

**HABITAT OCCUPANCY BY WILD UNGULATES IN
PENCH TIGER RESERVE, MADHYA PRADESH**

**DISSERTATION SUBMITTED TO SAURASHTRA UNIVERSITY, RAJKOT,
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**by
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**UNDER THE SUPERVISION OF
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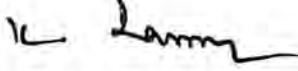


भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE

This is to certify that Mr. B. Bhaskar Acharya of the Wildlife Institute of India has carried out an original research work titled "Habitat Occupancy by Wild Ungulates in Pench Tiger Reserve, Madhya Pradesh" in partial fulfilment of the M.Sc. (Wildlife Science) degree of Saurashtra University. These investigations were carried out under my supervision from November 1996 to June 1997. I also certify that this research work has not been submitted for any other degree to any University.

Date: 30th June 1997
Place: Dehra Dun


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APPENDIX I

LIST OF PLANT SPECIES IDENTIFIED FROM WITHIN THE VEGETATION PLOTS OF THE STUDY AREA (PENCH TIGER RESERVE, MADHYA PRADESH)

TREES

Acacia catechu
Adina cordifolia
Aegle marmelos
Albizia odoratissima
Albizia procera
Anogeissus latifolia
Bauhinia racemosa
Bombax ceiba
Boswellia serrata
Bridelia retusa
Buchanania lanzan
Butea monosperma
Careya arborea
Casearia tomentosa
Casearia graveolens
Cassia fistula
Chloroxylon swietenia
Cleistanthus collinus
Cochlospermum gossypium
Dalbergia sissoo
Dalbergia paniculata
Diospyros montana
Diospyros melanoxylon
Emblica officinalis
Ficus glomerata
Gardenia latifolia
Grewia tiliaefolia
Hymenodictyon excelsum
Kydia calycina
Lagerstroemia parviflora
Lannea coromandelica
Maduca longifolia
Miliusa velutina
Mitragyna parviflora
Nyctanthes arbor-tristis
Ougeinia dalbergioides
Pterocarpus marsupium
Schleichera oleosa
Schrebera swietenoides
Semecarpus anacardium
Soymida febrifuga
Sterculia urens
Syzygium cumini
Tectona grandis
Terminalia tomentosa
Zizyphus xylopyra

SHRUBS AND CLIMBERS

Bauhinia vahlii
Butea superba
Grewia hirsuta
Helecteres isora
Holarrhena antidysenterica
Lantana camara
Randia uliginosa
Ventilago madraspatana
Zizyphus oenoplia

HERBS

Achyranthes aspera
Barlaria sp.
Desmodium sp.

OTHERS

Dendrocalamus strictus
Phoenix acaulis

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SUMMARY

This study on the habitat occupancy by wild ungulates was carried out from November 1996 to April 1997 in the Pench Tiger Reserve, Madhya Pradesh. The spatial and seasonal difference in habitat occupancy of the major forest types by the wild ungulates viz. chital (*Axis axis*), sambar (*Cervus unicolor*), gaur (*Bos gaurus*), nilgai (*Boselaphus tragocamelus*) were assessed.

The study area was stratified into three major forest types based on floristics and physiognomy as: Teak dominant forest, *Anogeissus-Boswellia* mixed forest and Miscellaneous forest. A total of 12 transects were laid in three forest types. Data was collected on ungulate densities, dung abundance and habitat parameters. The Line transect Method was used for estimating ungulate densities. Dung abundance was quantified using a belt transect, at each 200 m point on the transects. Habitat parameters were also quantified at these points.

The relationship between habitat factors and the distribution of ungulates were examined using bivariate and multivariate analyses.

The results showed that chital densities were significantly lower in Teak dominant forest type in winter, and in the *Anogeissus-Boswellia* mixed forest type in summer. Both Teak and Miscellaneous forest types showed greater chital densities in summer than in winter. Sambar densities showed no significant differences between forest types both in winter and in summer. *Anogeissus-Boswellia* mixed forest type showed a significant increase in sambar density from winter to summer.

Chital dung abundance showed no significant differences between forest types, both in winter and in summer, while sambar dung abundance in the *Anogeissus-Boswellia* mixed forest type was significantly higher than other forest types in both seasons. There were significant seasonal differences in chital dung abundance in all forest types, whereas sambar dung abundance increased only in the miscellaneous forest type.

CHAPTER 1: INTRODUCTION

The term habitat refers to an area that meets an animals basic life requisites such as food, water, cover and space (Giles 1978). A number of interdependent variables play a role in the formation of a particular habitat. An animal occupies or utilizes a habitat based on the spatio-temporal variation of such interdependent habitat variables (Norman *et al* 1975).

Most wildlife habitats are shared by more than one species of wild ungulates. Wild ungulates, coexisting in the same habitat, use it differentially, with reference to resource, space and time, as a result of resource competition or overlap (Lamprey 1963, Rosenzweig 1981, Scogings *et al* 1990). Even among two species using the same habitat, there is a certain degree of temporal or dietary separation. Seasonal changes in habitat use also occur in most wild ungulates (Green 1987, Chakraborty 1991, Khan 1996, Sankar 1994).

The knowledge about differential use of habitat in space and time by ungulates can greatly help in the management and conservation of the species (Seidensticker 1976). Moreover, changes in the vital habitat requisites such as food, water, cover have long-term implications for the management of threatened animals and their habitats (Gilpin and Soulé 1986), especially wild ungulates which form the prey base for many endangered and threatened large carnivores. Thus, a sound understanding of the habitat requirements of ungulates and the habitat parameters affecting their distributions becomes very essential. The same is true for the Indian scenario, where most wildlife habitats are shared by two or more ungulate species.

In the context of rapidly declining forest cover, mainly due to loss or degradation of land through human use, decreased water availability, and increasing human energy demands

and poaching, many ungulate species of India require urgent attention for their conservation. Most of these species, being generalist feeders or grazers, contribute overall the greatest percentage to terrestrial mammalian biomass in any given habitat (Eisenberg and Scidensticker 1976). Moreover, chital and sambar together form the bulk of the prey base for large predators of the Indian sub-continent such as the tiger (*Panthera tigris*), the Asiatic lion (*Panthera leo*), and the leopard (*Panthera pardus*). As pointed out by Daniel (1991), without the benefit of thorough scientific studies and the information generated out of them, it is difficult to plan for their conservation and management and to ensure their long-term survival.

The Pench Tiger Reserve is an area which offers an unique opportunity for research on large mammal populations and their habitats. The Reserve is endowed with fairly large populations of four large wild ungulates sambar (*Cervus unicolor* Blainville), chital (*Axis axis* Erxleben), gaur (*Bos gaurus* H. Smith) and nilgai (*Boselaphus tragocamelus* Pallas). Moreover, the National Park area of the Tiger Reserve is relatively undisturbed, providing ideal conditions for ecological studies.

1.1. REVIEW OF LITERATURE

1.1.1. Habitat use

There have been relatively few studies on large ungulate-habitat interactions in the Indian sub-continent, notable among them being those of Schaller (1967), Eisenberg and Lockhart (1972), Berwick (1974), Dinerstein (1979), Mishra (1982), Balakrishnan and Easa (1986), Green (1985), Karanth and Sunquist (1992), Haque (1990), Bhatnagar (1991), Chakraborty (1991), Khan (1993), Sankar (1994), Bhat and Rawat (1995), and Raman (1997).

1.1.2. Study animals

Chital

The chital or spotted deer is the third largest deer inhabiting the plains and undulating terrain of the Indian sub-continent. Its distribution ranges from the foot hills of Himalayas throughout the peninsular India in the forested areas, and from western Assam up to Eastern Rajasthan and Gujarat. It is found in a variety of forest types ranging from dry deciduous forests to moist deciduous, thorn and scrub jungles, and also in mangals.

The chital prefers flat terrain and valley habitats, frequenting ecotones with a high diversity of palatable grass and herb species, and early to middle successional stages of vegetation (Schaller 1967, Dinerstein 1979, Mishra 1982, Bhat 1995, Khan 1996). They are highly dependent on water and shade (Schaller 1967). Being more dependent on grass (Schaller 1967, Johnsingh & Sankar 1991), the chital avoids areas of heavy cattle grazing (Khan 1996). Relatively more information is available on chital (*Axis axis*) though only a few of these are quantitative studies e.g. Schaller (1967), Berwick (1974), Haque (1990), Khan (1993) and Raman (1997). The definitive research on these species to date are on the populations introduced into other parts of the world such as Hawaii (Graf and Nichols 1966), Texas (Ables and Ramsey 1974), Argentina and Australia (Lever 1985).

Sambar

Sambar deer is the largest deer species native to South East Asia. It has an exceedingly wide geographical distribution, including India, Myanmar and Sri Lanka extending through Indo-China and Malay countries and eastward to the Philippines and beyond (Prater 1965).

In spite of the wide distribution of sambar (*Cervus unicolor*), and its importance as a prey animal (Schaller 1967, Johnsingh 1983, Johnsingh *et al* 1993, Mukherjee *et al* 1994, Sankar 1994), there have been a few detailed studies (Schaller 1967, Green 1985, Khan 1993,

Sankar 1994) on its population biology or habitat requirements. This could very well be due to its low density and crepuscular habits over much of its range. A lot of information has been generated from studies on sambar introduced into Texas (e.g. Richardson II 1972), Florida (e.g. Shea *et al* 1990), and the Thai population (e.g. Ngampongsai 1987).

Probably no other wild ungulate in the Indian subcontinent, has adapted itself to such a wide variety of conditions and habitat types as the sambar (Schaller 1967, Rodgers 1988). Nevertheless, it definitely avoids disturbed areas (Schaller 1967, Prater 1965, Khan 1993, Sankar 1994). Availability of water and forests on hill slopes with dense understorey are believed to be essential components of sambar habitat (Schaller 1967, Dinerstein 1979, Johnsingh 1983, Bhatnagar 1991). Sambar densities in the moist deciduous forests and teak dominated plantation forests are higher than in the dry deciduous forests (Karanth and Sunquist 1992). Forage availability is an important factor determining the utilization of a habitat by sambar (Richardson II 1972).

