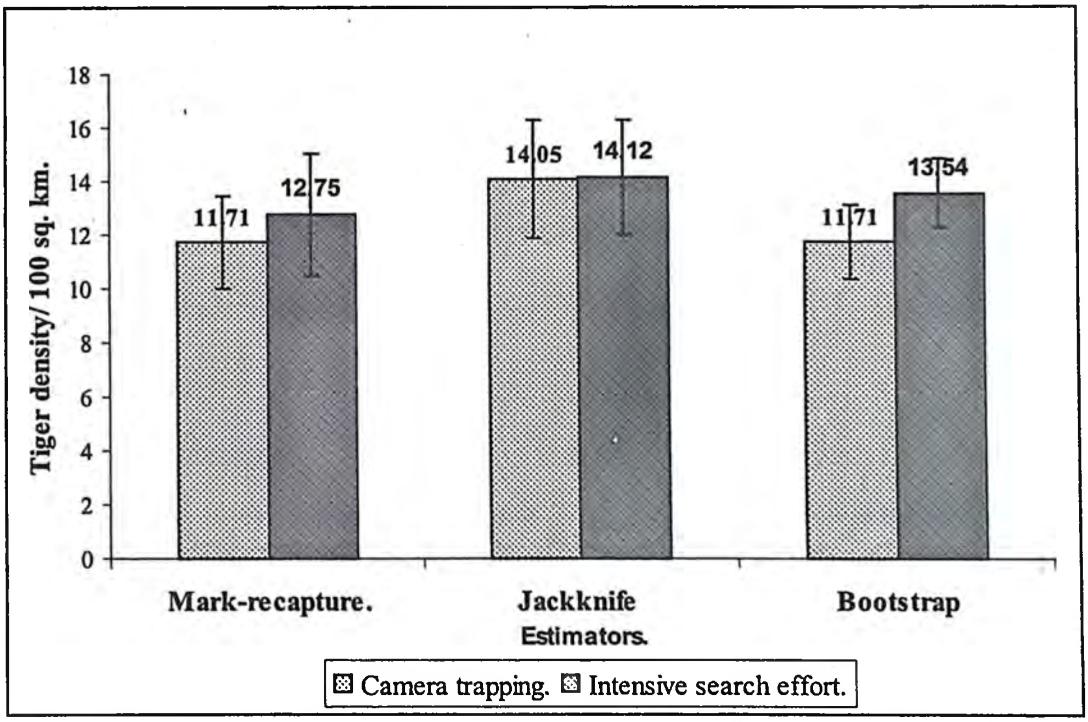


Figure 24. Comparison between tiger density estimates by "camera trapping" and "intensive search" effort across various estimators.

CHAPTER 5

DISCUSSION

Reliable estimates of numbers of animals in a population are of special importance in the conservation of big cats, not only for the formulation of conservation strategy but also for political reasons, for allocating resources for conservation efforts, and for evaluating success of conservation programs (Nowell & Jackson, 1996; Karanth, 2003). Population estimation of carnivores is extremely difficult owing to an extensive spatio-temporal distribution, secretive life, wide ranging behaviour, low detectability and low densities.

Camera trap surveys have been widely used to estimate population of cryptic and endangered felids such as Tigers, Leopards and Jaguars (Karanth, 1995; Karanth & Nichols, 1998; Karanth *et al.,* 2004; Kawanishi & Sunquist, 2004; Kostyria *et al.* 2003; Silver *et al.,* 2004) and have proved to be a reliable technique for population estimation. But issues regarding sampling design have received relatively less attention (Wegge *et al.,* 2004). In the present study, I have attempted to address the issues of sampling design and sampling effort.

Sampling design.

Since the present study was planned with a camera spacing of 1.5 km, it is capable of addressing the issue of sampling design. The results from program CAPTURE (Rexstad & Burnham, 1991) suggest that the closure assumption was violated for both camera trapping and intensive search effort. But I assumed the sampled population to be closed. This was done because closure consists of two factors viz. demographic closure and geographic closure. In the present study, since the sampling was carried out for a very short period (30 days for camera trapping and 50 days for intensive search effort) and the individual tigers less than 1 year of age were not considered for population estimation, demographic closure can be safely assumed. As far as geographic closure is concerned, fortunately tigers are highly territorial animals and so this assumption can also be assumed but it may need further investigation. However it should be noted that closure tests are often confounded with behavioural response to capture, eg. an animal that becomes uncatchable, or nearly so, is indistinguishable from one that dies or emigrates (Otis *et al.,* 1978). Moreover, whether or not a population is closed should be assessed keeping in mind the ecology of the species and not just from the results shown by a statistical test. I found that the number of individual tigers captured declined with increasing average inter-trap distance as well as with reducing number of sessions. It is evident from Figure 3 that there is a considerable loss of photographic “captures” (35%) when the camera spacing is increased from 1.5 to 2.5 km. I noticed that the loss of captures results in an underestimate of true population while the level of precision also goes down. This suggest that in areas where camera trap survey is to be carried out, the cameras will have to be placed at a much smaller distance particularly in high density areas having small home range sizes of individual tigers. The home ranges of individual tigers will play an important role as optimal camera spacing will depend on the presumption of placing a minimum of two to three cameras in the respective home ranges of all individual tigers using the sampled area.

