DENSITY, BIOMASS AND HABITAT OCCUPANCY OF UNGULATES IN BHADRA TIGER RESERVE, KARNATAKA

Final report submitted to Save the Tiger Fund of the National Fish and Wildlife Foundation, Washington, DC and the Exxon Mobil Corporation.

By

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Contents

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Introduction

This project was carried out when I was at the Wildlife Institute of India, pursuing a Masters' Degree in Wildlife Science, with a grant from Save the Tiger Fund of the National Fish and Wildlife Foundation and the Exxon Mobil Corporation. The course consisted of four semesters, of which the fourth semester was a six-month field study, where each student was required to propose a research topic with biological and/ or conservation implications, design the study, carry out the field study as well as the data analysis, and submit a thesis, based on the results of the field study. We defended our thesis at a presentation held at the institute, which was followed by a viva voce with external examiners.

Theory courses completed as part of the course are as follows:

I Semester- Ecosystem Ecology, Evolutionary Ecology, Biogeography, Plant Systematics & Vegetation Science, Mammology, Ornithology, Herpetology and Fish, Invertebrates, Population Ecology, Quantitative Methods-I, and Conservation of Natural Resources.

II Semester- Behavioural Ecology, Habitat Ecology, Quantitative Methods-II, Community Ecology, Wildlife Restraint & Barriers, Conservation Biology, Wildlife Health, Remote Sensing & GIS, Elective Topic in Wildlife Biology (Term Paper on 'Optimal Foraging and Carnivore Community Structure'), Human Ecology, Natural Resource Economics, and Environmental Impact Assessment.

III Semester- Wildlife Physiology & Nutrition, Advanced Statistics, Captive Breeding &Wildlife Utilisation, Elective Topic in Habitat Ecology and Management (Term Paper on 'Reserve Design and Management in the Light of the Island Biogeography and Metapopulation Biology Paradigms'), Coastal & Wetland Ecology, and Forest and Wildlife Management & Management Planning.

In addition, the course had a strong field component with several field tours to various protected areas in India as well as the field study, which will be described in detail elsewhere in this report. The following field tours were conducted, where the principal investigator underwent training in several field techniques in various field conditions, and was given first hand, in-the-field exposure to important conservation issues, conservation practices and management practices.

Orientation Tour (31st July 1999- 8th August 1999)

Site: Koluchaur Reserve Forest, Uttar Pradesh.

-Introduction to wildlife and their habitats, quantitative observations, field skills, collection of study material, identification of wildlife signs & evidences.

Zoo Orientation Tour (9th September 1999- 12th September 1999)

Sites: Morni Hills Red Junglefowl Captive Breeding Centre, Himachal Pradesh; Chatt Bir Zoological Park, Punjab.

-Introduction to captive breeding and zoos, principles and objectives, design of facilities, education and research in zoos.

Techniques Tour- I (3rd October 1999- 13th October 1999)

Site: Sariska Tiger Reserve, Rajasthan.

-On-site training in field techniques:

Animal abundance- Line transects, Point counts, Dung counts, Block counts, Vehicle transects;

Quantification of habitat and vegetation parameters- Total enumeration, Sample plots & Plotless methods for tree abundance and DBH, Line intercept method for ground cover;

Radio-telemetry- Triangulation and homing-in;

Trapping techniques;

Use of GPS and maps;

Analysis of kills- identification of predator, age/ sex of the prey, assessment of body condition.

Techniques Tour- II (Wetlands: 3rd February 2000-8th February 2000)

Site: Keoladeo Ghana National Park, Bharatpur, India.

-Field exercises in waterfowl counts, feral cattle counts, terrestrial & aquatic vegetation sampling, calculation of water budget, identification of waterfowl. Problems of park management and effects of tourism.

Techniques Tour III (Wetlands: 3rd March 2000- 5th March 2000)

Site: National Chambal Sanctuary, Madhya Pradesh.

- Boat surveys for gharial, marsh crocodile, Gangetic dolphin, freshwater turtle and waterfowl abundance; water sampling; visit to smooth-coated otter den sites, identification of otter spraints, tracks & holts.

Conservation Practices Tour (6th March 2000- 7th March 2000)

Sites: Ghatigaon Great Indian Bustard Sanctuary, Karera GIB Sanctuary, Madhav National Park, Madhya Pradesh.

- Visit to semi-arid grasslands and dry decidous forests; Conservation of the great Indian Bustard; Management problems; Effect of habitat changes, grazing and woodland invasion; conservation problems in sub-optimal habitats.

Wildlife Health Tour (8th March 2000- 9th March 2000)

Site: Van Vihar National Park, Bhopal, Madhya Pradesh.

- Exercises in vaccination, blood sample collection, restraint & immobilisation of carnivores and ungulates; haematological tests; wildlife diseases.

Techniques Tour IV (High Altitude: 11th June 2000- 19th June 2000)

Site: Kedarnath Musk Deer Sanctuary, Uttar Pradesh.

- Techniques for estimating abundance of western Himalayan ungulates; Himalayan flora, avifauna; vegetation and soil sampling.

Management Practices Tour (North East India: 8th September 2000- 22nd September 2000)

Sites: Kaziranga National Park & Pigmy Hog Conservation Program (Guwahati), Assam; Shillong & Cherrapunji, Meghalaya.

Problems associated with conservation of Asian one-horned rhinoceros and sympatric large herbivores: tall-wet grassland management; burning & flooding; anti-poaching strategies; tourism in protected areas; captive breeding and re-introduction programs for endangered species; problems of slash and burn (shifting) cultivation; discussions with state Forest Department, and Ministry of Environment & Forest officials.

I had started thinking about a suitable research topic early in the first semester, when Dr. Karanth, my advisor, suggested a tiger prey study at Bhadra Tiger Reserve, which had recently been made a Project Tiger Reserve and presented excellent opportunities to study herbivore populations and human impacts. After several discussions, and much reading up, I was able to formulate my objectives, and submitted a proposal to NFWF/ STF, which was subsequently accepted. I focused my questions and fine-tuned the methodology after a reconnaissance visit to Bhadra in July 2000, when I was able to familiarise myself with the area, as well as speak to several people, especially Mr. D.V. Girish, Honorary Wildlife Warden, Bhadra Tiger Reserve, who introduced me to the reserve and its problems. A question that struck me (like it does several other visitors to the place) was that though the habitat seemed to be excellent as far as resources for herbivores were concerned (abundant bamboo, grass, water, clearings), the animals themselves were extremely scarce. Though many problems were immediately evident (e.g. cattle grazing, poaching, extraction of forest products), I was intrigued and puzzled by the extreme scarcity of animals, especially when compared to other reserves with fairly similar vegetation which supported extremely high densities of large mammals (e.g. Nagarahole).

Fieldwork for the project started in November 2000 with line transect surveys. After that I spent some time carrying out decay rate experiments before I started investigating the local distribution, and environmental correlates of distribution, of my study species. I wound up camp at the end of April, when I returned to Bangalore, and later to Dehradun, for data analysis. The report that follows is based on the results of those analyses.

Introduction to the field study

The study of distribution and abundance of organisms is recognised as an important concern in ecology (Burnham et al. 1993). Studying the distribution and abundance of animals, in relation to various factors that govern them, such as habitat features and anthropogenic disturbances, helps in understanding the relative importance of these factors in driving animal occupancy patterns, and at a larger spatial scale, abundance. This understanding is essential if we are to understand and address the problems leading to wildlife declines and maintaining low population densities.

A major problem in conserving and managing large mammal species is the relative lack of reliable quantitative information regarding the distribution, abundance and habitat requirements of these species, using which the effectiveness of management practices can be assessed, and goals set for the future. An important area, in which such studies have a great deal of relevance, is the conservation of tigers and other carnivores which depend directly on the large ungulates for their energy needs. Large mammalian carnivore populations are mainly resource limited (Hairston, Smith and Slobodkin 1960). The fitness of a predator population depends on the availability of its prey (Sunquist and Sunquist, 1989). Karanth and Sunquist (1995), Karanth and Nichols (1998), and Karanth and Stith (1999) suggest that densities of tigers are governed primarily by the abundance of prey species. In fact, the evolution and radiation of the *Panthera* stock is closely tied to that of the cervids and bovids (Sunquist et al. 1999). Thus, ecological densities of tigers show a high degree of correlation with densities of cervid and bovid prey species.

Large herbivores, particularly, are very difficult to conserve due to several factors: inherently low population densities, unique habitat requirements, tendency to raid crops and, in several cases, their consumption by local people (Karanth and Sunquist 1992). In addition, we need to consider the fact that we cannot hope to plan and effectively implement any conservation measures unless we have on hand basic information regarding the status and health of these animals and their habitat. The urgent need, then, is to collect quantitative data, which will help us not only to assess and monitor the present situation, as well as to formulate future strategies, but will also strengthen our understanding of various ecological processes.

Models that relate an organism's distribution to environmental variables (Brown 1984, Brown et al.1995, Ferrar and Walker 1974) by considering the relevant environmental variables as axes in a species' niche (*sensu* Hutchinson 1957) provide us with a useful framework, using which we can expect a strong relationship to exist between a species' local distribution and environmental variables (i.e. habitat features). According to these models, non-random distribution of organisms in space is explained by deterministic processes that cause individuals to aggregate in favourable locations, approximating an 'ideal free distribution'. Variations in abundance of organisms across sites is related to the variation of combinations of environmental variables, with sites that are closer together tending to have, on average, similar conditions and therefore similar abundance of plants and animals. This niche model includes no population dynamics, but simply assumes that some combination of natality, mortality and dispersal will maintain the abundance at a level set by the extent to which the local environment meets the requirement of the individuals.

However, Brown et al. (1995) point out that in certain cases, the distribution patterns seen may not be best explained by environmental conditions, such as when time lags in responses to environmental changes decreases the correspondence between environmental conditions and abundance, or when territoriality/ aggregation for group benefits changes distribution in a way different from that expected by availability of resources. Certain anthropogenic factors, such as human presence (Ceballos-Lascurain 1996) and poaching may also be expected to affect abundance in ways not reflected in the environmental conditions. Lack of a clear pattern indicates the confounding effects of factors external to the system being considered. Further, it is possible to gauge the effects of these confounding factors themselves.

Anthropogenic disturbances may affect animal distribution and abundance in different ways. Certain types of disturbances may cause highly localised declines (e.g. around point sources of pressures), thus forming new gradients of density, different from those that were determined solely by habitat features. Other types of disturbances (or even animal movements) may result in a uniform thinning over a large area. In addition, different species respond differentially to pressures.

The present study looked at ungulate densities and biomass in the forests of Bhadra Tiger Reserve, Karnataka, using line transects (Anderson et al. 1979, Burnham et al. 1980, Buckland et al. 1993). Density of dung/ pellets, which is a measure of relative ungulate densities and habitat occupancy, was estimated across different habitat and disturbance gradients. Relationships between habitat occupancy and various habitat parameters were then examined to look at the relative importance of natural habitat gradients and disturbance related gradients (cattle grazing, extractive practices, human presence, poaching) as determinants of ungulate habitat occupancy in the study area. Specifically, I was interested to see if low population densities were a result of decline of species around habitation and disturbed areas, or if pressures caused uniformly low densities across the study area, or if animal distribution did indeed follow habitat features.