Sambar have been successfully introduced to numerous locations outside their native range e.g Texas (Richardson II 1972, Ables and Ramsey 1974), on St.Vincent Islands, Florida (Lewis *et al* 1990), and in Australia (Slee 1984).

Nilgai

The nilgai occurs in more open forests from the Himalayan foot hills including Nepal, southward through central India (Prater 1971).

Nilgai occur in relatively open areas with undulating or flat terrain (Berwick 1974), avoiding dense forests (Daniel 1994) and preferring scrublands, with low tree and shrub densities (Chakraborty 1991, Sankar 1994, Khan 1996). They are reported to tolerate scarcity of water (Bohra *et al* 1992).

Quantitative studies on nilgai include those by Schaller (1967), Berwick (1974), Haque (1990), Khan (1993) and Sankar (1994).

Introduced nilgai populations occur in Texas (Sheffield *et al* 1983), Mexico and in South Africa (Lever 1985).

Gaur

The gaur favour hilly terrain (Schaller 1967), and occur in the Western Ghats, hill forests of central and south-eastern peninsular India, north-east India and parts of Nepal.

Except two studies in the Kanha National Park by Schaller (1967) and Chandiramani (1984), no detailed study of the gaur has been conducted in the Indian sub-continent. Gaur in Central Highlands of India are essentially hill-forest dwellers, that descend to the lowland valleys and plains close to water sources and away from disturbance (Schaller 1967). They are known to favour cool, dense forest cover.

1.2. OBJECTIVES:

The overall objective of the study was to identify factors governing spatial and temporal variations in habitat use by sambar, chital, nilgai and gaur in Pench National Park.

The specific objectives are

1. to determine the habitat parameters that influence the distribution of these ungulates;
and
2. to assess the differences in habitat use by these ungulates between winter and summer.

The hypothesis, that there is no spatial and seasonal difference in occupancy of the major habitat types by the wild ungulates of the study area, was tested.

CHAPTER 2 STUDY AREA

2.1. GENERAL INFORMATION

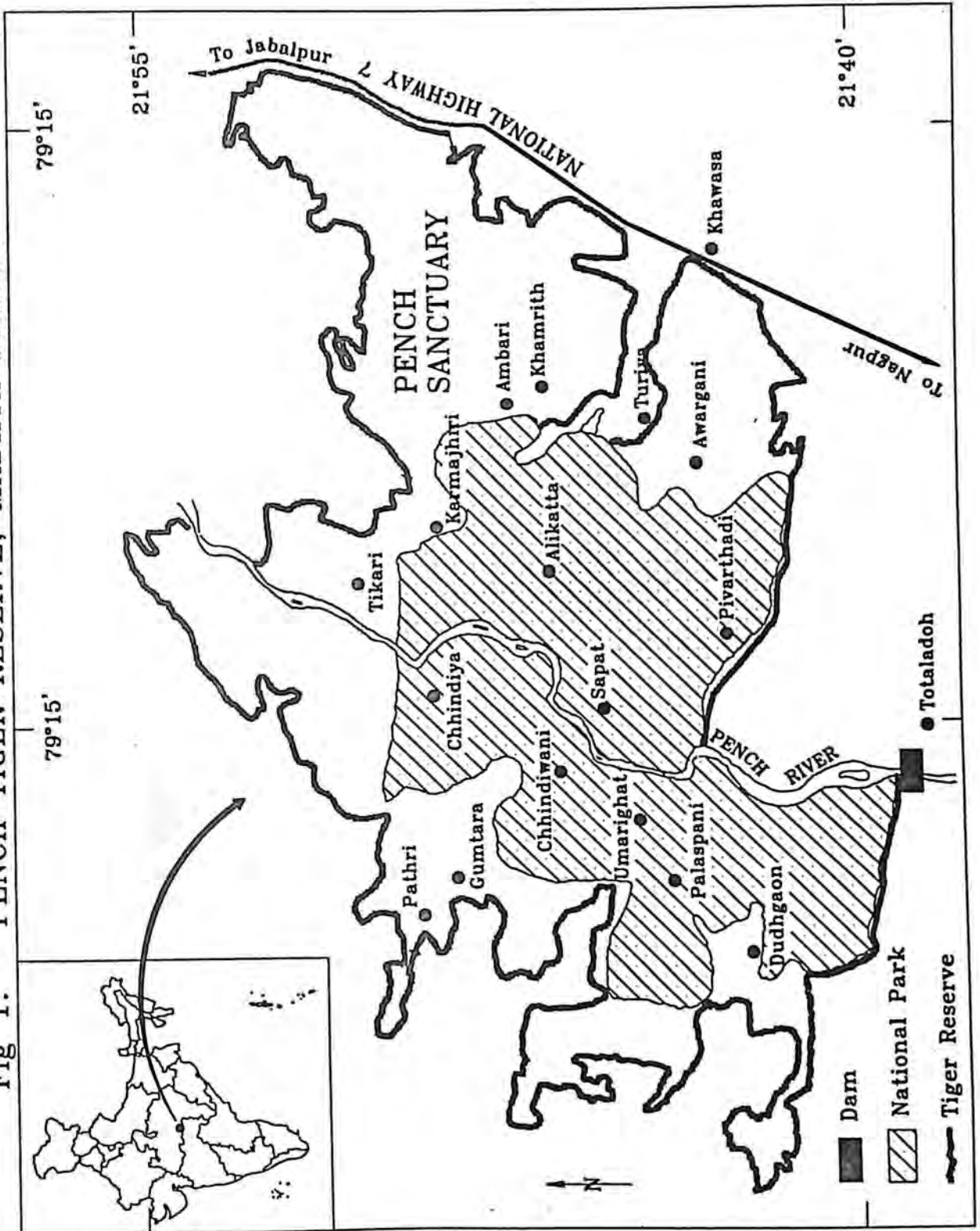
The study was conducted in the Pench Tiger Reserve (79° 35' E to 78° 55' W and 22° N to 21° 8' S), Madhya Pradesh. Biogeographically, the Tiger Reserve falls in ZONE 6E Deccan Peninsula (Rodgers and Panwar 1988).

Pench Tiger Reserve, which was established in November 1992, gets its name from the Pench river which flows through it. It lies in the southern lower reaches of the Satpura Hill range on the southern border of Madhya Pradesh. The total area of the Reserve is 758 km² of which, the Pench National Park, forming the core zone of the Reserve, is 292.85 km², and the Pench Wildlife Sanctuary is about 118 km² (Kumar 1990). The National Park is about 12 km west of National Highway No. 7 which runs between Nagpur and Jabalpur.

The Pench river bisects the Pench National Park into two parts, the 147.61 km² of the Western Block which falls in the Gumtara Range of the Chindwara Forest Division and the 145.24 km² of the Eastern Block in the Karmajhiri Range of the Seoni Forest Division (fig 1). While the Eastern Block is a prime undisturbed wildlife habitat, the Western Block has, to some extent, livestock grazing and associated biotic pressures. The Eastern Block formed the intensive study area.

During summer, the Pench river dries out leaving small pools of water locally known as "doh" or "khassa", which are the most important sources of water for the animals during this period.

Fig 1. PENCH TIGER RESERVE, MADHYA PRADESH



A significant part (54 km²) of the National Park has come under submergence of the Pench Hydroelectric Project. In summer, the draw-down areas of the reservoir have excellent growth of grass supporting large numbers of wild ungulates.

2.2. PHYSICAL FEATURES

The general topography in the Pench Tiger Reserve is mostly undulating, characterised by small ridges and hills having steep slopes, and with a number of seasonal streams and nullahs. The topography becomes flatter close to the Pench river. The mean altitude is around 600 m above M.S.L.

2.3. CLIMATE

The Central Indian Highlands have a monsoonal continental climate, with a distinct monsoon (July to September), summer (April to June) and winter (November to February).

The mean annual rainfall is around 1400 mm, with the south-west monsoon accounting for most of the rainfall in the region. For the dry season (November to May), the mean rainfall was 59.5 mm, and the temperature varies from a minimum of 0° C in winter to 45° C in summer (Source: WII Gaur Ecology Project).

2.4. VEGETATION

Floristically, the Tiger Reserve can be classified, according to Champion and Seth (1968), as

- I. Tropical Moist Deciduous Forests:
 - i. TYPE 3B/C_{1c} Slightly moist teak forests

II. Tropical Dry Deciduous Forests:

- i. TYPE 5A/C_{1b} Dry teak forests
- ii. TYPE 5A/C₃ Southern dry mixed deciduous forests

Teak (*Tectona grandis*), and associated species such as *Madhuca indica*, *Diospyros melanoxylon*, *Terminalia tomentosa*, *Buchanania lanzan*, *Lagerstroemia parviflora*, *Ougeinia dalbergoides*, *Miliusa velutina* and *Lannea coromandalica*, occur more or less in flat terrain. The undulating terrain and hill slopes have patches of Mixed Forest dominated by *Boswellia serrata* and *Anogeissus latifolia*. Species like *Sterculia urens* and *Gardenia latifolia* are found scattered on rocky slopes. Bamboo (*Dendrocalamus strictus*) forest occur in the hill slopes and along streams. Some of the open patches of the Park are covered with tall grasses interspersed with *Butea monosperma* and *Zizyphus mauritiana*. Evergreen tree species like *Terminalia arjuna*, *Syzygium cumini* and *Ixora parviflora* are found in riparian vegetation along nullahs and river banks. *Cleistanthus collinus* occur as dense dominant patches in some parts of the National Park.

Teak is a ubiquitous species in the region, with a presence ranging from a sporadic distribution in most parts of the study area to Teak-dominated patches.

2.5. STRATIFICATION OF HABITAT TYPES

The study area was stratified into three major habitat types based on a combination of topographic features and floristic characters, as

1. TEAK DOMINANT FOREST
2. ANOGEISSUS-BOSWELLIA MIXED FOREST and
3. MISCELLANEOUS FOREST.

TEAK DOMINANT FOREST

This habitat type is characterised by a more or less flat terrain, showing a predominance of teak (*Tectona grandis*), and its associated species. But by virtue of it not being a pure single species stand, the understorey is fairly rich in terms of shrubs and grasses. Moreover, this habitat type is localized only to those areas close to the Pench river.