Trapping effort (number of sampling occasions) plays a significant role in estimating population size accurately with good precision. Knowing the fact from my data that a minimum of 7 sampling occasions will be required to capture all the individuals in the study area, I assumed a situation in which the number of individuals captured was less than 12(Mt+1) as a result of reduced sampling effort. It was noticed that the precision of the estimate is considerably lowered though accuracy is not affected (Figure 4).

I also looked at the effects of pooling the sampling days (resulting in decrease in the number of sampling occasions) on the accuracy and precision of population estimate using tiger intensive search effort data. It was found that though pooling the days resulted in higher capture probability, the number of captures fell drastically, thus resulting in an overestimate of population in case of model M(h) (Table 4, Figure 11). However, the population estimate (N=12) remained constant for model M(o). The observed trends occur owing to the loss of information as program MARK recognizes only the presence-absence of individuals over the sessions and not the abundance of individuals in each sample. This suggests that it is better to capture the maximum information by keeping the number of days per sampling occasion to a minimum (thus resulting in increase in sampling occasions) while analyzing populations using capture-recapture sampling.

However estimates generated by jackknife and bootstrap estimators remain consistent (Fig. 22. & Fig. 23.) even if the number of days are pooled together leading to reduced number of sampling occasions. This is because these estimators use abundance information instead of incidence (presence-absence) information. Thus the accuracy and precision of estimates do not change even if number of sampling occasions is reduced by pooling days.

Assuming a practical situation, where the trap spacing is 2 or more than 2 km, precise estimates of population size could be arrived at by increasing trapping effort since fewer sampling occasions and increased trap spacing results in inaccurate estimates with low levels of precision. Increasing camera spacing to 2.10 km with a restricted sampling for only six sessions resulted in loss of 42% captures(n=16). This resulted in a loss of 25% of unique photo captured individuals (M_{t+1}=9). The population estimation resulted in an underestimate of 16% (*N*=10) with a standard error 1.84. This highlights the importance of a good study design in terms of camera spacing and sampling effort.

Importance of a good reconnaissance survey.

The basic assumption of normal ecological studies is to either have a random or a systematic sampling to get a good representation of the entire study area in order to reduce the sampling biases. In case of mark-recapture studies for tigers the assumption is to choose the sites having maximum probability of capture (Karanth and Nichols 2002). This is so because tigers usually occur at low densities and photo capturing a tiger is a rare event. I monitored track plots at all the 33 camera trap sites one month prior to camera trap survey. Based on the frequency of occurrence of tigers on these track plots, I excluded 9 trap sites having poor or no occurrence of tigers for population estimation through camera traps. The results recorded no loss of number of unique individual tigers captured (M_{t+1}=12), though there was a loss of 12% of captures (n=25). The population estimate *N* was 13 with a standard error of 1.63. Thus it resulted in an accurate population estimate with a very marginal standard error as compared with population estimate derived at by using all the 33 trap sites (*N*=13, S.E.=1.19). However when data from randomly selected 24 rap stations was analyzed, then population estimate *N* was 16 with a standard error of 4.38, which is a significant deviation from the actual estimate using all 33 trap stations.

Thus it is evident that a good reconnaissance survey is a prerequisite of a robust sampling design. A good reconnaissance can also help in minimizing wastage of sampling effort by helping in maximizing the capture probability at each trap site. This should be an important consideration in studies involving camera trapping as such studies are always limited by the availability of sufficient cameras.

Activity patterns of tigers.