Density and Biomass Estimation

Past studies in the sub-continent that have addressed this issue are few. Studies that looked at ungulate abundance include those by Schaller (1967), Eisenberg and Lockhart (1972), Berwick (1974), Seidensticker (1976), Dinerstein (1979), Tamang (1982), Johnsingh (1983), Sankar (1994), Varman and Sukumar (1995), Khan et al. (1996), Khan and Vohra (1997), Karanth and Sunquist (1992, 1995), Karanth and Nichols (1998, 2000), Ahrestani (1999) and Kumar (2000_1).

The results of the studies cited above are presented in Table. 9, where they are compared with the estimates derived in this study.

Habitat occupancy

Fewer still are studies that have considered factors that govern habitat use by ungulates with respect to vegetation, topography and/or disturbance parameters. Though the ungulate fauna of Africa has been relatively well studied, we must realise that their

Indian counterparts are unique and generalisations from the African studies may not apply (Eisenberg and Seidensticker 1976). Though this issue has been well studied outside the Indian sub-continent (e.g. Ben-Shahar and Skinner 1988, Shannon et al. 1975), relatively few investigators have examined these relationships within the sub-continent. These include Eisenberg and Lockhart (1972), Berwick (1974), Dinerstein (1979), Balakrishnan and Easa (1986), Bhatnagar (1991), Sankar (1994), Khan (1996), Bhat and Rawat (1995), Acharya (1997) and Mathai (1999).

Of special relevance to the present study are studies carried out previously on ungulates in Bhadra Tiger Reserve. Population estimation for large herbivores was carried out in 1998 (Ahrestani 1999, Karanth and Nichols 2000). Both line transects as well as pellet group counts were used to determine absolute ecological densities of large herbivores. It was found that dung counts were not a reliable method of estimating animal densities, because of unreliable decay rate and defecation rate correction factors. Dung counts were, however, found to be a useful way of monitoring ungulate populations, as long as conversions to absolute densities of animals were not attempted. In the study, dung counts were used solely as a population estimation technique, and not as a way of studying ungulate distribution.

Absolute ecological densities obtained from line transects indicate that ungulate densities in Bhadra are generally low (see Table. 9). In particular, chital densities were found to be lower than sambar densities, unlike other parks in India. Ahrestani (1999) suggests that this is because the habitat in Bhadra is more suited to browsers than to grazers. By comparing the densities in the northern half of the reserve which has no permanent residents, and the southern half, he goes on to suggest that the presence of people does not negatively affect ungulate densities.

Madhusudan (unpublished) studied human-wildlife conflicts in Bhadra, examining both the extent of crop losses to wild ungulates as well as livestock losses to large carnivores.

Madhusudan and Karanth's (in press) study on the intensity and effects of hunting of large mammals in Nagarahole and Kudremukh provides valuable insights into patterns of hunting under different protection regimes, intensity of hunting of various species and the impacts on the populations of these species. In Nagarahole, they compared large mammal densities two ecologically similar sites, one with high hunting pressures and the other with very low hunting pressures. Interviews were also held with a number of hunters to gauge the intensity of hunting and the species most sought after. Similarly, in Kudremukh, where protection is lax, relative abundance of large mammals was estimated and interviews were held with several poachers. Results show that with widespread poaching in the absence of strict protection (i.e. in Kudremukh), all large mammals are extremely scarce. In the two Nagarahole sites however, species were affected differentially. Chital and gaur were found at significantly lower densities in the heavily hunted site when compared to the strictly protected site. Muntjac and sambar abundance did not vary between the two sites. This pattern was attributed to the fact that in Kudremukh, where protection measures were negligible, hunting by shotgun was the most common technique employed, leading to declines in densities of all large mammal species. However, even in the heavily hunted site in Nagarahole, the small amount of protection that was followed made daytime hunting with guns risky and traditional methods of hunting were favoured. Thus species such as muntjac and sambar, which are most effectively hunted with guns owing to their solitary habits, affinity for cover and other factors, were not as greatly affected as chital, which are more susceptible to techniques not easily detected by the forest staff, such as snaring.

Study Area

General

The study was carried out in the Bhadra Tiger Reserve, Karnataka. The reserve, ($13^0$22'N- $13^0$47'N and $75^0$29'S- $75^0$47'S), which was notified as a Wildlife Sanctuary in 1972, and declared as the 25th Project Tiger Reserve in 1998, is spread over an area of $492km^2$. It is situated in Chikmagalur district of Karnataka (Karanth 1982, IUCN 1990, Manjrekar 2000). Wikramanayake et al. (1999) classify the reserve as a tropical moist forest (TMF) in priority category I

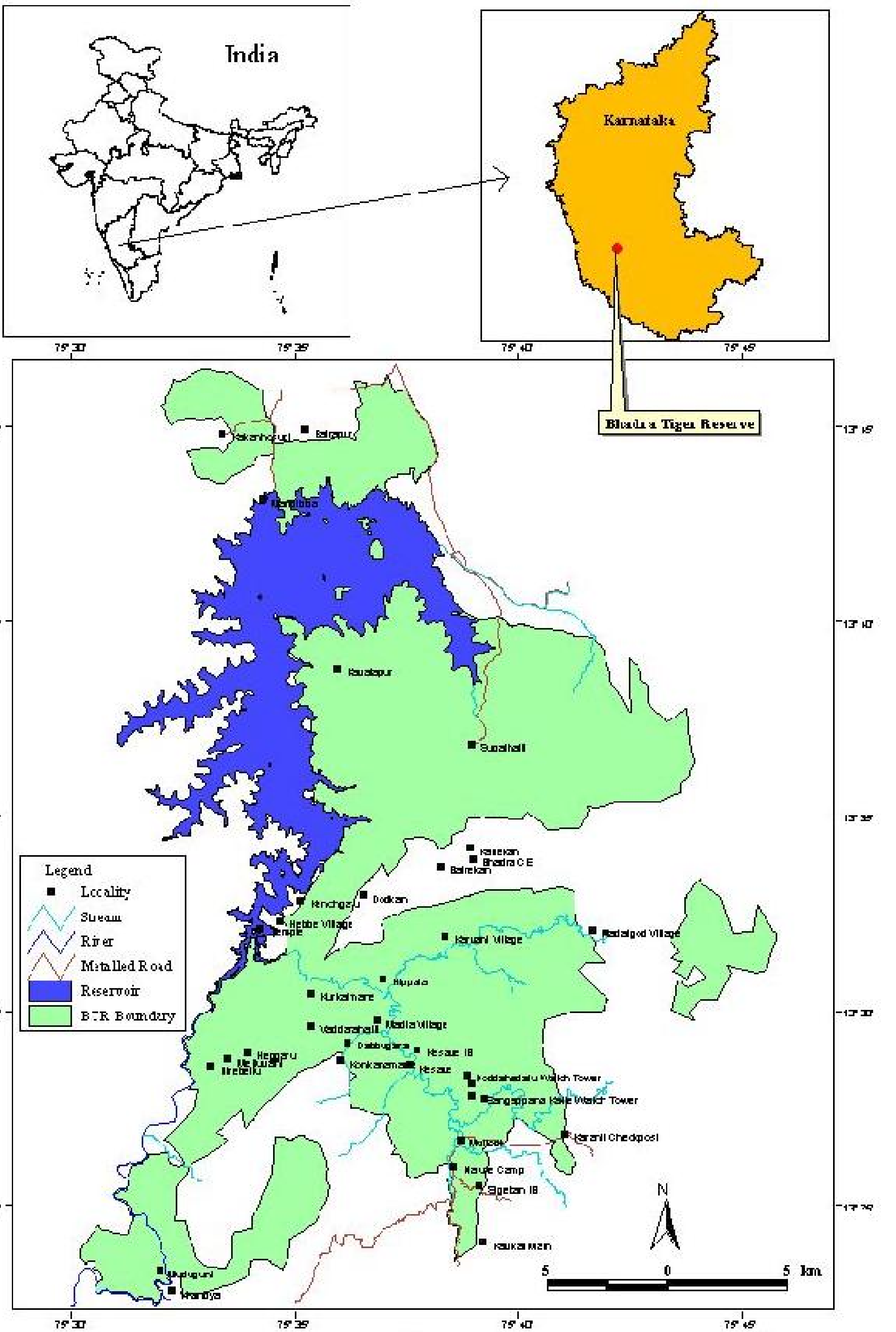
Topography

Bhadra Tiger Reserve (hereafter Bhadra) is bisected into two halves by the Bababudan hills, which encircle the lower half, Jagara Valley (Muthodi Range), almost completely. These hills are the highest in Karnataka and rise to a height of 1927m above m.s.l. Within the crescent formed by the hills, as well as in the northern half (Lakkavalli Range), the terrain ranges from gently undulating to hilly. The altitude is between 670m to 760m above m.s.l. The entire area is dissected by numerous *nullahs* and several perennial streams, such as Somavahini Halla, Tadve Halla, Wate Halla and Hippla Halla. The south-western and western boundaries of the reserve are defined by the Bhadra river. In 1967 the river was dammed near Lakkavalli, on the north-eastern edge of the reserve and the reservoir thus formed submerges large areas of the reserve (map on following page).

Climate

Temperatures range from 10^0C to 32^0C, the hottest months being April and May and the coolest being December and January. Annual precipitation, which occurs mainly between June and September due to the south-west monsoon, is as high as 2000-2540mm (Karanth 1982). The Lakavalli area, being in the rain shadow the Bababudans, receives less rainfall than the Jagara valley.

Map of Bhadra Tiger Reserve



Source : Centre for Wildlife Studies, Bangalore

18

Vegetation

A major portion of the reserve is covered by the *Tectona-Dillenia-Lagerstroemia* Series moist deciduous forests (Meher-Homji 1990), corresponding to type 3B (Southern Tropical Moist Deciduous Forests) in the revised classification by Puri et al. (1983). It gradually merges with Southern Tropical Dry Deciduous Forests (5A) towards the north-eastern edges. The inner slopes of the Bababudans are covered by grassy downs interspersed with evergreen 's*holas'* (Karanth 1982).

The most striking feature of the forests, in both the Jagara valley, as well as in the Lakkavalli area is the predominance of bamboo. *Bambusa arundinacea* occurs widely in the area, especially in wide belts along streams and *nullahs*. *Dendrocalamus strictus* forms an extensive understorey, and is found throughout the reserve. In addition, *Ochlandra readii* is found exclusively along streams, and *Oxytenanthera monostigma* as well as *O.stocki* are found on the steeper hills within the Jagara valley.