ANOGEISSUS-BOSWELLIA MIXED FOREST

The terrain of this habitat type is hilly. This habitat type is a mixed species forest type, and *Boswellia serrata* and *Anogeissus latifolia* dominate. Grass availability is less in comparison to the other habitat types, but browse availability is relatively high.

MISCELLANEOUS FOREST

This habitat type is characterised by flat or undulating terrain having a mixture of tree species, none of which is dominant. The vegetation ranges from moist deciduous patches to open savanna patches, and therefore a variety of food sources as understorey vegetation for the herbivores, both in terms of grass and browse.

2.6. FAUNA

Sambar, chital, gaur, nilgai, chowsingha (*Tetraceros quadricornis*), barking deer (*Muntiacus muntjac*), chinkara (*Gazella bennetti*), and wild pig (*Sus scrofa*) are the wild ungulate species found in the study area. Sambar, chital and wild pigs are found all over the National Park. With the distribution of water governing their movement patterns to a great extent, gaur migrate down in large numbers from the hills during the dry season and occupy the forests along the Pench river and other sources of water, and migrate back to the hill forests during the monsoon. Nilgai are found mostly in a few open areas, scrub jungles and periphery

of the Park. Chowsingha are more localized to the greatly undulating areas of the Park. Barking deer frequents moist riverine stretches. Chinkara is reported to occur near Turia village outside the boundary of the Tiger Reserve.

The carnivores are represented by the tiger (*Panthera tigris*), leopard (*Panthera pardus*), jungle cat (*Felis chaus* Gueldenstaedt), leopard cat (*Felis benghalensis* Kerr), desert cat (*Felis lybica* Forster), dhole (*Cuon alpinus* Pallas), striped hyena (*Hyaena hyaena*), jackal (*Canis aureus*), small Indian civet (*Viverricula indica* Rasse), common palm civet (*Paradoxurus hermaphroditus*), sloth bear (*Melursus ursinus* Shaw), common mongoose (*Herpestes edwardsii*) and ruddy mongoose (*Herpestes smithii*),

The common langur (*Presbytis entellus*) and rhesus macaque (*Macaca mulatta*) represent the primate fauna of the area. The black-naped hare (*Lepus nigricollis nigricollis*) also occurs.

2.7. PEOPLE

The park is surrounded by villages, inhabited by people of the Gond tribe who speak in a local dialect called Gondi. Being forest dwellers, they hold great respect for the forest and its fauna, many of which are worshipped.

No human settlements are present in the Eastern Block of the National Park, with the last remaining village Alikatta having been relocated. There are nearly 100 villages in a 5 km belt along the boundary of the Reserve.

CHAPTER 3 METHODS

3.1. INTRODUCTION

Quantification of habitat use by wild ungulates is done mainly by obtaining estimates of the densities of the ungulates in each habitat type. This is done based on direct sightings of the target species, or indirect evidences such as pellets or dung. Use of both direct and indirect methods of estimating mammal densities have already demonstrated in the sub-continent (Karanth and Sunquist 1992).

The information generated through these techniques can be used to predict the response of the wild ungulates to alteration of their habitat or habitat components through management practices (Hirst 1975, Khan *et al* 1990, Sharma 1995).

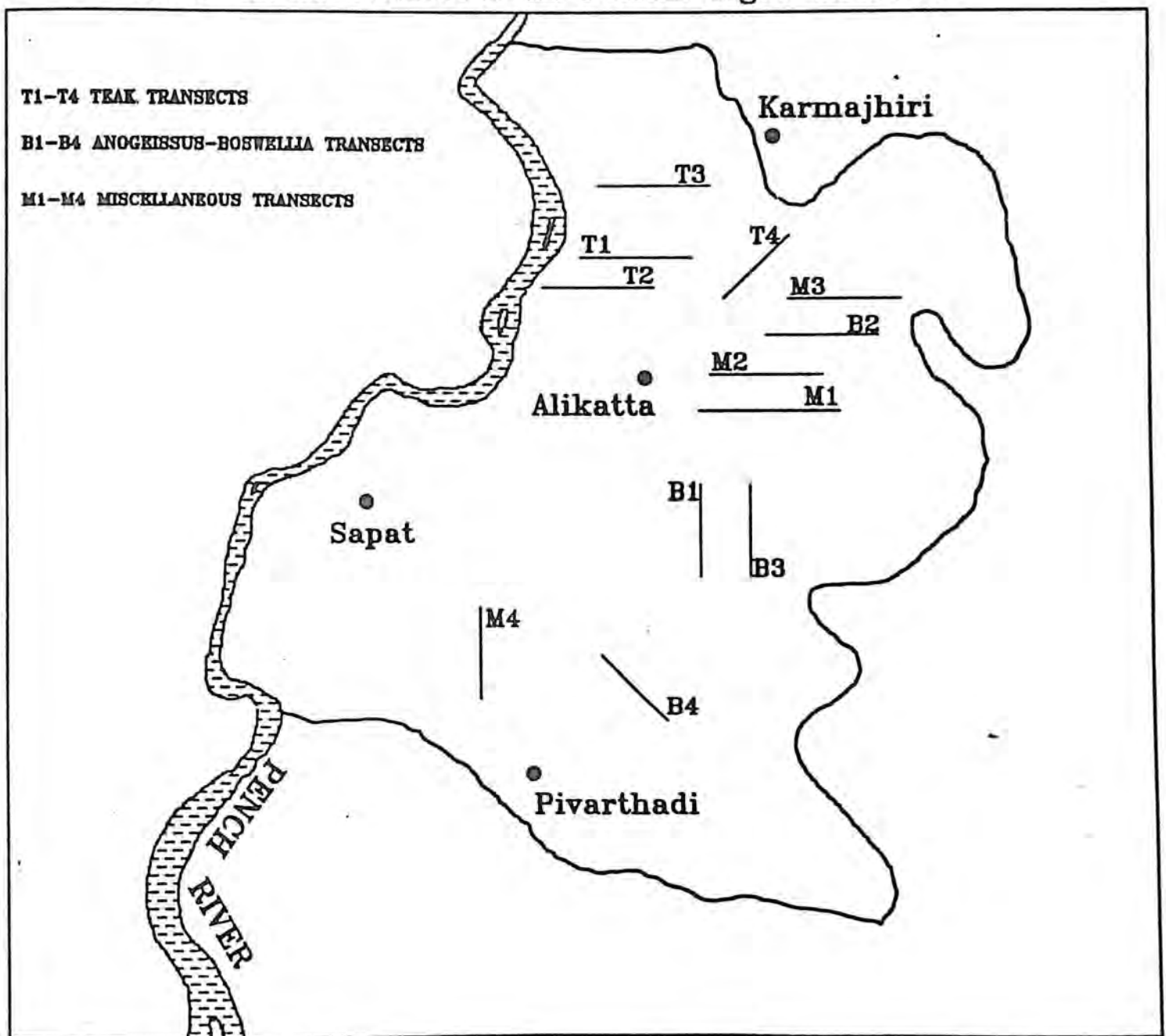
3.2. DATA COLLECTION

Due to the lack of detailed vegetation map of the study area, the proportions of area occupied by different vegetation types could not be arrived at. Thus, equal area sampling was resorted to.

The study area was stratified into three major vegetation types *viz.* Teak dominant forest type, *Anogeissus-Boswellia* mixed forest type, and Miscellaneous forest type. Only these three forest types were found to have large contiguous areas fit for laying long transect lines (minimum 2 km). The riverine forest, bamboo forests, and the *Cleistanthus collinus* dominant forest type were found to be too small in size to lay transects. The 54 km² area of the submergence zone of Pench reservoir was not available for sampling in winter, as it was under submergence till end February.

Within the three major forest types, four transects averaging a length of 2.5 km (total length per forest type = 10 km) were randomly laid (fig. 2). The total length of transects in the

Fig 2. Intensive study area (eastern block) showing location of transects in Pench Tiger Reserve



study area was 30 km. Transect walks were optimized by first saturating the number of replicates possible in a forest type ($n = 4$) and then using repetitions i.e. pseudo-replicates ($n = 4$). Ideally, it is better if the replicates were greater in number than the repetitions (i.e. more area, and so more variability covered, fewer number of times). Since only a maximum of two transects could be walked in a day (morning and evening), time was a definite constraint in laying more of transects with shorter length.

Along each transect, circular plots (with a radius of 10 m for trees and 5 m for shrubs), and point-intercept lines of 50 m (for ground cover), were laid at every 200 m point where quantification of vegetation (structure and composition of vegetation, species diversity) and habitat parameters were carried out, once each in summer and winter.

The parameters that were quantified in the 10 m radius plot are

Tree species and number

Canopy cover (%)

Average height of lowest foliage branch of trees

Number of trees with foliage below 2.5 m

Evidence of fire

Distance to nearest water source (natural/artificial) and

Slope(°).

Canopy cover was measured using a spherical densiometer. The mean of four readings was taken and converted into percentage figures. The height of the lowest foliage branch was measured up to a maximum height of 2.5 m, considered accessible to sambar (Bhatnagar 1991). Data on evidences of fire were ranked on a scale of one to four (1 = no evidences of fire, 2 = old fire more than a year old, 3 = more than one month old fire, and 4 = less than one month old fire). Distance to nearest water source was estimated in kilometres using topographic maps of the study area. A clinometer was used to measure the slope (mean of three readings).

The parameters that were quantified in the 5 m radius plot are:-

Shrub species and numbers

Shrub volume for a height of 2 m and

Vegetation cover % (horizontal and vertical dimensions).

The shrub volume for a plot was calculated by measuring the length, breadth and height of each shrub in the plot and adding up the individual volumes. Vegetation cover was measured both along the horizontal and vertical dimensions using a banded pole of 2 m length, with 20 bands of alternating white and red. This was held first horizontal (at 1 m height) and then vertical, and an observer 20 m away counts the number of bands visible each time. The proportion of bands visible gives an index of visibility for each dimension and the reciprocal of this gives the cover value. This is converted to percentages for both dimensions. The final value is a mean of three readings taken per plot.

The parameters that were quantified using the 50 m point-intercept method are:-

Grass height

Grass %

Herb %

Weed %

Litter %

Rock %

Bare soil %.