Tigers are known to be most active during night as they hunt primarily after dark when their superior vision confers an advantage (Sunquist, 1981; Karanth & Sunquist, 2000). Usually tigers become active at dusk and remain so through the night until dawn (Karanth, 2003). Radio telemetry locations in Chitwan and Nagarhole (Sunquist, 1981; Karanth & Sunquist, 2000) showed that tigers moved around a lot more during night (80% of locations) compared to midday (10%) locations. Camera trap surveys are usually done only in the night i.e. from dusk to dawn owing to the practical consideration of minimizing the risk of theft by humans. However keeping in mind the activity pattern and hunting behaviour of tigers, it may be safe to use camera traps only in the night at least in high density areas where the probability of capturing a tiger will be fairly high even if the camera traps are used only from dawn to dusk. It is quite likely that sampling only during the night time would result in the loss of some "captures", but the accuracy of population estimate probably would not be affected though precision of estimates may decrease.

Individual heterogeneity of capture and trap shyness.

Individual tigers have different capture probabilities depending upon their movement patterns, access to trap sites and response to photographic flash. Some tigers may become trap shy after being captured once. All these factors manifest in the differential capture rates of tigers. Out of a total of 12 tigers captured in the study area, four were captured only once. On at least three different occasions, clear instances of trap avoidance were seen. Poor recaptures can affect population estimation and it is understandable that larger number of recaptures will result in more accurate and precise population estimates. Therefore it becomes very important to camouflage cameras properly to avoid trap shyness. The present study suggests that cameras should not be kept at a fixed location for a long duration. Moving cameras slightly away from usual trap sites can help to reduce instances of trap shyness. It is recommended that in sampling designs involving blocks like the present study, the camera should be frequently moved from one block to another and should not be deployed at one block for a very long period of time.

As noted by Karanth (1995) and Karanth & Nichols (1998), I found that the tiger cubs less than 1 year of age had low capture probabilities. Though there were three females having cubs in the study area, cubs of only one particular litter were captured twice while the mother was captured only once. On first occasion, only one cub that triggered the camera was captured, while the mother and other two cubs were not captured owing to the longer camera delay of 40 seconds. In second instance, both the mother as well as her litter of three cubs was captured.

Use of camera traps for estimating population density of species that are not individually identified.

Carbone *et. al.,* (2001) suggests use of camera traps as a method of surveying abundance. Based on computer simulations and an analysis of the rates of camera trap capture from 19 study sites of tiger across the species range, they show that the number of camera days per tiger photograph correlate with independent estimates of tiger densities. They further go on to suggest that since this statistic do not rely on individual identity, it can be particularly useful for estimating the population density of species that are not individually identified. However one should keep in mind that the frequency of captures of animals in photo captures may not be a truly correlate of their abundance (Jenelle *et al*., 2002). This is because the basic sampling design for photo capturing tigers (maximizing the number of captures) is different from the usual sampling approaches adopted for the population estimation of other large mammals. I found that camera trap photographs show a high rate of capture for chital (*Axis axis*) and langur (*Semnopethecus entellus*), but the capture rates of tigers at this scale seem to be exceptionally high. This suggests that the tigers occur in highest abundance in the study area which is definitely not true. Thus capture of other animals may not tune to densities as the study design for tigers is targeted to maximize the capture probability of tigers only.

Estimates generated by capture-recapture, jackknife and bootstrap estimators.

The estimates generated by the three different statistical methods viz. capture-recapture, jackknife and bootstrap did not vary significantly from "camera trapping" as well as " intensive search effort" approach. For "camera trapping" data, the population estimates were N=13, S.E.=1.1931 (capture-recapture), N=15, S.E.=1.99 (jackknife estimator) and N=13.81, S.E.=0 (bootstrap estimator). Similarly for "intensive search effort" approach, the population estimates were N=13, S.E.=1.9376 (capture-recapture), N=14, S.E.=1.47 (jackknife estimator) and N=13, S.E.=0.51 (bootstrap estimator). The population estimate from "capture-recapture" and "bootstrap estimator" were same, though the standard errors varied.

Camera trapping versus intensive search effort.

The difference between the population estimates arrived at by two different approaches of "camera trapping" and "tiger intensive search and photography" does not seem to be significant (Fig. 24). The "intensive search approach" is also cheaper as it does not involve the procurement of costly camera trapping equipment. This approach can also help to arrive at crude estimates of survival, mortality and dispersal etc. This approach may also help to study interactions amongst tigers as well as interactions with other animals though on a very limited scale. One two occasions, I found mating pairs of tigers and on one occasion interaction between a male tiger and a female leopard with cubs was noted. The approach also performed better than camera trapping in terms of cub detection as the cubs were seen on six occasions as compared to two occasions for camera trapping. Another advantage with this approach is that it can be executed by managers during their regular duties and thus can be used for long term monitoring.