The dominant tree species forming the upper canopy include *Tectona grandis, Dalbergia latifolia, Terminalia tomentosa, T.paniculata, T.bellerica, Pterocarpus marsupium, Adina cordifolia, Lagerstroemia lanceolata* and several *Ficus spp.* The middle storey comprises of species such as *Randia dumetorum, Emblica officinalis, Kydia calcina, Wrightia tinctoria, Dillenia pentagyna* and *Gmelina arborea.* The northern valley, being drier in parts, has species such as *Anogeissus latifolia* and *Dalbergia paniculata.* Even within the deciduous forests, strips of evergreen vegetation with species like *Syzygium cumini* are seen along riparian tracts, often extending down into the valley from the *sholas*.

Bhadra has, similar to some other south Indian deciduous forests (e.g. Nagarhole), low-lying swampy fallows, locally known as '*hadlus*'. These are often perennially moist and covered by luxuriant grass growth. '*Hadlu*s' are especially important for large ungulates, and help maintain high densities of grazer species (Karanth and Sunquist, 1992). About 6% of the area is covered by Forest Department plantations, mainly teak (*Tectona grandis*), and some parts have been encroached and converted to coffee plantations and paddy fields.

Fauna

Large carnivores in the reserve are tiger (*Panthera tigris*), leopard (*P. pardus*), dhole (*Cuon alpinus*), and striped hyena (*Hyaena hyaena*). Smaller carnivores include several lesser cats *(Felis spp.*), civets (*Viverricula* and *Paradoxurus spp.)* and mongooses (*Herpestes spp*). Jackals (*Canis aureus*) are common, and sloth bear (*Melursus ursinus*) also occur, though in low numbers.

The ungulates in Bhadra are gaur (*Bos gaurus*), sambar (*Cervus unicolor*), chital (*Axis axis*), muntjac (*Muntiacus muntjak),* Indian chevrotain *(Tragulus meminna*) and wild pig *(Sus scrofa*). Elephants (*Elephas maximus*) are also found in all parts of the reserve and appear to migrate locally within the area. Primates are represented by the common langur (*Presbytis entellus*) and bonnet macaque *(Macaca radiata*) (Karanth 1982).

Conservation Issues

The reserve is subject to several pressures, both from the surrounding areas as well as from within its boundaries. The shape of the reserve is such that several incursions extend well into the reserve, so that various parts maintain only the most tenuous link with each other (e.g. the northern and southern halves, the south-western part of Hebbe range and Jagara valley proper, Bababudangiri State Forest (i.e. Kemmangundi) and the rest of the reserve).

The Bababudans are largely taken over by coffee plantations, and consequently the Jagara valley is almost completely surrounded by these private estates. In addition there are 16 villages, with about 4000 people in the southern half of the reserve. Large tracts of low-lying areas along the Somavahini and Hippla streams have been converted to paddy fields (Ahrestani 1999, Kumar 2000_2).

The residents own about 2000 heads of cattle, which are grazed in the reserve. Besides competing with the wild herbivores for fodder, domestic cattle also transmit diseases such as Rinderpest to wildlife. Bhadra, which was once known for very high gaur densities, lost several of these animals in a Rinderpest epidemic in 1989 and the gaur population is yet to recover (Mr. D.V. Girish, pers. comm).

Residents of the villages also extract several forest products such as *Acacia sinuata* pods, firewood and bamboo from the reserve. Poaching (with guns, dogs or by snaring) is a major problem, and is indulged in by coffee planters, estate workers and local residents alike (pers. obs). Not only are animals straying into the plantations/ crop fields removed, poaching also occurs well within the reserve boundaries. Timber poaching is another problem, and is intense in parts of the reserve.

Another problem is the seasonal pollution of all the major streams entering the Jagara valley from the Bababudans by the effluents from coffee pulpers in the surrounding estates. The effluent has a high organic load, high BOD and COD levels, low pH and polyphenols. The effects these have on mammals within Bhadra, which depend on these streams for their water needs, are not known. Aquatic fauna are likely to be greatly affected by it.

These problems continue despite the concerted efforts of the Forest Department and several conservation N.G.Os. The Department has recently initiated a relocation program for the villages within the reserve, with the active and enthusiastic participation of the residents. At the time this was written, the first village was slated to move out within a month. If successful, this move should result in removing a large part of the pressure on the forests. In addition, returning the cultivated areas along the streams to wildlife use, and the subsequent formation of *hadlus* may be expected to greatly benefit the herbivore assemblage.

Objectives

The objectives of the study were:

1. To estimate ecological densities and biomass of the ungulate prey species of tiger (gaur, sambar, chital, muntjac, wild pig).
2. To study habitat occupancy by the study species across habitat and disturbance gradients.
3. To examine the possible influence of various habitat parameters and human impacts on the habitat use patterns of the study species.

Significance of the study

Considering the habitat in Bhadra Tiger Reserve, which has high rainfall, excellent availability of grasses (especially in the *hadlus*), abundant bamboo growth and relatively low invasion by weeds, one would expect, *a priori*, that the area supports high ungulate densities. However, previously estimated densities show that ungulate densities are very low (Ahrestani 1999, Karanth and Nichols 2000). Consequently, densities of carnivores are also extremely low: Karanth and Nichols' (2000) estimate for tiger densities in the central, better protected part of Bhadra is 3.42(0.84) tigers $100km^{-2}$ (D(SE[D])). In the light of this, it is important to monitor ungulate abundance and to determine what really restricts habitat occupancy (and therefore, abundance).

The density estimation gains added importance when viewed as a part of a long term monitoring of ungulate populations, especially in the context of the proposed rehabilitation. The estimates will serve as baseline estimates that will help track changes in herbivore populations as disturbances are removed over a period of time. Not only will ungulates benefit from the absence of human induced pressures, the conversion of village sites and agricultural fields into secondary successional sites and *hadlus* may be expected to lead to high ungulate densities, as was seen in Nagarahole (Karanth and Sunquist 1992). If the population monitoring is carried on for several years, it will provide conservationists and managers with invaluable insights into recoveries of herbivore populations with removal of human impacts.

While the long-term changes are taking place, it is also important to consider the present situation and gauge the scale of the problem, by examining how herbivores respond to human pressures. An important question is if patterns of ungulate distribution follow habitat features or if the distribution is explained more by human disturbance.

Methods

Density and Biomass

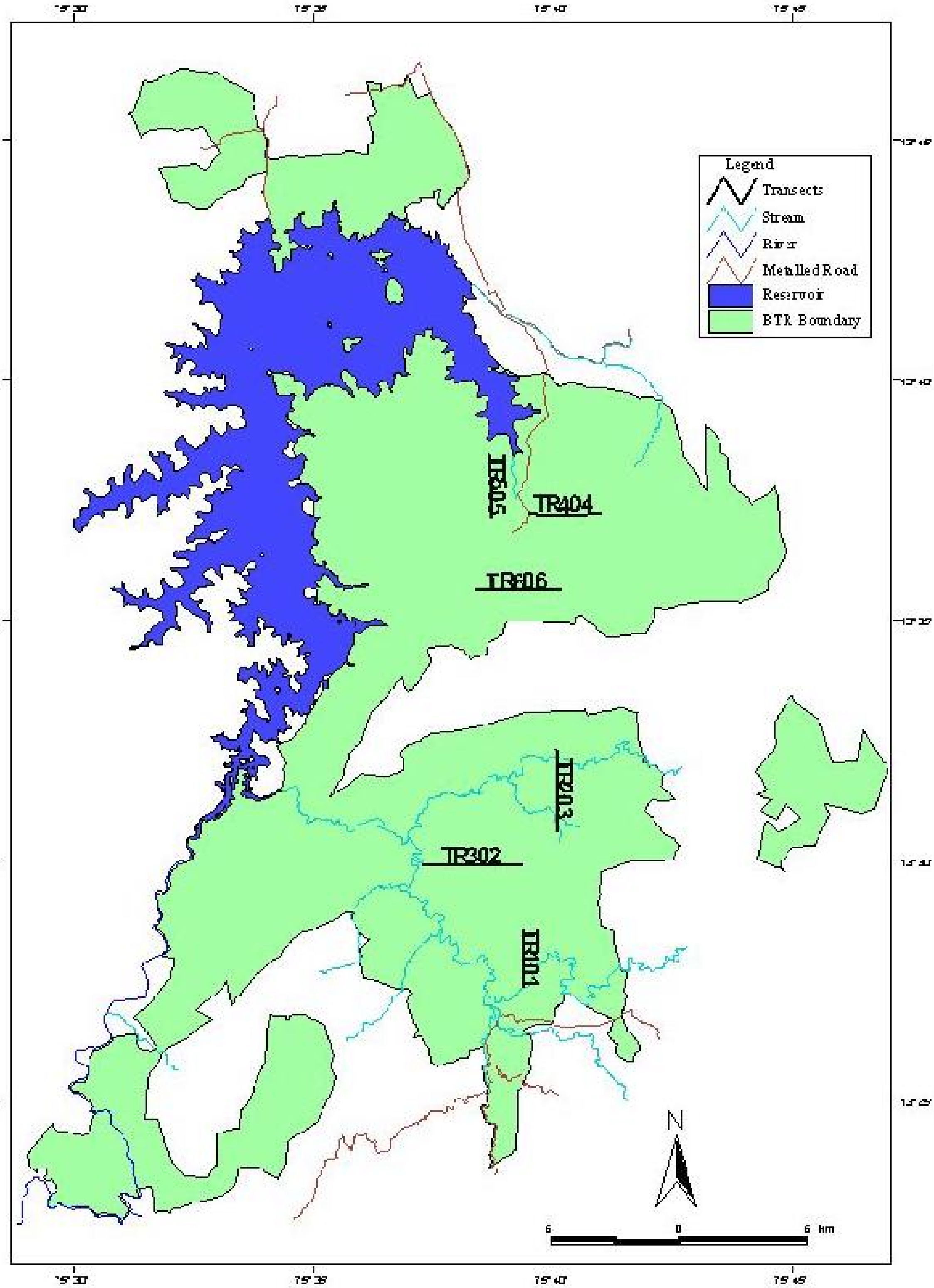
<u>Field Methods</u>

Ecological densities and biomass of the study species were estimated using the line transect method (Anderson et al. 1979, Burnham et al. 1980, Buckland et al. 1993). Line transects have been found to be very effective and reliable in estimating densities of ungulates in the Indian sub-continent (Varman and Sukumar 1995, Khan et al. 1996, Raman et al. 1996, Karanth and Sunquist 1992, 1995; Karanth and Nichols 1998) and have also been used for primates (Brockleman and Ali 1987). The strength of this method is largely in its ability to take into account non-detectability of animals and their non-random distribution, by incorporating the detection function g(x).

The permanent transects used in the present study were established in 1997 and previously used by Ahrestani (1999) and Karanth and Nichols (2000) to estimate densities of large herbivores. Six transects were established, three in the Jagara valley and three in the Lakkavalli area (map on following page). The transects were between 2.6-3.6km long, totalling 18.2km. The transects were laid so that the various habitat types within the study area were represented proportionally.