This ground cover estimation was done using a rope of 50 m length laid across the plot. On this were 100 knots 50 cm apart representing point-intercepts. The different categories of ground layer immediately below the intercepts were enumerated. Since a total of 100 intercepts were present, this directly gave the percent figures of the different ground layer variables.

Grass height was measured at three locations on the line and the mean was recorded for the plot.

Indirect estimates of wild ungulate habitat use was calculated from dung or pellet counts. Data for this was collected by laying 30 m x 2 m belt transects at each vegetation sampling point. These belt transects were cleared of any dung at the beginning of the study period (December). A pellet count was then carried out at the end of winter (February), to obtain dung accumulated through winter. The belt transect was again cleared of all dung. The second pellet count was carried out at the end of the study period (April) when dung accumulated through summer was counted. Fresh pellets/dung of the ungulates was also placed in the different vegetation types in December and monitored to assess the rate of disintegration through the course of the study period.

Wild ungulate abundance data was estimated by direct sightings using the Line Transect Method (Anderson *et al* 1979). Each transect was walked 4 times in a season. A total of 120 km was walked for each season. For each sighting, the **species, group size, group composition (age classes and sex), sighting angle** and the **angular sighting distance** from the transect line was recorded. Additional information such as topography of the animal location was noted for each sighting.

3.3. DATA ANALYSES

3.3.1. Direct sightings

Direct estimation of ungulates densities in tropical forests is difficult mainly because of poor visibility and relatively low density of these populations, resulting in inadequate sample sizes for statistically precise results. With the development of sophisticated statistical methods of sampling animal densities (Burnham *et al* 1980), this difficulty has been reduced to a large extent. The most common and scientifically accepted method of estimating animal densities is

the Line Transect Sampling method (Anderson *et al* 1979, Burnham *et al* 1980, Buckland *et al* 1993). Line transect sampling is practical, efficient and relatively inexpensive for many biological populations. One of the assumptions of the Line Transect Method is that objects on the line are seen with probability 1 and the probability decreases in some way as objects are sighted away from the line. The way this probability decreases is known as the probability density function (PDF), (Burnham *et al* 1980) having a particular shape. Different models are available to fit this shape in order to estimate the density of the objects eg. Half-Normal, Fourier Series, Uniform and Negative Exponential.

The programme **DISTANCE** (Laake *et al* 1994), was used to obtain estimates of wild ungulate densities using the direct sightings data from line transects. With the four successive walks of a transect considered as individual sample efforts, the pooled estimate of density is calculated by resampling from these different walks. The half-normal, the uniform and the negative exponential models were tried out to obtain the model that best fitted the data. The model that best fits the data is the one which gives the minimum **Akaike Information Criteria** value. The output is a pooled density estimate with an empirical variance. Thus a density estimate was obtained for each species, for each habitat type, in each season. These density estimates and their associated variance were analyzed using single factor ANOVA (Model I) (Zar 1984), to assess differences in densities of each species between seasons, and also between habitat types in each season (e.g. Khan 1993, Sankar 1994). This was done separately for each ungulate species.

3.3.2. Indirect evidences

Indirect evidences (e.g. Cairns and Telfer 1980) such as dung or pellets reflect habitat use over a longer period of time, giving a better picture of habitat use by the ungulate species, under the assumption that the defecation pattern is uniform among all habitat types. Dung is

a reliable indicator of ungulate presence (e.g. Edge and Marcum 1989) and has been extensively used for quantifying habitat use in the Indian sub-continent (e.g. Eisenberg and Lockhart 1972, Berwick 1974, Dinerstein 1979, Khan 1993, Sankar 1994). The use of dung count is often restricted to the dry season, since dung disintegration and decay is rapid during the monsoon. In addition, dung beetle activity is significantly higher during the wetter months, thus decreasing the accuracy of pellet counts in that season (Dinerstein 1979).

The abundance of dung of the different ungulate species, recorded in each plot using the belt transect, was analyzed using the nonparametric Wilcoxon Matched Pair rank test to assess significant differences in dung abundances in individual plots, between winter and summer. Kruskal-Wallis Analysis of Variance was used to determine significant differences in dung abundance between habitat types within each season. Mann-Whitney U test was used to find the individual habitat type(s) that was/were showing significant difference in dung abundance.

The above mentioned statistical tests, being non-parametric tests, were preferred over parametric tests, because unlike the latter, they do not require the fulfilment of any conditions on the underlying distribution of the variable, in this case, dung abundance.

3.3.3. Habitat factors

The relationship between habitat factors and the distribution of ungulates species can be examined using bivariate and multivariate analyses (e.g. Ben-Shahar and Skinner 1988, Scogings *et al* 1990, Khan 1993, Sankar 1994), through which major factors affecting wild ungulate distribution can be identified. Multiple regression analysis (Austin 1971) is an effective parametric technique to identify major factors to which a dependent variable is sensitive. A coefficient of determination R^2 is obtained which serves as an estimate of the proportion of variation in the dependent variable explained by the regression (Draper and Smith

1981). Multiple regression has been used to assess relationships between ungulate dung abundance and a range of independent habitat variables (e.g. Ben-Shahar and Skinner 1988, Khan 1993, Sankar 1994).

Many of the measured habitat variables were used as such, while some of the variables were converted into other derived variables. Among these, ground cover percentage variables such as grass percentage and litter percentage were arcsine transformed to remove the effect of proportions (percentage in this case), and make them independent of each other. Total available browse volume per plot was calculated as the total volume of all palatable shrubs in a plot up to a height of 2 m. The variable, height of lowest foliage branch of a tree yielded another variable, the number of trees with foliage branch below 2.5 m (assumed to be the average reach of a sambar) and the average height of lowest foliage per plot.

The programming language PASCAL and the database package LOTUS 1-2-3 were used to convert, sort and structure the data.

The relationship between dung abundances and the habitat parameters or variables quantified, was analyzed using statistical techniques such as factor analysis and multiple regression available on the statistical software package SPSS/PC+ (Norusis 1990).

Factor analysis is a statistical technique which identifies a relatively small number of factors that can be used to represent relationships among sets of many interrelated variables. These underlying, not directly observable factors, can be used to explain complex phenomena and observed correlations between variables, in the process using fewer, but more meaningful factors. **Bartlett's test of sphericity** is used to test that the correlation matrix is an identity matrix (i.e. correlation coefficients tend towards zero). **Kaiser-Meyer-Olkin measure of sampling adequacy** is an index for explanation of correlations between pairs of variables by other variables. A value of 0.6 or greater, indicates adequacy.

The factors representing groups of related variables is determined using **principal components analysis** (PCA), a factor extraction method, in which linear unrelated combinations of variables called principal components are formed from a set of correlated variables. Finally for each individual case of the data, a factor score for each factor is obtained, which can be used in subsequent analyses to represent the values of that factor.

In this case, the range of habitat variables were subjected to factor analysis, not only to reduce their dimensionality to fewer and simpler factors, but also make the data compatible for multiple regression analyses. Multiple regression analysis requires the variables regressed to be independent of each other. The fact that most of the variables are related in some way to each other precludes their inclusion into the regression model.

Ultimately, the factor scores (representing the variability in the habitat) being independent of each other, were regressed against the dependent variable, the dung abundance, plot-wise. The same factors were regressed separately for dung of different ungulate species.

The process was carried out separately for winter and summer using all plots ($n = 135$).

Paired t-tests between winter and summer were also performed as such for each habitat parameter to test for significant seasonal differences in these parameters.

In late February, due to forest fires, some areas of the *Anogeissus-Boswellia* mixed forests and Miscellaneous forests were burnt. The abundance of dung accumulated thereafter in these plots were compared with those in the plots that were not burnt, using Mann-Whitney U - Wilcoxon Rank Sum W test. There were totally 67 unburnt plots and 35 recently burnt (one month earlier ie. February end) plots. This was to test the hypothesis that no significant differences would be present between chital and sambar dung abundance between unburnt and recently burnt areas.

CHAPTER 4 RESULTS

From the line transect data and dung counts, it was found that data for estimating abundance of gaur and nilgai was not adequate. Nilgai were only sighted five times on transects in summer; four times in *Anogeissus-Boswellia* mixed forest type and once in Miscellaneous forest type. Gaur was sighted on transects only once at the end of the study period in the Teak dominant forest type.

Nilgai pellets occurred only once in the *Anogeissus-Boswellia* mixed forest type and gaur dung also was found only once in the Teak dominant forest type. Abundance data of these two large ungulates were thus excluded from any analyses. Only data on chital and sambar were subjected to further analyses.

4.1. DIRECT SIGHTINGS

The density estimates obtained for line transect data is given in tables 1, 2, 3, and 4. In the case of chital, the Negative Exponential model showed the best fit (minimum AIC value), for the transect data of the *Anogeissus-Boswellia* forest type and Miscellaneous forest type in winter. The chital density data of these two forest types also gave the least coefficient of variance with the Half-Normal model. The Uniform model consistently fitted the rest of the data for chital, and all the data of sambar. For the purpose of uniformity, only those estimates calculated from the uniform model were thus taken for further analysis.

The results from the single factor ANOVA (one-way analysis of variance - Model I), to assess differences in densities between seasons, and also between forest types in each season, are summarised in tables 5 and 6, for chital and sambar respectively.

TABLE 1. CHITAL DENSITY ESTIMATES BASED ON DATA COLLECTED ON LINE TRANSECTS FOR WINTER (DECEMBER 1996 - FEBRUARY 1997) USING HALF-NORMAL, UNIFORM, AND NEGATIVE EXPONENTIAL MODELS, IN PENCH TIGER RESERVE.

HABITAT TYPE	MODEL USED	DENSITY No./km ²	% CV	df	95% C. I.	AIC VALUE	BEST FIT
TEAK	HALF-NORMAL	9.9158	32.29	27	5.1963	-102.22	
	UNIFORM	9.9158	18.23	14	6.7281	-104.218	✓
	NEGATIVE EXPONENTIAL	10.216	43.71	23	6.3012	-102.221	
ANO-BOS	HALF-NORMAL	17.594	26.14	28	10.274	-159.99	
	UNIFORM	18.719	26.72	29	10.94	-159.96	
	NEGATIVE EXPONENTIAL	21.404	33.86	38	10.987	-160.30	✓
MISC	HALF-NORMAL	48.372	24.38	51	29.862	-192.155	
	UNIFORM	51.638	24.73	52	31.673	-192.31	
	NEGATIVE EXPONENTIAL	63.431	32.65	48	33.455	-192.40	✓

TEAK - TEAK DOMINANT FOREST
 ANO-BOS - ANOGEISSUS-BOSWELLIA MIXED FOREST
 MISC - MISCELLANEOUS FOREST

TABLE 2. CHITAL DENSITY ESTIMATES BASED ON DATA COLLECTED ON LINE TRANSECTS FOR SUMMER (MARCH 1997 - APRIL 1997) USING HALF-NORMAL, UNIFORM, AND NEGATIVE EXPONENTIAL MODELS, IN PENCH TIGER RESERVE.