However it should be noted that this approach also have limitations in terms of individual heterogeneity of captures as tigers shy to humans and elephants have poor probability of being sighted. Therefore a better approach is to analyse this data within capture-recapture framework and not for a simple species accumulation curve. Terrain accessibility is another limitation as this approach will be useful only in areas having a good road network. This approach can definitely be used in areas that have an inherent tradition of monitoring tigers from elephants.

CHAPTER 6

CONCLUSIONS

1. Tiger density estimate (*D* (*SE D*)) obtained by capture-recapture using camera traps was found to be 11.71(1.74)/100 km^2 in Kanha meadows.
2. Tiger density (*D* (*SE D*)) using jackknife and bootstrap estimators on camera trap data was 14.05(2.20) and 11.71(1.40) per 100 km^2 respectively.
3. Intensive search method of tiger density estimation yielded a tiger density (*D* (*SE D*)) of 12.75(2.27) using capture-recapture, 14.12(2.15) using jackknife estimator and 13.54(1.28) using bootstrap estimator.
4. In high density tiger population both the "camera trapping" based capture-recapture, jackknife, bootstrap and "intensive search" based capture-recapture, jackknife and bootstrap estimators seem to perform equally well. In such cases, the "intensive search" method would be most economical and practical to implement, especially when used in a capture-recapture framework to account for individual capture heterogeneity among tigers.
5. An important inference that can be drawn from the study is that based on tiger densities in an area, camera placement should be such (spacing and location) so that all the tigers have the chance of being photographed.
6. Trap spacing and sampling effort were found to affect the precision of the estimates but the accuracy was not affected.
7. The need of a good reconnaissance survey is felt in order to maximize the capture probabilities of tigers in camera trapping studies.

8. Data suggest that when cameras are placed to maximize tiger captures (in space and time), they are not likely to generate an abundance index for other species.
9. The "intensive search" for tigers can be used within a capture-recapture framework to arrive at reliable estimates of population size.

LITERATURE CITED

Beier, P., Choate, D. & Barrett, R.H. (1995). Movement patterns of mountain lions during different behaviours. *Journal of Mammology* 76:1056-1070.

Bertram, B.C.R. (1979). Studying predators. Second edition. African Wildlife Leadership Foundation, Nairobi.

Carbone C., Christie, S., Conforti, K., Coulson, T., Franklin, N., Ginsberg J.R., Griffiths, M., Holden, J., Kawanishi, K., Kinnaird, M., Laidlaw,R., Lynam, A., Macdonald, D.W., Martyr, D., McDougal, C., Nath, L., Brien, T.O., Seidensticker, J., Smith, D.L.J., Sunquist, M., Tilson, R. & Shahruddin Wan, W.N. (2001). The use of photographic rates to estimate densities and other cryptic mammals. *Animal Conservation* 4: 75-79.

Champion, F.W. & Seth, S.K. (1968). A revised survey of the forest types of India. Govt. of India, New Delhi.

Choudhary, S.R. (1970). Let us count our tiger. *Cheetal* 14(2): 41-51

Choudhary, S.R. (1971). The Tiger Tracer. *Cheetal* 13(1): 27-31.

Choudhary, S.R. (1972). Tiger census in India, Part I and Part II, *Cheetal* 15(1): 67-84.

Colwell, R. K. (2005). EstimateS: Statistical estimation of species richness and shared species from samples. Version 7.5. User's Guide and application published at: http://purl.oclc.org/estimates.

Colwell, R. K., C. X. Mao, & J. Chang. (2004). Interpolating, extrapolating, and comparing incidence-based species accumulation curves. *Ecology* 85, 2717-2727.

Cooch, E. & White, G.(1995). *Program MARK*. Analysis of Data from Marked Individuals. "A Gentle Introduction" 2nd Edition. http://www.phidot.org/software/mark/docs/book/

Franklin, N., Bastoni, Sriyanto, Siswomartono, D., Manansang, J. & Tilson, R.(1999). Using tiger stripes to identify individual tigers. In *Riding the Tiger: Tiger Conservation in Human Dominated Landscapes*: 138-139. Seidensticker, J., Christie, S. & Jackson, P. (Eds).Cambridge University Press, Cambridge, United Kingdom

Froyland, R. (1998). Assessing the number of tigers *Panthera tigris* in the Western part of Royal Bardia National Park in Nepal using camera trapping. M.Sc. thesis: Agricultural University of Norway.

Gopal, R. & Shukla, R. Management Plan of Kanha Tiger Reserve for the period 2001-02 to 2009-10.