Line transect data were collected between 0615hrs–0830hrs and between 1545hrs-1800hrs. Animal clusters were used as the analytical unit since individual data tends to underestimate true variance (Southwell and Weaver 1993). At each detection, data on time of detection, species ID, sighting distance, transect bearing and group centre bearing were collected. Sighting distances were measured using optical rangefinders and a liquid filled compass (SUUNTO Challenger, MCA-D) was used to measure the bearings. The bearings were subsequently used to obtain sighting angles. To obtain a substantial number of detections, suitable for statistical analysis, line transect data were collected with the help of trained transect volunteers. The field protocol followed is as described in Karanth and Sunquist (1992) and Kumar (2000_1).

Transect Locations in Bhadra Tiger Reserve



Source Centre for Wildlife Studies, Bangalore

Statistical Methods

The line transect data were analysed using program DISTANCE (Laake et al. 1993). The distribution of the data was first examined by assigning very small cut points to the distance intervals during the curve fitting, to detect evidences of evasive movements by the animals or heaping of data at certain distance intervals. Based on the distribution of the data, data were truncated at suitable distances from the line. After choosing convenient cut-points for the distance intervals, the best key function (with the appropriate adjustment term, where necessary) was selected using the criterion of lowest AIC (Akaike's Information Criterion). The AIC is computed as:

$$AIC = -2 \log_e(£) + 2q$$

Where $\log_e(£)$ is the log likelihood function evaluated at the maximum likelihood estimates of the model parameters and q is the number of parameters in the model. AIC thus chooses the model with the best fit with the least terms (i.e. the most parsimonious model). The model selection was carried out only after the truncation and distance intervals were decided on since AIC cannot be used to choose between models that have different truncation distances (Buckland et al. 1993).

Estimation of the variance associated with the mean density presented some difficulties, since the theoretical variance estimated by program DISTANCE is likely to be underestimated in biological populations, the underestimation becoming more acute with species that are highly clumped. Therefore, an over-dispersion factor of 3, recommended as a reasonable estimate for most biological populations (Buckland et al. 1993, Burnham et al. 1980), was applied.

Biomass densities of the different species were computed by multiplying the estimated mean numerical densities by the published average weights of the respective species. Since I did not have reliable data on the population structure of study species, the biomass could not be corrected for the actual population structure and the average weights of the species were used instead.

Habitat Occupancy

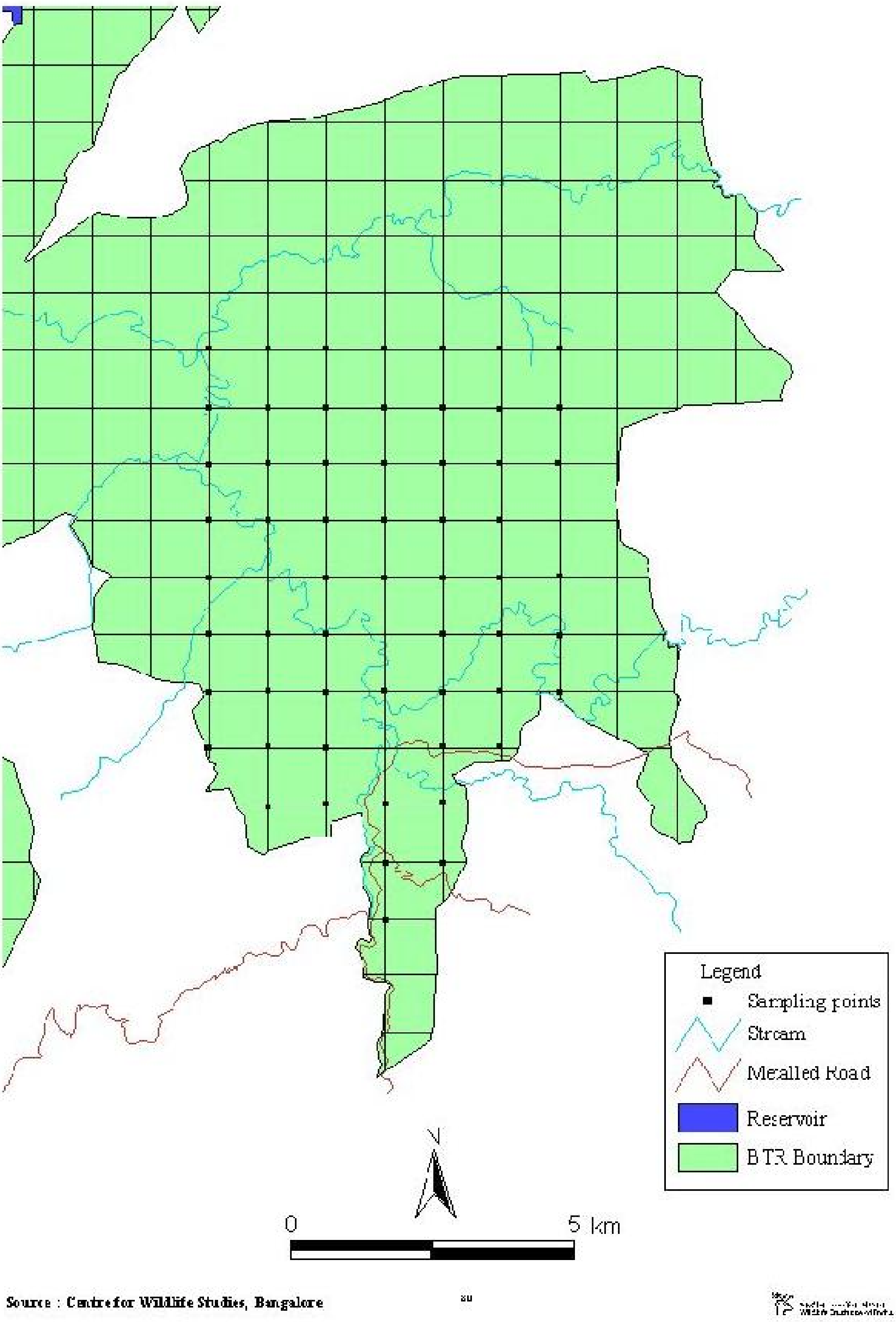
Field Methods

A different sampling design was adopted to sample for animal occupancy and habitat parameters. This part of the study was restricted to the Jagara valley (Muthodi Range). The area was gridded into $1km^2$ grids (map on following page) using the Geographic Information System software package MAPINFO™ (MapInfo Corporation, Troy, New York). Each of the grid intersections was thus marked by its co-ordinates. The co-ordinates were entered into a hand held Global Positioning System unit (Magellan™ ColorTrack), which helped locate them during the sampling. This systematic random sampling design ensured that the sampling points could be treated as a set of independent data points. At each sampling point, plots were laid to quantify ungulate occupancy as well as habitat parameters as described below.

Dung Density: Dung/ pellet density was used as the indicator of ungulate habitat occupancy. Dung /pellet counts have been widely used to estimate parameters such as absolute ecological densities, relative densities and habitat occupancy by numerous animal species, in a variety of climatic and vegetation conditions (Neff 1968, Kufeld 1968, McClanahan 1986, Case and McCullough 1987, Koster and Hart 1988, Hiby and Lovell 1991, Dawson and Dekker 1992, Barnes et al. 1995, Plumptre and Harris 1995). Some investigators have used the Line Transect Method estimate dung/pellet densities (Koster and Hart 1986, Barnes et al. 1995), rather than census sample plots.

Dung has been found to be a reliable indicator of habitat occupancy by ungulates (Cairns and Telfer 1980, Edge and Marcum 1989, Latham et al. 1997). One needs to assume that defecation is random with respect to habitat type, which may not always hold true. Dung, however, gives a much better indication of habitat use than methods based on direct sighting since inferences from the latter need to be restricted to the actual time of sighting, whereas dung densities reflect habitat use over longer time periods. It is also much more effective when considering differences in animal distribution at the scale at which this study dealt with.

Sampling Design for Habitat Variables- Ungulate Occupancy



Source : Centre for Wildlife Studies, Bangalore

The method has seen a lot of changes over the last few decades It was earlier necessary to assume steady-state (McClanahan 1986, Koster and Hart 1988, Dawson and Dekker 1992, Barnes et al. 1995). Hiby and Lovell (1991) have developed refined techniques using software (Program DUNGSURV) to estimate densities of pellet/ dung piles and pellet decay rates, without having to assume steady state.

Since dung decay rates may differ across habitat conditions even within a study site, which may lead to differential dung densities independent of animal abundance, it was necessary to first find out if decay rates really did differ, and if they did, to estimate the decay rates so that suitable correction factors could be applied to the observed dung densities so that they would be comparable across different environmental conditions.

Dung Decay Rates: In a series of decay rate experiments, dung piles were placed in different cover and slope categories, and their decay was monitored. Only fresh piles were used in the experiments. Piles were collected by intensively searching areas known to be frequented by the study species. In order to obtain reliable estimates of decay rates, attempts were made to collect as many fresh piles as possible. Three cover categories (low, medium and high) and two slope categories (flat and sloping) were chosen, and piles were assigned to each category equally. In each experiment new piles were placed in the respective cover/ slope category, tagged for future identification and piles placed previously were checked and their decay stages recorded.

Five decay stages were identified:

Stage A: Moist with odour

Stage B: Dry, hard and intact

Stage C: Decay/ decomposition discernible in a few pellets

Stage D: More than 50% of the pile decayed/ disintegrated

Stage E: Unrecognisable as belonging to a species/ distinct pile

Initially (late November 2000 through mid-December 2001), the piles were monitored at four day intervals, later on (December to end-February) they were checked at eight day intervals. All the piles were checked again at the end of the study (28th

April 2001).

Ungulate occupancy was quantified by counting dung piles in a 25 x 2m rectangular plot centred at the sampling point indicated by the GPS. The rectangular shape helped ensure that no piles were missed within the plot. Further, this was ensured by intensively searching the ground above and under the litter/grass layer. The decay stage of each dung pile found was recorded and the plot was assigned to the appropriate cover/ slope category.

Habitat Parameters: In the present study, quantification of vegetation and other habitat parameters was carried out using 10m radius circular plots for trees, topography and disturbance, circular plots of 4m radius for shrubs, 3m circular plots for seedlings/ saplings/herbs and a point-intercept lines of 10m, with a 'hit' every 20cm (a total of 50 hits/ sampling point) for ground cover, at each of the sampling points (Hays, Summers and Seitz 1981). The plot sizes were decided on after several trials in the field. A nested design was chosen, with the three circular plots, the line intercept as well as the rectangular dung plot centred on the same point. The rectangular plot was oriented in an east-west direction. The parameters to be quantified were decided upon based on the results of previous studies that looked at ungulate-habitat relationships, especially in the deciduous forests of India.

Parameters recorded in the 10m radius circular plot are:

Mean Canopy Cover: Measured using a spherical densiometer. Four readings were taken at each point (one in each of the cardinal directions) from which a mean was computed subsequently. Expressed as a percentage

Slope: Measured using a clinometer in the direction of maximum slope.