HABITAT TYPE	MODEL USED	DENSITY No./km ²	% CV	df	95% C. I.	AIC VALUE	BEST FIT
TEAK	HALF-NORMAL	70.22	20.08	23	46.540	-301.9	
	UNIFORM	63.229	16.88	12	43.931	-302.57	✓
	NEGATIVE EXPONENTIAL	67.334	29.95	54	37.423	-300.63	
ANO-BOS	HALF-NORMAL	17.873	41.13	18	7.7895	-128.214	
	UNIFORM	20.743	29.33	6	10.271	-130.214	✓
	NEGATIVE EXPONENTIAL	13.517	54.83	27	4.7201	-128.22	
MISC	HALF-NORMAL	116.42	18.45	26	79.9172	-365.08	
	UNIFORM	107.72	16.34	16	76.362	-365.27	✓
	NEGATIVE EXPONENTIAL	121.66	28.02	64	70.264	-363.53	

TEAK - TEAK DOMINANT FOREST
 ANO-BOS - ANOGEISSUS-BOSWELLIA MIXED FOREST
 MISC - MISCELLANEOUS FOREST

TABLE 3. SAMBAR DENSITY ESTIMATES BASED ON DATA COLLECTED ON LINE TRANSECTS FOR WINTER (DECEMBER 1996 - FEBRUARY 1997) USING HALF-NORMAL, UNIFORM, AND NEGATIVE EXPONENTIAL MODELS, IN PENCH TIGER RESERVE.

HABITAT TYPE	MODEL USED	DENSITY No./km ²	% CV	df	95% C. I.	AIC VALUE	BEST FIT
TEAK	HALF-NORMAL	11.584	27.47	14	6.4960	-100.14	
	UNIFORM	11.15	24.40	10	6.5051	-100.72	✓
	NEGATIVE EXPONENTIAL	15.712	38.71	22	7.2390	-100.54	
ANO-BOS	HALF-NORMAL	5.0323	29.03	19	2.7749	-94.508	
	UNIFORM	5.8667	10.94	15	4.6498	-96.506	✓
	NEGATIVE EXPONENTIAL	4.7004	45.37	17	1.8867	-94.512	
MISC	HALF-NORMAL	-	-	-	-	-	-
	UNIFORM	5.3409	30.27	5	2.4948	-68.367	✓
	NEGATIVE EXPONENTIAL	8.6838	65.39	14	2.4151	-66.36	

TEAK : TEAK DOMINANT FOREST
 ANO-BOS : ANOGEISSUS-BOSWELLIA MIXED FOREST
 MISC : MISCELLANEOUS FOREST
 - : NO CONVERGENCE WAS ARRIVED AT BY PROGRAMME DISTANCE FOR THIS DATA

TABLE 4. SAMBAR DENSITY ESTIMATES BASED ON DATA COLLECTED ON LINE TRANSECTS FOR SUMMER (MARCH 1997 - APRIL 1997) USING HALF-NORMAL, UNIFORM, AND NEGATIVE EXPONENTIAL MODELS, IN PENCH TIGER RESERVE.

HABITAT TYPE	MODEL USED	DENSITY No./km ²	% CV	df	95% C. I.	AIC VALUE	BEST FIT
TEAK	HALF-NORMAL	16.907	33.24	29	8.7206	-118.323	
	UNIFORM	13.789	17.58	20	9.5816	-120.323	✓
	NEGATIVE EXPONENTIAL	19.050	48.84	23	7.3163	-188.654	
ANO-BOS	HALF-NORMAL	17.826	36.54	31	8.6580	-145.746	
	UNIFORM	17.826	30.00	16	9.5664	-149.746	✓
	NEGATIVE EXPONENTIAL	25.094	40.30	30	11.365	-147.75	
MISC	HALF-NORMAL	16.894	34.07	10	8.0744	-129.907	
	UNIFORM	17.709	32.32	9	8.6811	-130.26	✓
	NEGATIVE EXPONENTIAL	20.935	42.76	19	8.8796	-129.86	

TEAK - TEAK DOMINANT FOREST
 ANO-BOS - ANOGEISSUS-BOSWELLIA MIXED FOREST
 MISC - MISCELLANEOUS FOREST

4.1.1. Chital

Chital showed significant differences in densities between different forest types both in winter ($F_{0.05(1),2,95}^2=3.23$, $p<0.05$) and in summer ($F_{0.05(1),2,34}^2=4.44$, $p<0.025$) (table 5). Using the Tukey's multiple comparison test (Zar 1984), it was found that in winter the chital densities in Teak-dominant forest type was significantly lower ($q_{0.05,95,3}=4.42$ at $p=0.05$ level) than that of the Miscellaneous forest. In summer, in the *Anogeissus-Boswellia* mixed forest type that the chital density was significantly lower ($q_{0.05,34,3}=4.96$ at $p=0.05$ level) than that in the Miscellaneous forest type. There was a significant increase in chital densities from winter to summer, both in the Teak-dominant forest type ($F_{0.05(1),1,26}^2=10.64$, $p<0.025$) as well as in the Miscellaneous forest type ($F_{0.05(1),1,71}^2=5.57$, $p<0.025$).

4.1.2. Sambar

Sambar densities showed no significant differences between forest types both in winter ($F_{0.05(1),2,30}^2=2.17$, $p>0.1$) and in summer ($F_{0.05(1),2,45}^2=0.21$, $p>0.25$) (table 6). In the *Anogeissus-Boswellia* mixed forest type, sambar densities increased significantly ($F_{0.05(1),1,31}^2=4.63$, $p<0.05$) from winter to summer.

4.2. INDIRECT EVIDENCES

The results from the Kruskal-Wallis one-way analysis of variance to assess differences in dung densities between seasons, and also between forest types in each season, are summarised in table. 7 and 8, for chital and sambar respectively. Fresh chital and sambar dung placed in different sites in the forests in December, showed change in colour but did not show disintegration up to the end of the study in April.

TABLE 5. RESULTS OF ONE-WAY ANALYSIS OF VARIANCE OF CHITAL DENSITIES (DIRECT SIGHTINGS) BETWEEN SEASONS AND BETWEEN FOREST TYPES IN PENCH TIGER RESERVE

SEASONS → ↓ V		WINTER			SUMMER		
		TEAK	AN-BO	MISC	TEAK	AN-BO	MISC
W I N T E R	TEAK						
	AN-BO	X					
	MISC	✓	X				
S U M M E R	TEAK	✓✓					
	AN-BO		X		X		
	MISC			✓✓	X	✓	

X - Denotes pairs of groups not significantly different at $p < 0.05$ level
 ✓ - Denotes pairs of groups significantly different at $p < 0.05$ level
 ✓✓ - Denotes pairs of groups significantly different at $p < 0.01$ level

TABLE 6. RESULTS OF ONE-WAY ANALYSIS OF VARIANCE OF SAMBAR DENSITIES (DIRECT SIGHTINGS) BETWEEN SEASONS AND BETWEEN FOREST TYPES IN PENCH TIGER RESERVE

SEASONS → ↓ V		WINTER			SUMMER		
		TEAK	AN-BO	MISC	TEAK	AN-BO	MISC
W I N T E R	TEAK						
	AN-BO	X					
	MISC	X	X				
S U M M E R	TEAK	X					
	AN-BO		✓		X		
	MISC			X	X	X	

X - Denotes pairs of groups not significantly different at $p < 0.05$ level
 ✓ - Denotes pairs of groups significantly different at $p < 0.05$ level

TEAK = TEAK DOMINANT FOREST TYPE
 AN-BO = ANOGEISSUS-BOSWELLIA MIXED FORE

4.2.1. Chital

Chital dung abundances showed no significant differences between forest types both in winter ($\chi^2=0.374$, $n=135$, $p>0.8$) and summer ($\chi^2=0.813$, $n=135$, $p>0.6$) (table 7). But each forest type individually showed significant increase in dung abundances from winter to summer (Teak-dominant forest type $Z=-3.03$, $p=0.0025$, *Anogeissus-Boswellia* mixed forest type $Z=-2.02$, $p=0.0435$, and Miscellaneous forest type $Z=-2.05$, $p=0.04$).

4.2.2. Sambar

Sambar dung abundances showed significant differences between forest types both in winter ($\chi^2=14.24$, $n=135$, $p=0.0008$) and summer ($\chi^2=16.14$, $n=135$, $p=0.0003$) (table 8). It was determined, using the Mann-Whitney U - Wilcoxon rank sum W test, that this was due to the dung abundance in the *Anogeissus-Boswellia* forest type being significantly higher in both seasons than those of the Teak-dominant forest type (winter $Z=-2.59$, $n=45$, $p=0.0095$, summer $Z=-3.7$, $n=45$, $p=0.0002$) and the Miscellaneous forest type (winter $Z=-3.57$, $n=45$, $p=0.0003$, summer $Z=-3.09$, $n=45$, $p=0.002$). The only forest type that individually showed significant increase in dung abundances from winter to summer was the Miscellaneous forest type ($Z=-2.05$, $p=0.04$).

4.3. HABITAT FACTORS

A list of habitat variables taken for factor analysis is given in table 9.

The factor analysis yielded 6 distinct factors for both winter and summer respectively. The details of factors extracted are given in tables 10 and 11, for winter and summer respectively. A total variance of 73 percent for winter and 68.1 percent for summer were accounted for by these factors. **Bartlett's test of sphericity** significantly proved that the correlation matrices were not identity matrices. **Kaiser-Meyer-Olkin measure of sampling adequacy** values for both seasons were greater than 0.6 indicating sampling adequacy.