Gotelli, N., & Colwell, R.K. (2001). Quantifying biodiversity: Procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* 4:379-391.

Goyal, S.P. & Johnsingh, A.J.T. (1996). Problems of identification of camera-trapped Tigers. *Cat News* 25:20

Grigione, M.M., Burman, P., Bleich, V.C., & Pierce, B.M. (1999). Identifying individual Mountain Lions *Felis concolor* by their tracks: refinement of an innovative technique. *Biological Conservation* 88:25-32.

Jackson P. and Kemf. E. 1996. *Wanted Alive! Tigers in the Wild.* Gland, Switzerland: World Wide Fund for Nature.

Jennelle, C. S., Runge, M. C. & Mackenzie, D. I. (2002). The use of photographic rates to estimate densities of tigers and other cryptic mammals: a comment on misleading conclusions. *Animal Conservation* 5: 119 – 120.

Jhala, Y.V. & Qureshi, Q. (2004). *Monitoring Tiger Status and Habitat Part-I. A Field Guide.* A Technical Publication of Project Tiger Directorate.

Karanth, K.U. (1987). *Tigers in India*: A critical review of field censuses. In *Tigers of the World: The Biology, Biopolitics, Management and Conservation of an Endangered Species*: 118-133. Tilson, R.L. & Seal, U.S. (Eds). Park Ridge, Noyes Publication, New Jersey, USA.

Karanth, K.U. (1995). Estimating tiger *Panthera tigris* populations from camera-trap data using capture-recapture models. *Biological Conservation* 71: 333-38.

Karanth, K.U. (1999). *Counting tigers with confidence.* In *Riding the Tiger*: Tiger Conservation in Human Dominated Landscapes: 350-353. Seidensticker, J., Christie, S. & Jackson, P. (Eds).Cambridge University Press, Cambridge, United Kingdom

Karanth, K.U. (2003). Tiger ecology and conservation in the Indian subcontinent. *Journal of Bombay Natural History Society*100:169-189.

Karanth, K.U. & Chundawat, R.S. (2002). Ecology of the tiger. Implications for Population Monitoring. In *Monitoring Tigers and their Prey: A Manual for Researchers, Managers and Conservationists in Tropical Asia:* 9-22. Centre for Wildlife Studies, Bangalore, Karnataka, India.

Karanth, K.U. & Nichols, J.D. (1998). Estimation of tiger densities in India using photographic captures and recaptures. *Ecology*79 (8): 2852-2862.

Karanth, K.U.& Nichols, J.D. (2000). *Ecological Status and Conservation of tigers in India*: Final Technical report to the Division of international conservation, US Fish and wildlife service, Washington DC and Wildlife Conservation society, New York, Center for wildlife Studies, Bangalore, India.

Karanth, K.U., Nichols, J.D., Seidensticker, J., Dinerstein, E., Smith J.L.D.,McDougal, C., Johnsingh, A.J.T., Chundawat, R.S. & Thapar, V. (2003). Science deficiency in conservation practice: the monitoring of tiger populations in India. *Animal Conservation* 6: 1-10.

Karanth, K.U., Chundawat, R.S., Nichols, J.D., & Kumar, N.S. (2004). Estimation of tiger densities in the tropical dry forests of Panna, Central India, using photographic capture-recapture sampling. *Animal Conservation* 7: 285-290.

Karanth, K.U., Kumar S.K. & Nichols, J.D. (2002). Field Sureys: Estimating absolute densities of tigers using capture-recapture sampling. In *Monitoring Tigers and their Prey: A Manual for Researchers, Managers and Conservationists in Tropical Asia* :139-152. Centre for Wildlife Studies, Bangalore, Karnataka, India.

Kawanishi K. & Sunquist. M.E. (2004). Conservation status of tigers in a primary rainforest of Peninsular Malaysia. *Biological Conseration* (Article in Press).

Kitchner, A.C. (1999). Tiger distribution, phenotypic variation and conservation issues. In *Riding the Tiger*: *Tiger Conservation in Human Dominated Landscapes*: 19-39. Seidensticker, J., Christie, S. & Jackson, P. (Eds).Cambridge University Press, Cambridge, United Kingdom

Lal, J.A., Kumar, A. & Kotwal, P.C. (1986). The botany of Kanha Tiger Reserve, Madhya Pradesh, India. *Biological Memoirs* 12:1-85.