Trees: For each individual tree the species, height (using an optical rangefinder), leaf stage (young/ mature/ yellow-green/ yellow/ yellow-brown/ brown/ leafless) and fruiting stage (flower bud/ flower/ fruit/ seed) were recorded. Mean values were subsequently computed for all the individual tree measurements. The number of trees with foliage below 2.5m, considered to be accessible to sambar (Bhatnagar 1991) was also recorded.

Number of clumps of *Bambusa arundinacea*: Flowering, if present, was recorded.

In addition, nominal variables such as topography and a verbal description of the site were also recorded.

Parameters recorded in the 4m radius circular plots are:

Shrubs: For each individual, the height, average diameter, approximate shape, leaf stage and fruiting stage were recorded. Signs of browsing, if any, were also noted. The measurements taken for individual shrubs were later used to compute mean values for the point.

Number of clumps of *Dendrocalamus strictus*.

Parameters recorded in the 3m radius circular plots are:

Density of seedlings/ saplings/weeds.

The Point Intercept (10m long, along the centre of the dung plot) was used to quantify grass cover, herb cover, litter cover, rock cover, bare soil and other cover types. Since 50 points were covered for each sampling point, the percent cover was obtained by simply multiplying the observed count by two.

Disturbance signs were noted down whenever they occurred within the plots, as well as in the vicinity or while approaching the sampling points. Signs recorded include presence of people, number of tree stumps, signs of firewood removal, signs of bamboo removal, cattle dung, presence of tree climbing notches (used to poach flying squirrels or remove fruits), signs of cooking fires, among others. However, two major problem in quantifying disturbance were that most of the plots did not have disturbance signs *within* them and assigning weightage to different types of disturbances was bound to be arbitrary. Therefore, since it was not possible to obtain a reliable measure of the intensity of disturbance for each of my sampling points, which would be comparable across space, it was decided to use distances to the nearest village and to the reserve boundary as a surrogate. All distances were measured on digitised maps (developed by the Centre for Wildlife Studies, Bangalore) using the GIS software package ARCVIEW

(ESRI, Inc. NY). In addition, distance to water was also measured and included among the habitat variables.

Statistical Methods

All statistical analyses pertaining to ungulate habitat occupancy were carried out using the statistical software package SPSS, Version 8.0 (1996). The data were first examined using scatter plots matrices, correlation matrices and histograms to detect overall patterns, and to determine what underlying distributions they were likely to have been sampled from.

Decay Rates: The time (in number of days) taken to reach decay stage C was compared between the different cover categories using One-way Analysis of Variance (ANOVA) (Zar 1984) to determine if decay rates differed significantly between the categories, and if it would be necessary to apply correction factors to the observed dung densities before using them as an indicator of ungulate occupancy.

Factor Analysis: A Factor Analysis (Pielou 1984) was performed on the habitat variables to reduce the dimensionality of the data set. Factor Analysis uses the redundancy in the data set (autocorrelations) to create a smaller number of new variables (factors), which can be used in subsequent analyses. An added advantage of this method is that the new set of variables are mutually independent (orthogonal), so that the problem of multicollinearity is taken care of. The Factor Analysis was performed using the correlation matrix, rather than the covariance matrix since the habitat variables were measured on different scales (Pielou 1984). A Varimax (variance maximising) rotation was performed to facilitate interpretation of the factors.

Logistic Regression: To examine relationships between habitat variables and ungulate occupancy (i.e. dung count data), Multiple Logistic Regressions (Hosmer and Lemeshow 1989) were used, since the dependent variable (dung density) had several zero values (plots with no dung of the species of interest). In the case of sambar, plots with two piles or less were designated as zero, and the rest were treated as one. Logistic Regression uses the observed patterns of ones and zeroes (presence and absence) to construct a predictive model by choosing the habitat variables that best predict the outcome.

Selection of the best set of predictor variables for each species was done using the stepwise backward conditional method. The 'p to enter' was chosen as 0.05, and the 'p to remove' was 0.1 (Hosmer and Lemeshow 1989). Models were constructed using both the factors as well as the original variables, to see which fit the data better.

The models (for each species) were first constructed for all the data points and their fit assessed by an examination of the classification tables and Nagelkerke's R^2, which approximates the R^2 obtained in Multiple Linear Regression by the least squares method (multiple coefficient of determination), thus indicating the proportion of variance in the dependant variable explained by all the independent variables together.

To examine the effect of disturbance on ungulate occupancy, the data set was then split into points close to habitation (less than 1km from village or boundary) and points farther from habitation (more than 1km away). Logistic Regression models were then constructed using the less disturbed cases (i.e. those more than 1km from habitation), so that the confounding effect of disturbance on the habitat-occupancy pattern was minimised. The same model was then applied to the remaining (more disturbed) cases. The procedure was repeated for each of the study species.

The classification tables and Nagelkerke's R^2 values were compared with that of the original model using the entire data set, to see if the percentage of correct classification and the coefficients of determination improved noticeably for the subset that was less disturbed and decreased for the more disturbed points, as would be expected if disturbance did have an appreciable effect on ungulate presence/ absence.

The predicted group memberships were saved as new variables. Of special interest were those cases that were predicted to have the species present, but were in fact observed as absent. These plots represented sites that, according to the model, were suitable for the species of interest, but were not occupied by that species.

I assigned each case to one of the following types based on the predicted and observed outcomes:

Predicted	Observed	Type
1	1	1
0	1	2
1	0	3
0	0	4

Thus, type 1 sites are those that are predicted to be one (species present) and are indeed one, while type 3 sites are those that are predicted to be one, but are in fact zero (species absent).

The hypothesis that type 3 sites were, on average, significantly nearer to villages and/or boundary than type 1 sites was tested using the distribution free Mann-Whitney U-test (Zar 1984) for each species.

Results

Density and Biomass

Each of the six transects were walked 26 times: thus there were 6 spatial replicates, and 26 temporal replicates. The total effort was 472.9km. Data from all temporal replicates for a transect were pooled and treated as one sample. The sample size, therefore, was six. The number of detections was generally very low (chital: 51, muntjac: 68, sambar: 25, gaur: 17); for sambar and gaur well below the 40 recommended by Burnham et al. (1980) and Buckland et al. (1993).

The results of the DISTANCE analysis are presented in Table.1, showing the number of detections, estimated density of clusters, estimated cluster size (mean cluster size where there was no size bias in detection), mean density of individuals, percent coefficient of variation and the 95% confidence interval about the mean.

Based on the criterion of lowest AIC, the half normal key function fit the chital and sambar data with no adjustment terms. Muntjac data were best described by the hazard rate model (with no adjustment terms). The half normal model with cosine adjustments proved to be the best fit for the gaur data.

Biomass density estimates, obtained by multiplying the estimated mean ecological density by the published average weights of each species, are presented in Table. 2.

Table 1: Density estimates for ungulates in Bhadra Tiger Reserve.

n= number of detections, D_g= density of clusters, Y= mean cluster size,

D= density of individuals, Cv(D)= coefficient of variation

and 95% CI= 95% confidence interval. Total effort = 472.9km.

Species	N	D_g (km^{-2})	Y	D (km^{-2})	Cv(D) (%)	95%CI (km^{-2})
Chital	51	1.60	2.81	4.50	31.12	2.46-8.25
Sambar	25	0.86	1.08	0.93	39.48	0.42-2.03
Muntjac	68	2.9	1.03	3.01	25.36	1.82-4.96
Gaur	17	0.64	2.31	1.48	55.29	0.51-4.30

Table2: Biomass density estimates for ungulates in Bhadra Tiger Reserve.

Average species weights from Karanth and Sunquist (1992).

Species	Average Weight (kg)	Biomass (kg km^{-2})
Chital	47	211
Sambar	134	124
Muntjac	21	63
Gaur	450	666

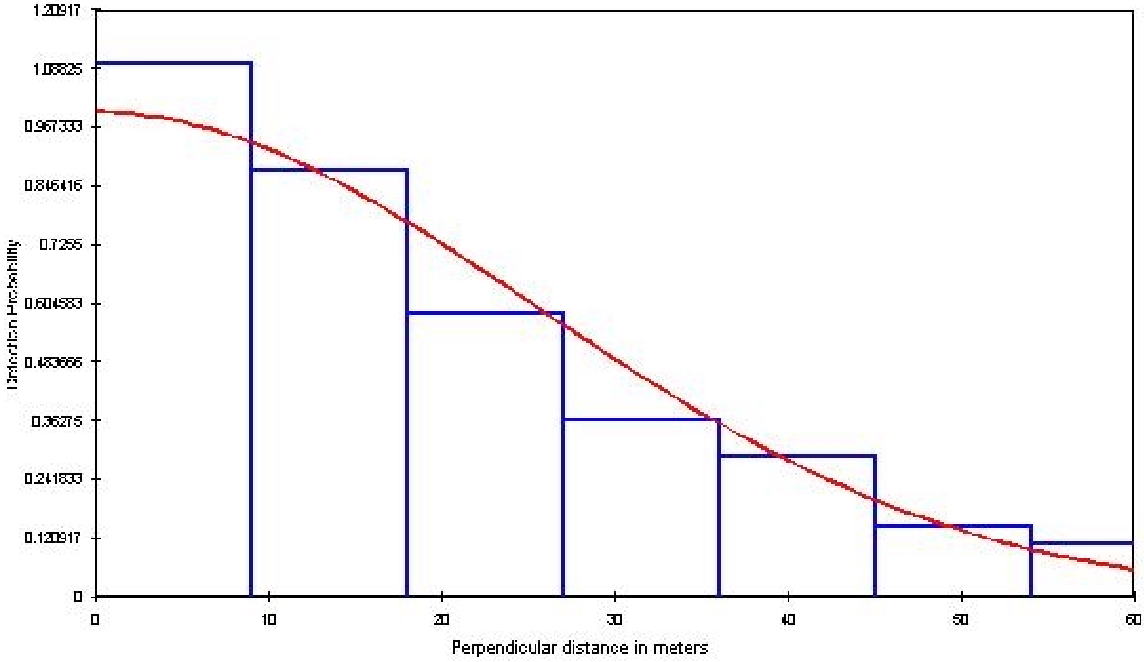


Fig. 1: Probability plot of chital detections from line transect sampling.
Model chosen: Half normal