TABLE 7. RESULTS OF KRUSKAL-WALLIS ANALYSIS OF VARIANCE OF CHITAL DUNG ABUNDANCE BETWEEN SEASONS AND BETWEEN FOREST TYPES IN PENCH TIGER RESERVE

SEASONS —> I V		WINTER			SUMMER		
		TEAK	AN-BO	MISC	TEAK	AN-BO	MISC
W I N T E R	TEAK						
	AN-BO	X					
	MISC	X	X				
S U M M E R	TEAK	✓✓					
	AN-BO		✓		X		
	MISC			✓	X	X	

X - Denotes pairs of groups not significantly different at $p < 0.05$ level
 ✓ - Denotes pairs of groups significantly different at $p < 0.05$ level
 ✓✓ - Denotes pairs of groups significantly different at $p < 0.01$ level

TABLE 8. RESULTS OF KRUSKAL-WALLIS ANALYSIS OF VARIANCE OF SAMBAR DUNG ABUNDANCE BETWEEN SEASONS AND BETWEEN FOREST TYPES IN PENCH TIGER RESERVE

SEASONS —> I V		WINTER			SUMMER		
		TEAK	AN-BO	MISC	TEAK	AN-BO	MISC
W I N T E R	TEAK						
	BOSW	✓✓					
	MISC	X	✓✓				
S U M M E R	TEAK	X					
	BOSW		X		✓✓		
	MISC			✓	X	✓✓	

X - Denotes pairs of groups not significantly different at $p < 0.05$ level
 ✓ - Denotes pairs of groups significantly different at $p < 0.05$ level

TEAK = TEAK DOMINANT FOREST TYPE
 AN-BO = ANOGEISSUS-BOSWELLIA MIXED FOREST TYPE
 MISC = MISCELLANEOUS FOREST TYPE

TABLE 9. LIST OF HABITAT VARIABLES TAKEN FOR FACTOR ANALYSIS
BASED ON DATA COLLECTED IN PENCH TIGER RESERVE.

SEASON	VARIABLES	MEAN	STD DEV
W I N T E R	GRASS HEIGHT (cm)	68.44444	26.40210
	GRASS %	54.55556	21.58381
	LITTER %	11.32593	8.12296
	TOTAL BROWSE VOLUME (m ³)	4.46443	7.15188
	NUMBER OF SHRUB SPECIES	4.14815	1.65952
	TOTAL NUMBER OF SHRUBS	11.25926	5.02525
	NUMBER OF TREE SPECIES	8.17778	3.04657
	TOTAL NUMBER OF TREES	17.76296	6.22730
	NUMBER OF TREES WITH FOLIAGE BELOW 2.5 M HEIGHT OF LOWEST	7.08889	3.63537
	FOLIAGE BRANCH (m)	160.21103	33.19567
S U M M E R	CANOPY COVER %	76.36417	13.93778
	HORIZONTAL COVER %	44.33348	22.89642
	VERTICAL COVER %	44.51839	16.45918
	SLOPE (°)	6.90178	4.72906
	DISTANCE TO WATER SOURCE (km)	1.32252	.70979
	GRASS HEIGHT (cm)	48.43457*	29.36690
	GRASS %	36.29630*	23.50391
	LITTER %	25.30370*	16.15100
TOTAL BROWSE VOLUME (m ³)	2.60324*	7.30099	
S U M M E R	NUMBER OF SHRUB SPECIES	4.14815	1.65952
	TOTAL NUMBER OF SHRUBS	11.25926	5.02525
	NUMBER OF TREE SPECIES	8.14815	3.05794
	TOTAL NUMBER OF TREES	17.70370	6.30100
	NUMBER OF TREES WITH FOLIAGE BELOW 2.5 M HEIGHT OF LOWEST	7.08889	3.63537
	FOLIAGE BRANCH (m)	160.21103	33.19567
	CANOPY COVER %	18.68572*	9.38975
	HORIZONTAL COVER %	37.76543*	20.15298
	VERTICAL COVER %	35.03704*	15.19833
	SLOPE (°)	6.84252	4.71057
DISTANCE TO WATER SOURCE (km)	1.34630	2.73364	

* - Significantly different from winter.

TABLE 10. LIST OF FACTORS EXTRACTED BY FACTOR ANALYSIS AND THE VARIANCE CONTRIBUTED BY THEM FOR WINTER IN PENCH TIGER RESERVE

FACTORS	VARIABLES	EIGEN VALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
FACTOR 1	HORIZONTAL COVER % VERTICAL COVER % AVERAGE GRASS HEIGHT	3.07527	20.5	20.5
FACTOR 2	NUMBER OF TREES NUMBER OF TREE SPECIES NUMBER OF TREES WITH FOLIAGE BELOW 2.5 M	2.44093	16.3	36.8
FACTOR 3	NUMBER OF SHRUB SPECIES SLOPE	1.95869	13.1	49.8
FACTOR 4	GRASS % LITTER %	1.25167	8.3	58.2
FACTOR 5	HEIGHT OF THE LOWEST FOLIAGE BRANCH CANOPY COVER % DISTANCE TO WATER SOURCE	1.15269	7.7	65.9
FACTOR 6	TOTAL FORAGE VOLUME NUMBER OF SHRUBS	1.06988	7.1	73.0

TABLE 11. LIST OF FACTORS EXTRACTED BY FACTOR ANALYSIS AND THE VARIANCE CONTRIBUTED BY THEM FOR SUMMER IN PENCH TIGER RESERVE.

FACTORS	VARIABLES	EIGEN VALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
FACTOR 1	HORIZONTAL COVER % VERTICAL COVER % CANOPY COVER %	3.12179	20.8	20.8
FACTOR 2	NUMBER OF TREES NUMBER OF TREE SPECIES NUMBER OF TREES WITH FOLIAGE BELOW 2.5 M	2.09737	14.0	34.8
FACTOR 3	NUMBER OF SHRUB SPECIES NUMBER OF SHRUBS SLOPE	1.75455	11.7	46.5
FACTOR 4	GRASS % AVERAGE GRASS HEIGHT	1.16744	7.8	54.3
FACTOR 5	HEIGHT OF THE LOWEST FOLIAGE BRANCH LITTER %	1.05881	7.1	61.3
FACTOR 6	DISTANCE TO WATER SOURCE TOTAL BROWSE VOLUME	1.01573	6.8	68.1

A few variables had to be dropped because of either too many zero values or sampling inadequacy for particular variables.

For both winter and summer, the habitat cover axis (factor 1), accounted for the maximum variability (winter 20.5 %, summer 20.8 %), followed by the tree axis (factor 2) (winter 16.3 %, summer 14 %) and the slope-shrub axis (winter 13.1 %, summer 11.7 %).

The regression of factor scores for each independent factor, for each individual case of the data, taken as independent variables, against the dung abundances of each species, for each season, gave the partial correlation coefficients for each factor with the dung (table 12 and 13).

The regression against dung showed that in winter, variability in chital dung was accounted for by the cover factor (negatively correlated), ground cover factor and the tree factor (both positively correlated), while in summer it was the slope factor (negatively correlated) and the tree factor (positively correlated) that accounted for significant variability in dung abundance.

In the case of sambar, it was the ground cover factor (positively correlated), and tree factor (negatively correlated) that accounted for significant variability in dung abundances in winter. In summer, the factors were ground cover factor (negatively correlated), slope/shrub factor (positively correlated), tree factor (negatively correlated), and distance to water source factor (negatively correlated)

On the whole, the relationships obtained from the regression were not very strong (multiple $R < 0.5$ in all cases). Moreover, only a maximum variability of about 16 percent ($R^2=0.1659$) for sambar dung abundance, and about 13 percent ($R^2=0.1321$) for chital dung abundance, could be explained by the different factors.

Paired t-tests performed on each variable showed significant differences between winter and summer for variables such as browse volume ($t=-0.82$, $df=134$, $p<0.01$), grass height

TABLE 12. FACTORS CONTRIBUTING SIGNIFICANTLY ($P < 0.1$) TO VARIANCE IN CHITAL DUNG ABUNDANCE FOR WINTER AND SUMMER FROM MULTIPLE REGRESSION ANALYSIS BASED ON DATA COLLECTED IN PENCH TIGER RESERVE.

SEASON	FACTORS	VARIABLES	CORRELATION COEFFICIENTS	MULTIPLE R	R ²
W I N T E R	FACTOR 1	HORIZONTAL COVER % VERTICAL COVER % AVERAGE GRASS HEIGHT	- 0.3008	0.3635	0.1321
	FACTOR 2	NUMBER OF TREES NUMBER OF TREE SPECIES NUMBER OF TREES WITH FOLIAGE BELOW 2.5 M	+ 0.1437		
	FACTOR 4	GRASS % LITTER %	+ 0.1449		
	FACTOR 2	NUMBER OF TREES NUMBER OF TREE SPECIES NUMBER OF TREES WITH FOLIAGE BELOW 2.5 M	0.1388	0.3439	0.1183
S U M M E R	FACTOR 3	NUMBER OF SHRUB SPECIES NUMBER OF SHRUBS SLOPE	-0.3147		

TABLE 13. FACTORS CONTRIBUTING SIGNIFICANTLY ($P < 0.1$) TO VARIANCE IN SAMBAR DUNG ABUNDANCE FOR WINTER AND SUMMER FROM MULTIPLE REGRESSION ANALYSIS BASED ON DATA COLLECTED IN PENCH TIGER RESERVE.

SEASON	FACTORS	VARIABLES	CORRELATION COEFFICIENTS	MULTIPLE R	R ²
W I N T E R	FACTOR 2	NUMBER OF TREES NUMBER OF TREE SPECIES NUMBER OF TREES WITH FOLIAGE BELOW 2.5 M	- 0.1964	0.355	0.1261
	FACTOR 4	GRASS % LITTER %	+ 0.2958		
S U M M E R	FACTOR 2	NUMBER OF TREES NUMBER OF TREE SPECIES NUMBER OF TREES WITH FOLIAGE BELOW 2.5 M	- 0.1533	0.4073	0.1659
	FACTOR 3	NUMBER OF SHRUB SPECIES NUMBER OF SHRUBS SLOPE	+ 0.233		
	FACTOR 4	GRASS % AVERAGE GRASS HEIGHT	- 0.2548		
	FACTOR 6	DISTANCE TO WATER TOTAL BROWSE VOLUME	- 0.1521		

($t=9.66$, $df=134$, $p<0.001$), grass percentage ($t=-10.77$, $df=134$, $p<0.001$), litter percentage ($t=10.01$, $df=134$, $p<0.001$), canopy cover percentage ($t=47.66$, $df=134$, $p<0.001$), horizontal cover percentage ($t=11.79$, $df=134$, $p<0.001$) and vertical cover percentage ($t=12.9$, $df=134$, $p<0.001$).