Kostyria, A. V., Skorodelov, A. S., Miquelle, D. G., Aramilev, V. V. & McCulluogh, D. (2003). Results of camera trap survey of far eastern leopard population in southwestern Primorskikrai winter 2002 – 2003. *Wildlife Conservation Society.*

Miquelle, D.G., Smirnov, E.N., Quigley, H.G.,Hornocker, M.G., Nikolaev, I.G. & Matushkin, E.N. (1996). Food habits of Amur tigers in Sikhote- Alin Zapovednik and the Russian far east, and implications for conservation. *Journal of Wildlife Research* 1 (2): 138-147.

Nichols, J.D. (1992). Capture-recapture models: using marked animals to study population dynamics. *Bioscience* 42: 94-102.

Nichols, J.D. & Karanth. K.U. (2002). Statistical concepts: Estimating absolute densities of tigers using capture-recapture sampling. In *Monitoring Tigers and their Prey: A Manual for Researchers, Managers and Conservationists in Tropical Asia:*121-138. Centre for Wildlife Studies, Bangalore, Karnataka, India.

Nowell, K. & Jackson, P. (1996). Wild Cats: Status Survey and Conservation Action Plan. IUCN, Gland, Switzerland.

Otis, D.L., Burnham, K.P., White, G.C. & Anderson, D.R. (1978). Statistical inference from capture data on closed animal populations. *Wildlife Monographs* 62: 1-135.

Panwar, H.S. (1979). A note on tiger census technique based on pugmark tracings. *Indian Forester* (Special Issue) 70-77.

Pledger, S. (2001). Heterogeneity and finite mixture model in capture- recapture models. Australasian Biometrics and New Zealand Statistical association Joint Conference 2001. http:// atlas- conferences.com.

Pollock, K.H., Nichols, J.D., Brownie, C. & Hines, J.E. (1990). Statistical inference for capture recapture experiments. *Wildlife Monographs* 107:1-97.

Rodgers, W.A., Panwar, H.S. & Mathur, V.B. (2000). *Wildlife Protected Area Network in India: A Review (Executive Summary)*: 14-17. Wildlife Institute of India, Dehradun.

Sawarkar, V.B. (1987). Some More on Tiger Tracks. *Cheetal* 28(4): 1-8

Schaller, G.B. (1967). *The deer and the tiger*. University of Chicago Press, Chicago. Illinois. U.S.A.

Seber, G.A.F. (1982). *The Estimation of Animal Abundance and Related Parameters*. 2nd edition. Blackburn Press.

Seidensticker, J., Christier, S. & Jackson, P. (1999). Introducing the tiger. In *Riding the Tiger: Tiger Conservation in Human Dominated Landscapes*: 1-3. Seidensticker, J., Christie, S. & Jackson, P. (Eds).Cambridge University Press, Cambridge, United Kingdom

Seidensticker, J. (1986). Large carnivores and consequences of habitat insularisation: Ecology and conservation of tigers in Indonesia and Bangladesh. In *Cats of the World: Biology, Conservation and Management:* 1-41. Miller, S.D. & Everett, D.D. (Eds). National Wildlife Federation, Washington D.C..

Seidensticker, J.C., Hornocker, M.G., Wiles, W.V., & Messick, J.P. (1973). Mountain lion social organization in Idaho primitive area. *Wildlife Monographs* 35:1-60.

Sharma, S, Jhala, Y.V. & Sawarkar, V.B. (2003). Gender discrimination of tigers by using their pugmarks. *Wildlife Society Bulletin* 31(1):258-264.

Sharma, S. (2001). *Evaluation of Pugmark Census Technique*. Thesis, Saurashtra University, Rajkot (Gujarat) and Wildlife Institute of India, Dehradun, Uttaranchal, India.

Sharma, S., Jhala, Y.V. & Sawarkar, V.B. (2005). Identification of individual tigers from their pugmarks. *Journal of Zoology* 266: 1-10.

Silver, S.C., Ostro, L.E.T., Marsh, L.K., Maffei, L., Noss, A.J., Kelly, M.J., Wallace, R.B., Gomez, H., & Ayala, G. (2004). The use of camera traps for estimating jaguar (*Panthera onca*) abundance and density using capture/recapture analysis. *Oryx*38: (2): 148-154

Singh, A. (1972). A note on tiger census. *Cheetal* 15 (3)

Smallwood, K.S. & Fitzhugh, E.L. (1993). A rigorous technique for identifying individual mountain lions *Felis concolor* by their tracks. *Biological Conservation* 65:51-59.

Smallwood, K.S. & Fitzhugh, E.L. (1995). A track count for estimating mountain lion *Felis concolor californica* population trend. *Biological Conservation* 71: 251-59.