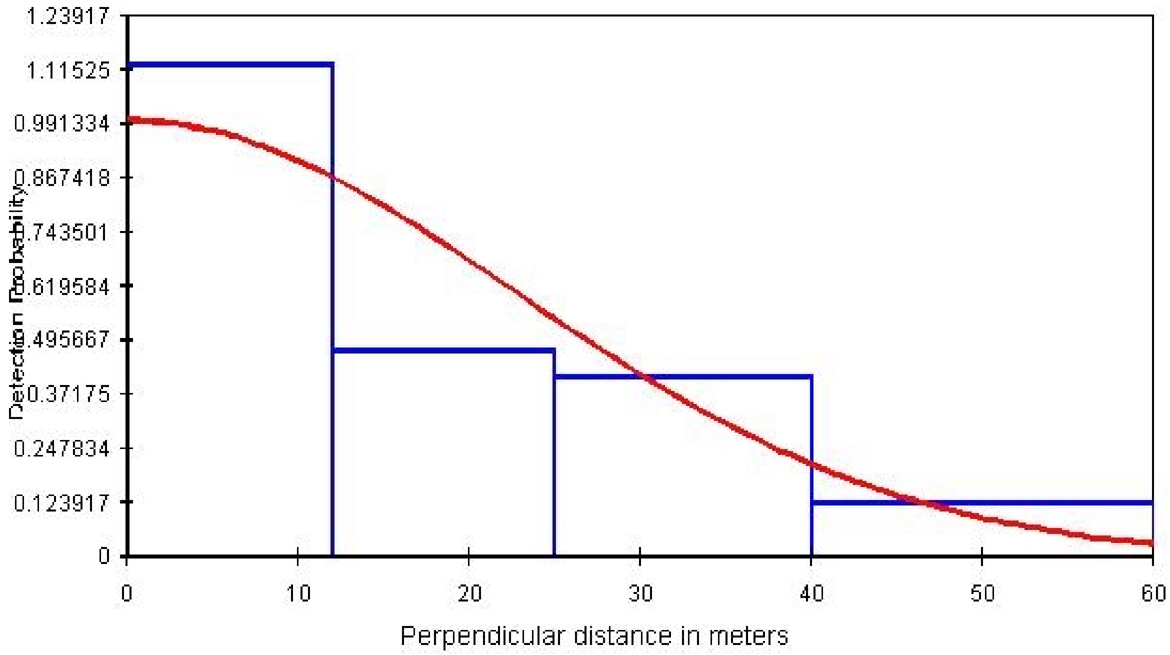
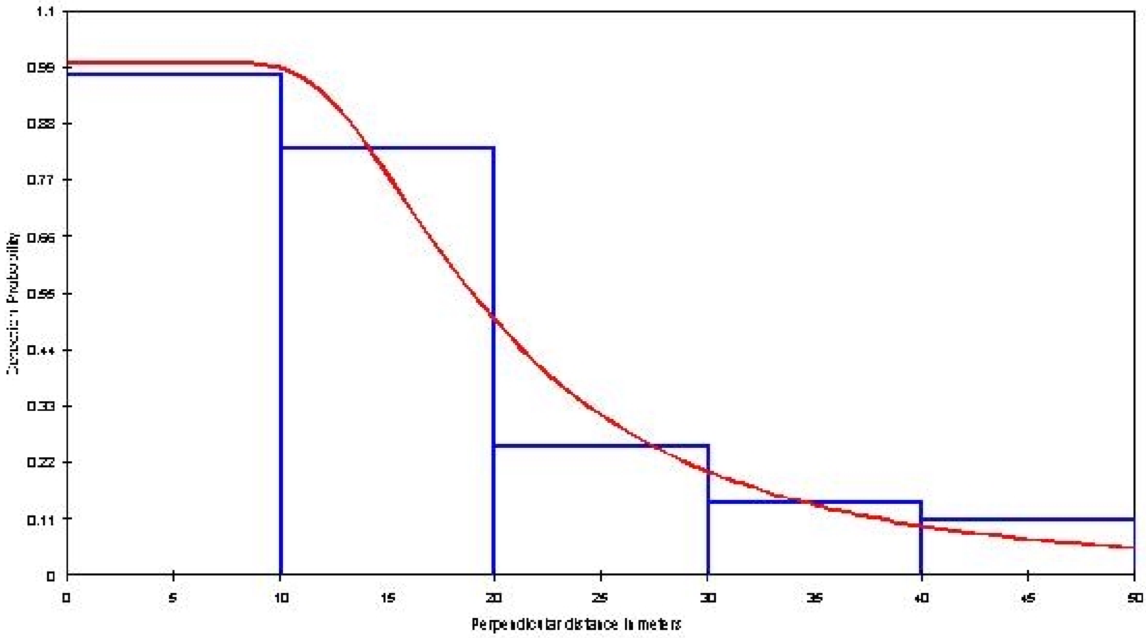
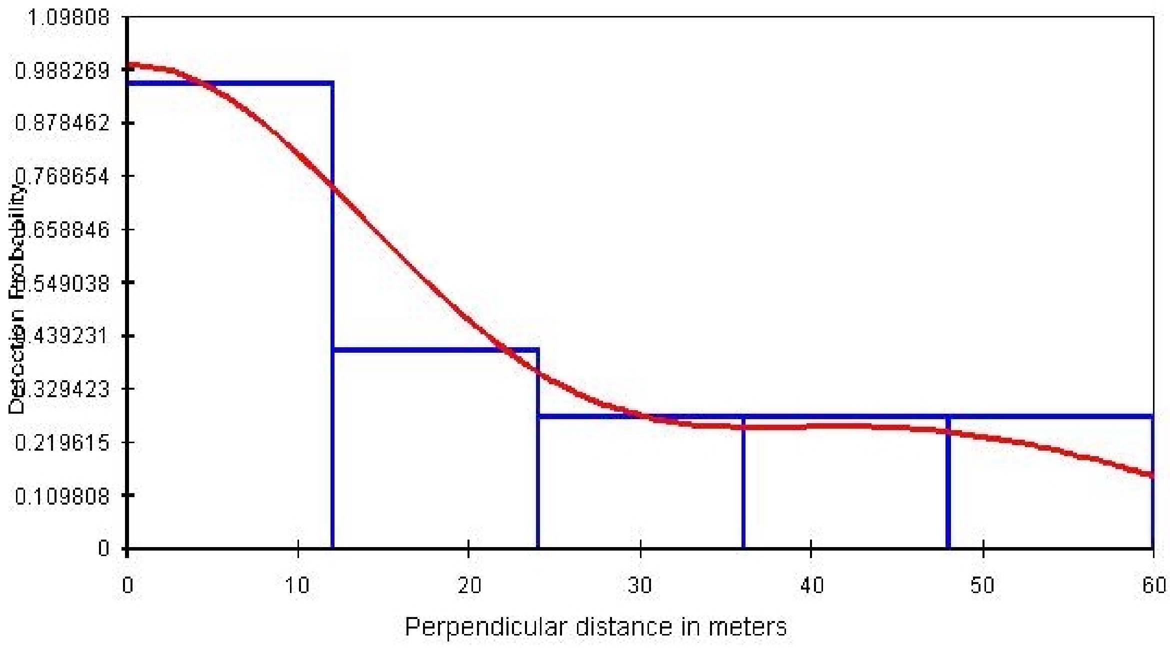


Fig. 2: Probability plot of sambar detections from line transect sampling. Model chosen: Half normal



<u>Fig. 3:</u> Probability plot of Muntjac detections from line transect sampling.
Model chosen: Hazard Rate



<u>Fig. 4</u>. Probability plot of gaur detections from line transect sampling.
Model chosen: Half normal with cosine adjustments.

Habitat Occupancy

Dung Decay Rates

A total of 173 fresh dung piles (chital, sambar, muntjac, cattle and elephant) were placed in different cover categories and monitored in the decay rate experiments. One way Analysis of Variance (on 74 sambar piles) indicated that dung piles in different cover categories did not vary significantly in the time taken to reach decay stage C ($F = 0.647$, $df = 2,71$, $p = 0.527$). Therefore it was not necessary to apply a decay rate correction factor. The standing crop of dung was used as the indicator of habitat occupancy.

Logistic Regression:

The results of the logistic regression analysis constructed for the different species using the selected cases (1km or more from village/ boundary) are presented in Tables. 3-6, which show the variables chosen by the model, their respective regression coefficients (β), standard errors and p-values as well as Nagelkerke's R^2. When the models constructed using the factors were compared with those constructed using the original variables, in every case the original variables gave a better model. Therefore, it was decided to use the original variables after ensuring that moderately to highly correlated variables were not included in the same model.

According to the chital model, chital occupancy is determined by shrub cover, water availability, lower grass cover, less slope, and fewer seedlings. Sambar tend to occupy areas with greater shrub cover, greater number of tree species, fewer seedlings and lower grass cover. Muntjac were found to occupy sites characterised by higher tree densities, higher *B. arundinacea* density, lower canopy cover, lower grass cover, higher densities of seedlings belonging to a few species. The gaur model, based on only eight 'hits', used distance to water as the sole variable to predict gaur presence/ absence. It is important to note that none of the models chose distance to village/ boundary (used here as a surrogate for disturbance) as an independent variable to predict species' presence or absence.

Variable	β	SE	Sig
Slope	-0.2137	0.1304	0.1012
Shrub height	2.6905	1.2579	0.0324
Grass cover	-0.2893	0.1376	0.0354
Distance to water	-2.6187	1.5666	0.0946
Number of seedlings	-0.1435	0.0622	0.0211
Constant	10.8763	4.7164	0.0211

Nagelkerke's R^2 = 0.752

Table 3: Independent variables in the model predicting chital presence/ absence. Model constructed for cases > 1km from village/ boundary.

β = regression coefficient, SE= standard error of β, Sig = significance of β.

Variable	β	SE	Sig
Tree species richness	0.8243	0.4582	0.0720
Number of shrubs	0.4656	0.3498	0.1832
Number of seedlings	-0.0579	0.0331	0.0804
Grass cover	-0.1283	0.0968	0.1850
Constant	0.9438	1.4028	0.5011

Nagelkerke's R^2 = 0.527

Table 4: Independent variables in the model predicting sambar presence/ absence. Model constructed for cases > 1km from village/ boundary.

β = regression coefficient, SE= standard error of β, Sig = significance of β.

Variable	β	SE	Sig
Mean canopy cover	-0.1105	0.0564	0.0502
Number of trees	0.3896	0.2179	0.0737
Number of *B. Arundinacea*	0.6147	0.4177	0.1411
Number of seedlings	0.0783	0.0376	0.0373
Seedling species richness	-0.6294	0.2630	0.0167
Grass cover	-0.2631	0.1112	0.0180
Constant	8.5726	3.9451	0.0298

Nagelkerke's R^2 = 0.609

Table 5: Independent variables in the model predicting muntjac presence/ absence. Model constructed for cases > 1km from village/ boundary.

β = regression coefficient, SE= standard error of β, Sig = significance of β.

Variable	β	SE	Sig
Distance to water	2.3182	0.8675	0.0075
Constant	-4.1152	1.2887	0.0014

Nagelkerke's R^2 = 0.397

Table 6: Independent variables in the model predicting gaur presence/ absence. Model constructed for cases > 1km from village/ boundary.

β = regression coefficient, SE= standard error of β, Sig = significance of β.

Examination of the classification tables and Nagelkerke's R^2 for the logistic regression models constructed for the selected and unselected cases showed consistent patterns for all species except gaur (Table 7 a-d). The R^2 showed consistent improvements from the model for the entire data set to the model for the selected cases. Further, the percentage of correctly classified cases improved for the cases farther than 1km from habitation (when compared to the percentage of correctly classified plots for the unselected cases model) and decreased for the cases 1km or nearer. A closer look revealed that the majority of misclassifications in the selected cases 1km or nearer to habitation was in the top right cell of the classification table (predicted -one, observed zero).