In summer, sambar showed significantly higher dung abundance ($U=693$, $p=0.0003$), in plots that were recently burnt (one month earlier ie. February end) ($n=35$) than in unburnt plots ($n=67$).

CHAPTER 5 DISCUSSION

5.1. UNGULATE ABUNDANCES

5.1.1. DIRECT SIGHTINGS

As mentioned earlier, the Uniform model fitted the data best in most cases, except in the case of chital in *Anogeissus-Boswellia* mixed forest and Miscellaneous forest in winter, where The Negative Exponential model gave the best fit and the Half-Normal model gave least coefficient of variation. In all other cases, the Uniform model was the one that gave the least coefficient of variance. For sambar, the Uniform model consistently gave the best fit. Varman and Sukumar (1995) had reported that line transect data of chital consistently fitted the Half-Normal model based on χ^2 values and Fourier Series model had given the lowest coefficients of variance. The low sample sizes of gaur and nilgai, in terms of both direct sightings on transects and dung counts, yielded little information on their habitat use pattern.

The nilgai populations in the study area are mostly localized in the open areas, in and around Alikatta meadow, which is a site of a recently relocated village. The small size of this vegetation type prevented it from being sampled. Also, most casual sightings of nilgai were in the vicinity of roads. Rarely were nilgai sighted deep in forest areas, except where large scale ground fires had occurred in summer.

Casual sightings of gaur increased in summer only towards the end of April, that too, only in the proximity of the Pench river.

CHITAL

Chital densities estimated using the line transect method showed that density in Teak-dominant forest type was significantly lower than those in the other forest types. In summer, it was in the *Anogeissus-Boswellia* mixed forest type that the chital density was significantly

lower in comparison to other forest types. Moreover, both Teak and Miscellaneous forest types were used to a greater extent in summer than in winter.

The Miscellaneous forest type, more of a moist-deciduous vegetation and gaps in the canopy had lots of grass. This resulted in a relatively higher heterogeneity both in the tree composition and understorey. It is clearly the favoured forest type for chital, demonstrated by their high densities in both seasons in this forest type. But when it comes to the Teak forest type having higher densities during summer, it is not known whether the forest type is actually being favoured, or if it is only an artifact of sampling arising due to the fact that most of the Teak-dominant stands are located in the proximity of the Pench river. It is also not known whether the hilly *Anogeissus-Boswellia* mixed forest type, which showed consistently lower densities, is actually avoided by chital. As the proportional availability of this forest type is not known, no strong conclusions can be arrived at about avoidance. It can only be said that this forest type is used relatively less by chital. Grass percentage and grass height was high in the beginning of winter, and remained till forest fires cleared the ground layer of grass, in this forest type.

SAMBAR

Sambar densities showed no significant differences between the forest types both in winter and in summer, indicating a more or less even distribution.

Anogeissus-Boswellia mixed forest type showed a significant increase in sambar density from winter to summer. Chakrabarty (1991) had however reported that, in Sariska, sambar showed preference for the *Anogeissus* mixed type only in winter.

The widespread distribution of handpumps in Pench, operational in different parts of the study area during summer, could affect sambar distribution to some extent. If this bias were absent (i.e. no artificial water sources), one would have been able to test the hypothesis

whether sambar also follow the trend shown by chital of frequenting habitats closer to water sources.

5.1.2. DUNG ABUNDANCE

In the case of chital dung densities, there were no significant differences between forest types, both in winter and in summer. However, sambar dung abundance in the *Boswellia* forest type was significantly higher than those of the other forest types in both seasons, indicating the relatively higher preference for this forest type. Unlike the trend seen from direct sightings, sambar dung abundance increased only in the Miscellaneous forest type.

Ungulate densities and dung abundance do not show exactly the same trends. It is debatable whether this could be due to the fact that time for accumulation of dung was short (2 months). Both in winter and summer, there were many plots with no dung. Keeping this fact in mind, it was nevertheless conclusively shown that significant seasonal differences in chital dung abundances did exist in each of the forest type between the two seasons.

5.2. HABITAT FACTORS

The factor analysis of the habitat variables isolated distinct factors for winter and summer, though the four major factors were the same i.e. representing cover, trees, slope and grass percentage. This shows that there is some seasonal variability in the associations of different habitat variables. A maximum of 73 percent of the variability in the habitat could be accounted for by the factors.

The regression of the factors against dung showed that in winter, chital avoided dense understorey, and favoured grassy patches. The tree factor was favoured both in winter and summer. Slope was a factor that was significantly avoided in summer.

Grass height, which was significantly higher in winter, was associated with cover only in winter, and could have been a deterrent for chital (negative correlation). Similarly, slope had shrub species richness associated with it for both seasons. This could be explained by the fact that in areas of great undulation, characterised by widely fluctuating slope values (slope-valley-slope), the understorey shows very high heterogeneity due to habitat interspersion. With this undulation being most prominent in the *Anogeissus-Boswellia* mixed forest type, and chital being a slope avoiding species (Schaller 1967, Chakrabarty 1991, Khan 1996), it is not surprising that chital showed low densities in this forest type.

In the case of sambar, the regression of factors against sambar dung indicates that in winter, they could prefer fresh grass (green yellow in colour), litter, and less of tree vegetation. There could be a tendency to forage in canopy openings having fresh grass patches. The fact that sambar favour leaf litter has also been reported by Chakrabarty (1991). However in summer, the grass, which had dried up (yellow-brown) by then, were avoided, and slopes with ample shrubs were favoured, while wooded regions with trees were used less. Khan (1996) had also reported similar finding of the preference of slopes and dense understorey by sambar, but reported a preference for high tree cover corroborating the findings of Schaller (1967), Dinerstein (1979) Johnsingh (1983) and Chakrabarty (1991). On the contrary Ngampongsai (1987) mentions the sambar as favouring more of open deciduous forests and does not favour much tree growth. Bhatnagar (1991) reported sambar preferring sparse shrub cover in the hills than in the plains, indicating higher cover requirement in the plains as an anti-predator strategy. Moreover, in the present study, it was found that sambar dung abundances were higher in the burnt areas, where the grass cover had been totally removed by fire. Most of the burnt plots (31 out of 35) were located in the hilly *Anogeissus-Boswellia* forest type. The fact that distance to water is negatively correlated with sambar dung proves the fact that sambar is strongly

attracted by water (Schaller 1967, Johnsingh 1983, Chakrabarty 1991, Khan 1993, Sankar 1994).

It has to be noted that Bartlett's test of sphericity significantly proved that almost all variables were related to each other to different extent. Thus regressing these variables directly against the dependent variable *viz.* dung abundances would violate a major condition of multiple regression that all the variables regressed be independent of each other.

As pointed out earlier, only a maximum variability of about 16 percent ($R^2=0.1659$) for sambar dung abundance, and about 13 percent ($R^2=0.1321$) for chital dung abundance, could be explained by the different factors by this method of regressing dung against factors. It is not known how this result compares with other similar studies. This is so because, in earlier studies on similar ungulate-habitat interactions in the Indian sub-continent (Khan 1993, Sankar 1994) and elsewhere (Hirst 1975, Ben-Shahar and Skinner 1988), though the multiple regression analysis was used, the fact that habitat variables are interrelated to a great extent has been grossly overlooked, thus violating one of the basic assumptions of multiple regression. Chance correlation of variables could give misleading results about the final regression relations with the dependent variables. There is thus a great need for a review of methods currently being used to find relationships in complex animal-habitat interactions.

The attempt, by this study, to get a clear idea about the distribution of these ungulates in the wild conditions necessitated the selection of the relatively undisturbed part of the Tiger Reserve. But this severely prevented the disturbance factor from coming into the picture.

The relevance of this study could probably be weighed down by the fact that the ungulates which contributed significant data to this study, chital and sambar, are more or less versatile species, favouring and tolerating a wide range of habitat conditions in diverse habitats. Moreover, these animals have successfully established themselves in different parts of the

world where they have been introduced. Still, the study of chital and sambar is vital to look for recognizable trends not only in their natural history but also in their habitat. This would effectively help in the conservation and management of these ungulates, especially chital and sambar, which together form the bulk of the prey base for large predators of the Indian sub-continent.

REFERENCES

- Ables, E. D. and C. W. Ramsey. 1974. Indian mammals in Texas rangelands. *Journal of the Bombay Natural History Society* 71:18-25.
- Anderson, D. R., J. L. Laake, B. R. Crain, and K. P. Burnham. 1979. Guidelines for transect sampling of biological populations. *Journal of Wildlife Management* 43(1):71-79.
- Austin, M. P. 1971. Role of regression analysis in plant ecology. *Proc. Ecol. Soc. Aus.* 6:63-75.
- Balakrishnan, M., and P. S. Easa. 1986. Habitat preferences of the larger mammals in the Parambikulam Wildlife Sanctuary, Kerala, India. *Biological Conservation* 37:191-200.
- Berwick, S. H. 1974. The community of wild ruminants in the Gir forest ecosystem, India. Ph.D Thesis. Yale University, New Haven.
- Ben-Shahar, R. and J. D. Skinner. 1988. Habitat preferences of African ungulates derived by uni- and multivariate analyses. *Ecology* 69(5):1479-1485.
- Bhat, S. D., and G. S. Rawat 1995. Habitat use by chital (*Axis axis*) In Dhaukhhand, Rajaji National Park, India. *Tropical Ecology*. 36(2):177-89.
- Bhatnagar, Y. 1991 Habitat preference of Sambar (*Cervus unicolor*) in Rajaji National Park. M.Sc. Dissertation, Saurashtra University, Rajkot. 51p.