Smith, J.L.D. (1993). The role of dispersal in structuring the Chitwan tiger population. *Behaviour* 124: 165-195.

Sunquist, M.E. (1981). Social organization of tigers (*Panthera tigris*) in Royal Chitwan National Park, Nepal. *Smithsonian Contributions to Zoology* 336: 1-98.

Wegge, P., Pokheral, C.P. & Jnawali, S.R. (2004). Effects of trapping effort and trap shyness on estimates of tiger abundance from camera trap studies. *Animal Conservation.* 7:251-256.

Wentzel, J., Stephens, C., Johnson, W., Raymond, M.M., Slattery, J.P., Yukhi, N., Carrington, M., Quigley, H.B., Miquelle, D.G., Tilson, R., Manansang, J., Brady, G., Zhi, L., Wenshi, P., Quing, H.S., Johnston, L, Sunquist, M., Karanth, K.U. & Brien Stephen, J.O. (1999). Subspecies of Tigers: molecular assessment using 'voucher specimens' of geographically traceable individuals. In *Riding the Tiger: Tiger Conservation in Human Dominated Landscapes.* Seidensticker, J., Christie, S. & Jackson, P. (Eds).Cambridge University Press, Cambridge, United Kingdom.

Plate 5. Setting Camera Trap Units in field.

Plate 6. Self portrait of a tigress taken by a remote camera trap showing the unique stripe pattern on her left and right side. Note the track plot for recording details of the tigers pugmark sets.

Appendix I. Sampling schedule for camera trapping- 14 April 2005 to 26 May 2005.

Session No.	Date.	Trap nights.
Session I (Block I, II & III)	14 April-16 April	33
Session II (Block I, II & III)	17 April-19 April	33
Session III (Block I, II & III)	21 April-23 April	33
Session IV (Block I, II & III)	25 April-27 April	33
Session V (Block I, II & III)	28 April- 30 April	33
Session VI (Block I, II & III)	10 May-12 May	33
Session VII (Block I, II & III)	13 May-15 May	33
Session VIII (Block I, II & III)	16 May-18 May	33
Session IX (Block I, II & III)	21 May-23 May	33
Session X (Block I, II & III)	24 May-26 May	33
TOTAL SAMPLING EFFORT		**330**

Appendix II. Camera trap locations in the study area. B1, B2 and B3 depict three different sampling blocks.

Trap Location ID	East (degree decimal)	North (degree decimal)
B1TL01	80.55781	22.30403
B1TL02	80.58075	22.29597
B1TL03	80.56625	22.27728
B1TL04	80.58214	22.26050
B1TL05	80.58200	22.28372
B1TL06	80.60703	22.26875
B1TL07	80.61625	22.25694
B1TL08	80.61683	22.26411
B1TL09	80.62064	22.27103
B1TL10	80.61156	22.27853
B1TL11	80.59675	22.28175
B2TL01	80.60839	22.29519
B2TL02	80.60908	22.28969
B2TL03	80.62033	22.29042
B2TL04	80.63053	22.28792
B2TL05	80.64017	22.27931
B2TL06	80.66394	22.26942
B2TL07	80.64639	22.27286
B2TL08	80.63061	22.27297
B2TL09	80.62400	22.25086
B2TL10	80.62956	22.26319
B2TL11	80.62753	22.27639
B3TL01	80.61744	22.29742
B3TL02	80.61378	22.30756
B3TL03	80.63956	22.32350
B3TL04	80.62978	22.31039
B3TL05	80.64925	22.30833
B3TL06	80.65906	22.30636
B3TL07	80.66153	22.29381
B3TL08	80.65883	22.28681
B3TL09	80.64175	22.30156
B3TL10	80.63856	22.29358
B3TL11	80.64183	22.28956

Appendix III- Tiger intensive search effort matrix.