For the gaur models, however, the percentage of correct classification for the selected cases farther than 1km from habitation was actually less than that for the entire data set, and more for the cases 1km or nearer.

The Mann-Whitney U test, used to test if the type 3 cases (predicted-1, observed -0: see page 37) were on average significantly closer to villages and/ or reserve boundary, showed that type 3 cases for chital *were* significantly closer to villages/ boundary (M-W U = 75, df = 30,11, p = 0.0035) while type 3 cases for sambar were significantly closer to villages (M-W U = 80, df = 45,7, p = 0.0185) (Fig. 5 and 6). However, no significant differences were found in the case of muntjac and gaur.

Table 7: Classification tables and Nagelkerke's R^2 for models with unselected cases, cases farther than 1 km from village/ boundary and cases 1 km or less from village / boundary:

a: Chital

Unselected Cases: R^2=0.633

		Predicted 0	*Predicted* 1
Observed	**0**	17	7
Observed	**1**	3	33

% Correct = 83.33%

Selected Cases: R^2=0.752

> 1 km

		Predicted 0	*Predicted* 1
Observed	**0**	9	3
Observed	**1**	2	23

% Correct = 86.49%%

< 1 km

		Predicted 0	*Predicted* 1
Observed	**0**	4	8
Observed	**1**	4	7

% Correct = 47.83%

b: Sambar

Unselected Cases. R^2=0.523

		Predicted 0	*Predicted* 1
Observed	**0**	7	6
Observed	**1**	3	44

% Correct = 85.00%

Selected Cases. R^2=0.527

> 1 km

		Predicted 0	*Predicted* 1
Observed	**0**	4	3
Observed	**1**	1	29

% Correct = 89.19%

< 1 km

		Predicted 0	*Predicted* 1
Observed	**0**	1	5
Observed	**1**	2	15

% Correct = 69.57%

c: Muntjac

Unselected Cases. R^2=0.364

		Predicted 0	1
Observed	**0**	18	8
	1	8	26

% Correct = 73.33%

Selected Cases. R^2=0.609

> 1 km

		Predicted 0	1
Observed	**0**	9	6
	1	3	16

% Correct = 75.68%

< 1 km

		Predicted 0	1
Observed	**0**	2	9
	1	1	11

% Correct = 56.52%

d: Gaur

Unselected Cases. R^2=0.402

		Predicted 0	1
Observed	**0**	51	1
	1	6	2

% Correct = 88.33%

Selected Cases. R^2=0.397

> 1 km

		Predicted 0	1
Observed	**0**	28	1
	1	4	4

% Correct = 86.49%

< 1 km

		Predicted 0	1
Observed	**0**	22	1
	1	0	0

% Correct = 96.65%

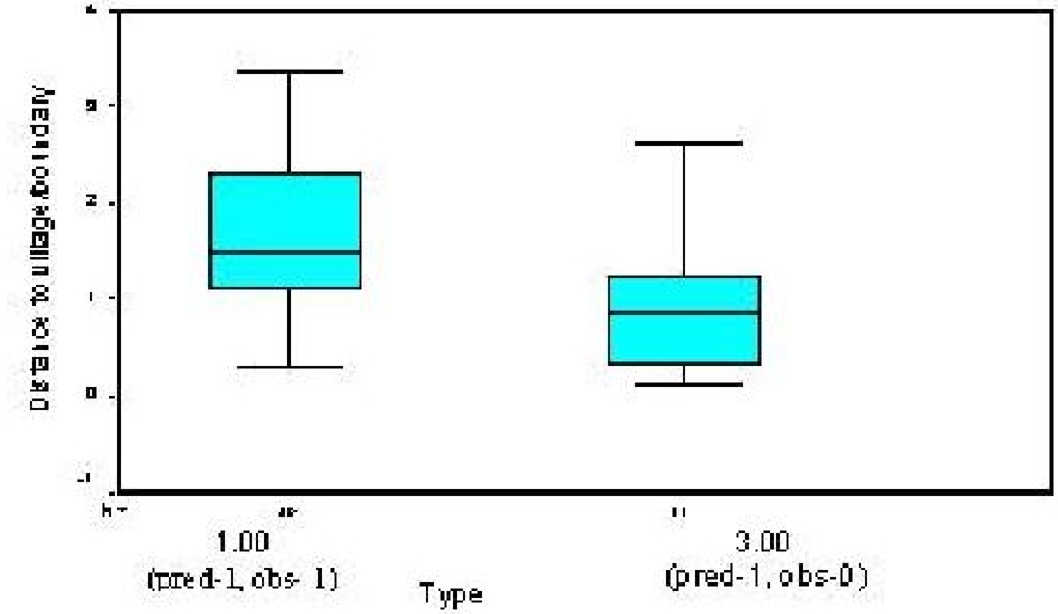


Fig 5: Comparison of median distance to village/ boundary of type-3 chital cases with type-1 chital cases.

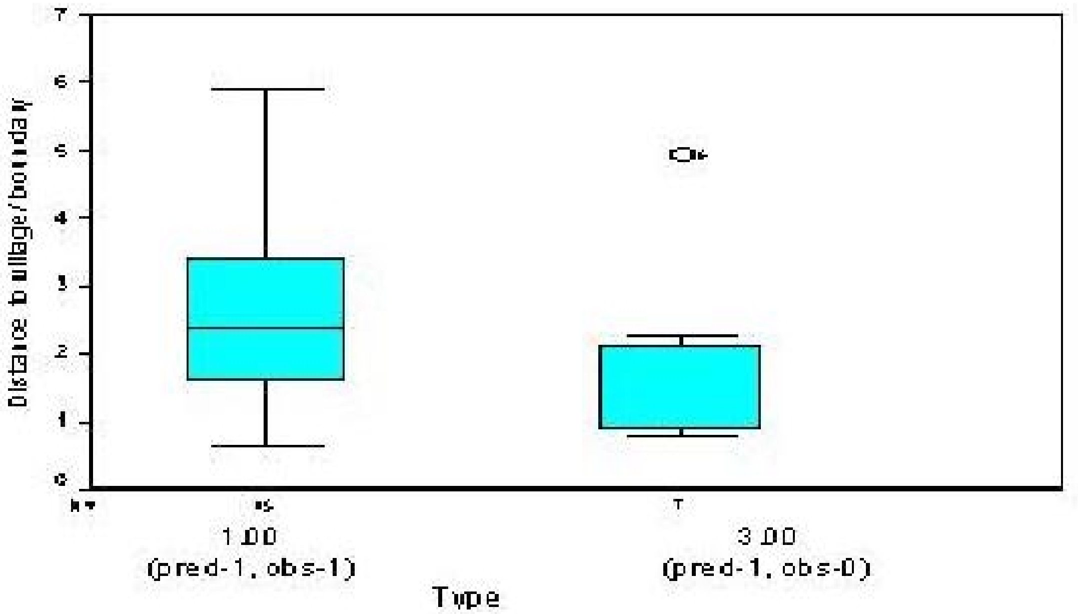


Fig. 6: Comparison of median distance to village for type-3 sambar cases with type-1 sambar cases.

Discussion

Density and Biomass

The high variances associated with the estimated mean densities are likely to be an outcome of the relatively low spatial replication in the sampling design. Most of the variance was seen to have been contributed by the encounter rate component of variance estimation, which captures the variance in the distribution of the animals. This was especially true for chital, which showed a highly clumped distribution within the study area. In addition the low encounter rates may also be expected to contribute considerably to the overall variance.

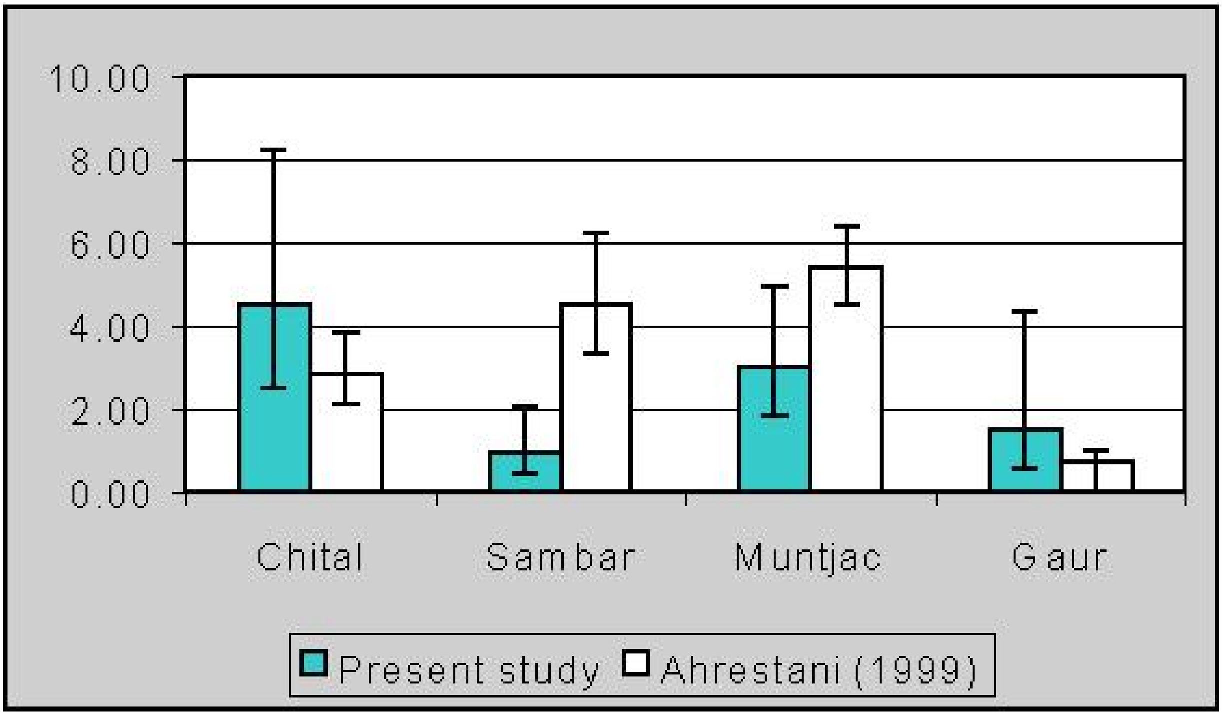
Extremely low sample sizes (number of detections) precluded the estimation of densities separately for habitat types or even for the two areas (Jagara valley and the Lakkavalli area).

A comparison of the density estimates derived in this study with those estimated earlier in Bhadra (Ahrestani 1999, Karanth and Nichols 2000) shows rather drastic differences (Table 8 and Fig. 7). The estimate for sambar, especially, requires some consideration. It is likely that the current sambar estimates are negatively biased, possibly due to evasive movements by the animals prior to detection, as was suggested by the initial examination of the sambar data by assigning small cut points to the distance intervals. For the other species as well, the point estimates from the two studies appear very different, but the large variances do not permit conclusions that the means really are significantly different. One problem that prevents a formal test to compare mean densities estimated by the two studies by looking at their variances is that the variance estimation was carried out differently by Ahrestani (1999). He treated each walk as a separate sample (as opposed to pooling data for all walks for a given transect), a procedure which underestimates the true variance. Therefore, the variances from the two studies are not comparable.