- Bohra, H. C., S. P. Goyal, P. K. Ghosh, and I. Prakash. 1992. Studies on ethology and eco-physiology of the antelopes of Indian Desert. *Annals of Arid Zone* 31(2):83-96.
- Buckland, S. T., Anderson, D. R., Burnham, K. P., and J. L. Laake 1993. Distance sampling: Estimating abundances of biological populations. Chapman and Hall. London.
- Burnham, K. P., Anderson, D. R., and J. L. Laake 1980. Estimation of density from line transect sampling of biological populations. *Wildlife Monograph*. 72:1-202.
- Cairns, A. L., and E. S. Telfer. 1980. Habitat use by four sympatric ungulates in boreal mixedwood forest. *Journal of Wildlife Management* 44(4):849-857.
- Chakraborty, B. 1991. Habitat use by radio-instrumented chital, sambar and nilgai in Sariska Tiger Reserve. M.Sc. Dissertation, Saurashtra University, Rajkot.
- Champion, H. G. and S. K. Seth 1968. A revised survey of the forest types of India. Manager of Publications, Government of India Press, New Delhi.
- Chandiramani, S. C. 1984. Biology of gaur (*Bos gaurus*) in Kanha National Park. Ph.D. Thesis, Bhopal University, India.
- Daniel, J. C. 1991. Ungulate conservation in India - problems and prospects. *Applied Animal Behaviour Science* 29:349-359.

- Daniel, J. C. 1994. Tropical wildlife with special reference to Indian Subcontinent. In: Balakrishnan, M., Borgstrom, and S. W. Bie. Oxford & IBH Publishing Co. pp 147-165.
- Dinerstein, E. 1979. An ecological survey of the Royal Karnali Bardia Wildlife Reserve, Nepal. Part II. Habitat/animal interaction. *Biological Conservation* 16:265-300.
- Draper, N.R., and H. Smith. 1981. Applied regression analysis. John Wiley and Sons, New York, U.S.A.
- Edge, W. D. and C. L. Marcum. 1989. Determining elk distribution with pellet-group and telemetry techniques. *Journal of Wildlife Management* 53:621-624.
- Eisenberg, J. F., and M. Lockhart. 1972. An ecological reconnaissance of Wilpattu National Park, Ceylon. *Smithsonian Contributions to Zoology* 101:1-118.
- Eisenberg, J. F., and J. Seidensticker. 1976. Ungulates in southern Asia: a consideration of biomass estimates for selected habitats. *Biological Conservation* 10:293-308.
- Giles, R. H. 1978. *Wildlife Management*. W. H. Freeman Co. San Francisco. 633 pp.
- Gilpin, M. E., and M. E. Soulé. 1986. Minimum viable populations: Process of species extinctions. pp 19-34. In: Soulé, M. E. (ed). *Conservation Biology: The Science of Scarcity and Diversity*. Sinauer.

- Graf, W. and L. Nichols. 1966. The Axis deer in Hawaii. *Journal of the Bombay Natural History Society* 63:629-734.
- Green, M. J. B. 1985. Ecological separation in Himalayan ungulates. *Journal of Zoology London* 1:693-719.
- Haque, N. 1990. Study on the ecology of wild ungulates of Keoladeo National Park, Bharatpur, Rajasthan. Ph.D. Thesis. Centre of Wildlife and Ornithology, Aligarh Muslim University, Aligarh. 308 pp.
- Hirst, S. M. 1975. Ungulate-habitat relationships in a South African woodland/savanna ecosystem. *Wildlife Monograph* 44:1-59
- Johnsingh, A. J. T. 1983. Large mammalian prey-predators in Bandipur. *Journal of the Bombay Natural History Society* 80(1):1-57.
- Johnsingh, A.J.T. and K. Sankar. 1991. Food plants of chital, sambar and cattle on Mundanthurai plateau, Tamil Nadu, South India. *Mammalia* 55(1):57-66.
- Johnsingh, A. J. T., S. P. Goyal and G. S. Rawat. 1993. Food habits of tiger and leopard in Rajaji, north west India. Abstract: International Symposium on the Tiger. 22-24 Feb. 1993. Ministry of Environment and Forests, Govt. of India, New Delhi.

- Karanth, K. U, and M. E. Sunquist 1992. Population structure, density and biomass of large herbivores in the tropical forests of Nagarahole, India. *Journal of Tropical Ecology* 8:21-35.
- Khan, J. A., W. A. Rodgers, A. J. T. Johnsingh, and P. K. Mathur. 1990. Gir Lion Project: Ungulate-Habitat ecology in Gir. Final Project Report, Wildlife Institute of India, Dehra Dun. 202 pp.
- Khan, J. A. 1993. Ungulate-habitat relationships in Gir forest ecosystem and its management implications. Ph.D. Thesis. Aligarh Muslim University, India.
- Khan, J. A. 1996. Factors governing habitat occupancy of ungulates in Gir Lion Sanctuary, Gujarat, India. *International Journal of Ecology and Environmental Science* 22:73-83.
- Kumar, S. 1990. Management Plan of Pench Tiger Reserve, Madhya Pradesh 1990-1995.
- Laake, J. L., S. T. Buckland, D. R. Anderson, and K. P. Burnham. 1994. DISTANCE. User's guide V2.1. Colorado Cooperative Fish & Wildlife Research Unit, Colorado State University, Fort Collins, Colorado. 84 pp.
- Lamprey, H. F. 1963. Ecological separation of the large mammal species in the Tarangire Game Reserve, Tanganyika. *East African Wildlife Journal* 1:63-92.
- Lever, C. 1985. Naturalized mammals of the world. Longman, London. 467 pp.

- Lewis, J. C., L.B. Flynn, R. L. Marchinton, S. M. and E. M. Marchinton. 1990. Part I: Introduction, study area description and Literature review. **In:** Ecology of sambar deer on St. Vincent National Wildlife Refuge, Florida. Bull. No. 25. Tall Timbers Research Station, Tallahassee, Florida. Pages 1-12.
- Mishra, H. R. 1982. The ecology and behaviour of chital (*Axis axis*) in Royal Chitwan National Park, Nepal. Ph.D. Thesis. University of Edinburgh, Edinburgh, U.K.
- Mukherjee, S., S. P. Goyal, and Ravi Chellam. 1994. Standardization of scat analysis techniques for leopard (*Panthera pardus*) in Gir National Park, Western India. *Mammalia* 58(1):139-143.
- Ngampongsai, C. 1987. Habitat use by the sambar (*Cervus unicolor*) in Thailand: A case study for Khao-Yai National Park. pp 289-298. **In:** Wemmer, C. M. (ed). *Biology and Management of Cervidae*. Smithsonian Institute Press, Washington D.C.
- Norman, H. S., R. J. Hudson, V. C. Brink, and W. D. Kitts. 1975. Determinants of spatial distribution of Rocky Mountain bighorn sheep. *Journal of Wildlife Management* 39(2):387-401.
- Norusis, M. J. 1990. *SPSS/PC+ Advanced Statistics 4.0 for the IBM PC/XT/AT and PS/2*. SPSS Inc. Chicago, Illinois.
- Prater, S. H. 1971. *The Book of Indian Animals*. Third Edition. Bombay Natural History Society. 324 p.

- Raman, T. R. S. 1997. Factors influencing seasonal and monthly changes in the group size of chital or axis deer in southern India. *Journal of Biosciences* 22(2):203-218.
- Richardson II, W. A. 1972. A natural history survey of sambar deer (*Cervus unicolor*) on the Powderhorn Ranch, Calhoun Country, Texas. M. Sc. thesis, A & M Univ., Texas.
- Rodgers, W. A. 1988. The wild grazing ungulates of India: an ecological review. In: Singh, P and P. S. Pathak (eds). *Rangelands - resource and management*. Proceedings of the National Rangeland Symposium, IGFR, Jhansi, November 9-12, 1987. pp 404-420.
- Rodgers, W. A. and H. S. Panwar 1988. *Planning a Wildlife Protected Area Network in India*. Vol I and II. Wildlife Institute of India, Dehra Dun.
- Rosenzweig, M. L. 1981. A theory of habitat selection. *Ecology* 62(2):327-335.
- Sankar, K. 1994. The ecology of three large sympatric herbivores (Chital, Sambar and Nilgai) with special reference for reserve management in Sariska Tiger Reserve, Rajasthan. Ph.D. Thesis. University of Rajasthan, Jaipur.
- Schaller, G. B. 1967. *The Deer and the Tiger*. University of Chicago Press, Chicago.
- Schoen, J. W., and M. D. Kirchhoff. 1990. Seasonal habitat use by Sitka blacktailed deer on Admiralty Island, Alaska. *Journal of Wildlife Management* 54:371-378.
- Scogings, P. F., G. K. Theron, and J. du P. Bothma. 1990. Two quantitative methods of analysing ungulate habitat data. *South African Journal of Wildlife Research* 20(1):9-13.

- Seidensticker, J. 1976. Ungulate populations in Chitwan valley, Nepal. *Biological Conservation* **10**:183-210.
- Sharma, D. 1995. Ecology and Management of Lion and Ungulate Habitats in Gir. Ph.D. Thesis. Saurashtra University, Rajkot. 195pp.
- Shea, S. M., B. L. Flynn, R. L. Marchinton and J. C. Lewis. 1990. Social behaviour, movement, ecology, and food habits. **In**: Ecology of sambar deer on St. Vincent National Wildlife Refuge, Florida. Bulletin No. 25, Tall Timbers Research Station, Tallahassee, Florida.
- Sheffield, W. J., B. A. Fall, and B. A. Brown. 1983. The nilgai antelope. The Caesar Kleberg Research Program in Wildlife Ecology and Department of Wildlife and Fisheries Sciences. The Texas Agricultural Experiment Station. A & M Univ., Texas.
- Slee, K. J. 1984. The sambar deer in Victoria. **In**: Deer. Post-Grad. Comm. Vet. Sci., Proc. 72. University of Sydney, Sydney. pp 559-572.
- Varman, K. S., and R. Sukumar. 1995. The line transect method for estimating densities of large mammals in a tropical deciduous forest: An evaluation of models and field experiments. *Journal of Biosciences* **20**(2):273-287.
- Zar, J. H. 1984. *Biostatistical Analysis*. Second Edition. Prentice-Hall Inc., Englewood Cliffs, New Jersey. 718p.