Sr. No.	Date	Tiger I.D.	Age	Sex	East	North
1	05.01.2005	A	3	F	80.64103	22.29694
2	10.01.2005	A	3	F	80.64097	22.29564
3	22.01.2005	B	9	F	80.63575	22.27586
4	24.01.2005	C	4	M	80.58125	22.28153
5	02.02.2005	D	7	F	80.56869	22.26461
6	03.02.2005	B	9	F	80.63553	22.26411
7	04.02.2005	E	6	M	80.61414	22.25997
8	08.02.2005.	A	3	F	80.63939	22.29733
9	09.02.2005	A	3	F	80.63881	22.29908
10	24.02.2005	B	9	F	80.63403	22.27308
11	25.02.2005	F	6	M	80.55411	22.28339
12	28.02.2005	E	6	M	80.57969	22.26642
13	02.03.2005	E	6	M	80.58333	22.25833
14	03.03.2005	B	9	F	80.62806	22.25761
15	03.03.2005	E	6	M	80.5765	22.26656
16	04.03.2005	B	9	F	80.63603	22.27189
17	04.03.2005	F	6	M	80.56369	22.24908
18	05.03.2005	B	9	F	80.63347	22.26419
19	05.03.2005	G	10	F	80.63347	22.26419
20	05.03.2005	H	4	M	80.63347	22.26419
21	07.03.2005	B	9	F	80.62819	22.25753
22	09.03.2005	I	8	F	80.62064	22.27103
23	09.03.2005	B	9	F	80.63022	22.27283
24	11.03.2005	B	9	F	80.50828	22.26853
25	16.03.2005	B	9	F	80.63717	22.26539
26	16.03.2005	F	6	M	80.576	22.27942
27	17.03.2005	G	10	F	80.64175	22.30156
28	18.03.2005	H	8	F	80.61742	22.26764
29	18.03.2005	F	6	M	80.5795	22.28336
30	19.03.2005	J	4	F	80.57272	22.26511
31	20.03.2005	I	8	F	80.62997	22.27261
32	20.03.2005	F	6	M	80.58225	22.26067
33	22.03.2005	E	6	M	80.6285	22.26147
34	22.03.2005	B	9	F	80.62742	22.26008
35	22.03.2005	F	6	M	80.52506	22.27878
36	23.03.2005	B	9	F	80.62917	22.25742
37	23.03.2005	J	4	F	80.56606	22.26169

Sr. No.	Date	Tiger I.D.	Age	Sex	East	North
38	23.03.2005	F	6	M	80.52506	22.27878
39	24.03.2005	F	6	M	80.55986	22.281
40	24.03.2005	K	9	F	80.624	22.26919
41	28.03.2005	F	6	M	80.57956	22.29003
42	29.03.2005	B	9	F	80.63661	22.2715
43	29.03.2005	I	8	F	80.62492	22.26283
44	30.03.2005	B	9	F	80.62797	22.258
45	31.03.2005	F	6	M	80.55244	22.28703
46	31.03.2005	B	9	F	80.63678	22.27136
47	31.03.2005	I	8	F	80.63678	22.27136
48	02.04.2005	E	6	M	80.63122	22.26431
49	02..04.2005	F	6	M	80.56872	22.29581
50	02.04.2005	B	9	F	80.63311	22.26422
51	03.04.2005	L	6	M	80.57669	22.25906
52	03.04.2005	B	9	F	80.63311	22.26422
53	03.04.2005	K	9	F	80.59475	22.28281
54	04.04.2005	B	9	F	80.64089	22.26725
55	04.04.2005	K	9	F	80.59686	22.28172
56	08.04.2005	C	4	M	80.61981	22.29667
57	09.04.2005	C	4	M	80.61981	22.29667
58	10.04.2005	C	4	M	80.61981	22.29667
59	10.04.2005	E	6	M	80.62753	22.27639
60	11.04.2005	C	4	M	80.61981	22.29667
61	12.04.2005	C	4	M	80.61981	22.29667
62	13.04.2005	C	4	M	80.61981	22.29667
63	14.04.2005	C	4	M	80.61981	22.29667
64	14.04.2005	B	9	F	80.63447	22.27292
65	14.04.2005	I	8	F	80.62239	22.27469
66	14.05.2005	E	6	M	80.62589	22.26336
67	16.04.2005	B	9	F	80.63439	22.27294
68	18.04.2005	F	6	M	80.57972	22.28964
69	18.04.2005	E	6	M	80.61669	22.25711
70	19.04.2005	F	6	F	80.57972	22.28964
71	21.04.2005	C	6	M	80.60839	22.29519
72	22.04.2005	B	9	F	80.63497	22.27264
73	22.04.2005	E	6	M	80.63061	22.27297
74	24.04.2005	B	9	F	80.63061	22.27297
75	24.04.2005	F	6	M	80.57558	22.29136
76	24.04.2005	E	6	M	80.64639	22.27286

Sr. No.	Date	Tiger I.D.	Age	Sex	East	North
77	26.04.2005	B	9	F	80.62772	22.27689
78	29.04.2005	I	8	F	80.61797	22.2575
79	29.04.2005	J	4	F	80.56708	22.27764
80	02.05.2005	D	7	F	80.57117	22.26644