Another possible reason for the discrepancy may be related to the different seasons in which transect sampling was done in the two studies: in the earlier study, 90% of the transect data were collected in February (Ahrestani 1999), while data for the present study were collected in November. Not only is the visibility poorer (i.e. fewer detections), there is often a marked seasonal movement of animals into valley habitats from surrounding hills during the dry months (pers. obs., A. J. T. Johnsingh pers. comm), which may have led to the higher sambar and muntjac densities in the earlier study.

Whether the mean densities estimated in this study and the previous studies do really differ or not, that ungulate densities in Bhadra are extremely low is evident from a comparison with estimates from other parks (Table 9). Particularly, mean chital density is lower (for both studies) than that estimated in any other deciduous forest. Ahrestani (1999) attributes this to the habitat in Bhadra being unsuitable to chital, which are primarily grazers. This may well be true, but whether that is the only reason leading to the low chital densities is debatable.

Fig 7: Density estimates for ungulates in Bhadra from this and an earlier study



Muntjac densities are comparable to densities in sites such as Nagarahole. The estimate for sambar seems to be rather low compared to other parks, but because of the possible negative bias, it is difficult to comment on this, especially since the estimate from the earlier study was fairly high. Gaur densities, estimated at 1.4 km^{-2}, are very low, and even though the estimate itself is not very reliable, being based on only 17 detections, clearly gaur are yet to recover from the Rinderpest outbreak of 1989. The fact that wild pig were recorded only twice on the transect, while precluding any kind of population estimation, clearly indicates the low densities of this species, which is much favoured by local poachers, especially in the neighbouring coffee estates.

Location	Habitat	Method Used	Species			
			Chital	Sambar	Muntjak	Gaur
Bardia	MDF/ Tall grass floodplain	Strip Census	29.7- 33.9 (1440-1644)	----	1.7 (31)	----
Wilpattu	Scrub/ Monsoon Forest	Direct and Pellet Counts	12.09 (544)	1 (135)	0.44 (0.59)	----
Chitawan	Riverine forest/ Tall grass	Belt Transects	17.3 (951	2 (308)	6.7 (94)	----
Gir	DDF	Roadside counts	50.8	2.0	----	----
Sariska	DDF, Thorn forest	Line Transects (foot and vehicle)	30.7	15.0	----	----
Ranthambore	Semi-arid, DDF	Line Transects	38.4	10.7	----	----
Pench	DDF	Line Transects	51.3	9.6	----	0.7
Kanha	MDF	Line Transects	49.7	1.5	0.6	----
Bandipur	DDF	Line Transects	20.1	5.6	0.7	7.0
Nagarahole	MDF	Line Transects	50.6 (2379)	5.5 (736)	4.2 (78)	9.6 (4311)
$Bhadra_1$	MDF	Line Transects	2.8 (130)	4.5 (607)	5.4 (112)	0.7 (329)
$Bhadra_2$	MDF	Line Transects	4.5	0.93	3.01	1.48

Table 8: Comparison of ungulate densities estimated in this study with other studies. MDF- Moist Deciduous Forest, DDF- Dry Deciduous Forest. Figures in parentheses indicate estimated biomass densities in kg km^{-2}.

Sources: Bardia- Dinerstein 1980, Wilpattu- Eisenberg and Lockhart 1972, Chitawan- Seidensticker 1976, Gir- Khan and Vohra 1997, Sariska- Sankar 1994, Ranthambore- Kumar 2000, Pench, Kanha, Kaziranga, Bandipur, - Karanth and Nichols 2000, Nagarahole- Karanth and Sunquist 1992, $Bhadra_1$- Ahrestani (1999), $Bhadra_2$ - This study.

Habitat Occupancy

The results of this study broadly agree with earlier studies with regard to the habitat variables that are important in determining the distribution of different species. Chital occupancy patterns concur with other studies, which found that chital preferred flat areas with shrub cover and adequate water (Schaller 1967, Johnsingh 1983, Sankar 1994). Acharya's (1997) findings that chital distribution correlated positively with ground cover is also borne out by my results.

However, a surprising and anomalous result was that chital, sambar as well as muntjac occupancy were apparently *negatively* associated with grass cover, as indicated by the negative slope parameters. This is certainly incorrect (Schaller 1967, Sankar 1944, Acharya 1997) and could have resulted from the fact the habitat sampling was spread over the space of three months (February through April), during which period the grass cover changed considerably, especially after a few showers in mid-April. Therefore, the grass cover in points measured towards the later part of the study may have seemed greater simply because of the fresh sprouts, and may not have reflected the true grass availability at those sites when they were used (or not used, as the case may be) by the animals.

Sambar distribution, as expected from results of the earlier studies, was positively correlated with shrub cover and tree species richness. It is not clear why there was a negative correlation with number of seedlings, but the apparent negative relationship with grass cover may have been an artefact of the sampling, as described above.

Muntjac occupancy correlated positively with tree density, *B. arundinacea* density, number of seedlings and negatively with canopy cover and seedling species richness. The seeming avoidance for grass cover may have been as discussed above.

The model for gaur, based on only eight 'hits' (present plots), is certainly not very reliable. However, it is important to note that the only variable chosen from amongst the set of potential predictors was distance to water, which had a negative correlation. Schaller (1967) observed that availability of water was an important requirement for gaur.

Analysis using the predictions of the logistic regression models indicated that chital occupancy is negatively associated with proximity to either villages or boundary, and sambar presence, with villages only. It may seem counter-intuitive that chital, which is known to be a species of secondary habitats and mosaics, is adversely affected by habitation. However, several studies have shown that chital are often the most vulnerable to various types of disturbance. Mathai (1999) noted that chital were far more averse to disturbance than sambar and his results showed that they occurred only in undisturbed plateau areas in Panna. Khan's (1996) study showed that chital were being affected the most by the presence of cattle in Gir and showed the most dramatic increase (1320%) on removal of most of the cattle from the park. He attributed this sensitivity to the fact that chital, being largely a grazer, was in direct competition with cattle, unlike the other ungulates, which were also browsers and thus were not competing with cattle as intensely. Sankar (1994) also observed intense competition between buffaloes and chital in the dry months. In addition to competition for forage, both chital and cattle prefer flat areas (A. J. T. Johnsingh pers. comm). Thus presence of cattle not only depletes forage that would otherwise have been available to chital (exploitative competition), inter-specific behavioural mechanisms may also exclude chital from prime habitats occupied by cattle (interference competition).

Chital are also more vulnerable to other forms of disturbance. Madhusudan and Karanth's (in press) study showed that in sites which had even a nominal amount of protection, poaching by silent traditional means, such as snaring, were favoured over the use of guns. As a result, chital, which are easily hunted by these methods, were the most affected by poaching, unlike sambar and muntjac, which are most effectively hunted with guns. I believe that this is the situation in Bhadra, where the presence of the Forest Department does deter hunting with guns *within* the reserve. If traditional methods are in fact favoured, that may contribute to chital being scarcer near habitation. This, and the competition with cattle within the reserve, may also explain the relative scarcity of chital in Bhadra, which may not just be the result of unsuitable habitat, as suggested by Ahrestani (1999).

Sambar, also being averse to disturbance (Johnsingh 1983, Sankar 1994), were found to be adversely affected by proximity to villages. However, muntjac did not show such patterns. The gaur analysis is not strong enough to draw inferences from.

A few caveats may be in order at this point. In a site where disturbance may play a significant role in determining ungulate distribution, looking at habitat factors that are important for the species may not be very meaningful, for which reason I have not placed much emphasis on the habitat variables important for my study species, considering instead the strength of the relationships between these variables and ungulate occupancy. The inability to separate out the effects of different types of human impacts restricts the kind of conclusions we can draw from the data. Though it may be valid to consider the lack of a strong relationship between habitat variables and ungulate occupancy as possible evidence of the importance of confounding factors such as anthropogenic disturbance (a conclusion further confirmed by the absence of animals in suitable sites close to villages), certain human impacts (e.g. poaching) may not actually show spatial patterns. Even if the removal of animals itself is highly localized and is indeed strongly associated with proximity to habitation, the visible effects may be confounded by animal movement. If animals constantly move into sites from which others have recently been removed, the effect may be of uniformly thinning the density all over the area, rather than forming gradients of density; the extent to which this may occur is some (unknown) function of the mobility of the species as well as the ability to take over newly unoccupied sites.

Though distance to village/ boundary was not among the set of independent variables to predict presence or absence of any of the study species, subsequent analyses did indicate that chital and sambar are affected negatively by habitation. The initial rejection of distance to village/ boundary as a predictor variable may mean either of two things: that ungulate distribution is not significantly affected by disturbance, or that distance is a poor surrogate for the actual intensity of human disturbances. A negative result in such a case may either occur from lack of effect or lack of power, and without being able to decide which is the case, one must be careful not to conclude that there is no effect.

Conclusions

Having looked at ecological densities of ungulates in Bhadra Tiger Reserve, and their distribution in relation to habitat and disturbance gradients, what take-home message are we left with? Results from the present study draw our attention to two important facts: that ungulate densities in Bhadra are precariously low, and that human impacts do have significant negative effects on the distribution of ungulates. It is but natural to link the two together. It is very likely that the first point is a natural consequence of the second.

An important point to note is that it is not just the proximity to villages that is restricting ungulate distribution but, in the case of chital, the proximity to the reserve boundary as well. Clearly, villages within the reserve do affect ungulates negatively, but pressures from the surrounding coffee estates also have a considerable influence on the reserve's wildlife. What this means in terms of managing the habitat for ungulates is that it would not suffice to simply move the villages out, continued efforts will be required to minimise pressures from the surrounding areas.

Besides reiterating the need for effective protection of both the habitat as well as the wildlife in Bhadra, I would like to stress the need for continued monitoring of ungulate populations. While the present study does indicate the adverse effects humans have on ungulate populations even within the tiger reserve, conclusive evidence can only come from following and recording population recoveries subsequent to removal of human pressures, as was seen in Nagarahole (Karanth and Sunquist 1992) and Gir (Khan 1996).

The proposed rehabilitation programme provides a unique opportunity to track such changes over a period of several years. The results of this study, and the kind of changes in the habitat that have been seen subsequent to rehabilitation of settlements in other reserves, indicate that chital, especially, may be expected to benefit from the removal of anthropogenic pressures over a period of time, and it would be extremely interesting to see if this really does happen. However, considering the low ungulate densities and, consequently, low sample sizes, future monitoring programmes need to consider issues such as increased effort, increased spatial replication as well as sampling in a suitable season to ensure collection of data that will help us make reliable inferences regarding the health of the system.

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