

*Nutritional Ecology of
Asian Elephants (*Elephas maximus*)
in
Chilla Range of
Rajaji National Park, Uttarakhand*

Dissertation submitted to Saurashtra University, Rajkot, in
partial fulfilment of the Master of Science Degree in Wildlife
Science

By

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CERTIFICATE

This is to certify that Mr. Suniti Bhushan Datta of the Wildlife Institute of India has carried out original research titled, "Nutritional Ecology of Asian Elephant (*Elephas maximus*) in Chilla Range of Rajaji National Park, Uttarakhand", in partial fulfilment of Master of Science (Wildlife Science) Degree from Saurashtra University, Rajkot. These investigations were carried out under our supervision at the Wildlife Institute of India from November 2008 to June 2009.

We also certify that this work has not been submitted for any other degree of any other university.

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Please be caring and kind to me, or else beware of my fury.'

Inscription on the entry gate to Tholpetty Sanctaury,
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Summary

Responses of animals to the habitat has been the central focus for management of species and of these aspects, nutritional ecology has been the key issue in foraging behaviour studies and habitat studies.

Therefore, the study focused on the nutritional aspect of forage selection by Asian elephants (*Elephas maximus*) in Chilla Range of Rajaji National Park. The main objectives were to determine whether habitat structural heterogeneity or nutritional quality of the selected food plant species was a determinant in the temporal and spatial habitat use by elephants and to determine the reasons behind seasonality in foraging.

The study area of 148km² in Chilla Range of Rajaji National Park was divided into twelve 2x2km grids, and these were further divided into 4 sub-grids each. In each sub-grid, a 1km long line transect was laid and along this 10m radial plots were placed at 100m intervals. Vegetation data were collected to characterize the habitat structural heterogeneity in terms of number of trees of each species, height of canopy base, canopy volume, percent canopy cover, species diversity, species density and geo-spatial variables such as NDVI, standard deviation of slope, mean elevation and the proximity to water. Parts of 12 most-preferred plant species were collected in the study areas for estimating nitrogen, ash, acid detergent fibre, and macro and micro minerals such as sodium, potassium, calcium, copper, magnesium and zinc. During the study period from December 2008 to May 2009, Elephant response was determined in terms of dung density along the 1km transect in winter and in summer.

The total number of trees in each grid varied from 124 to 268. Tree diversity ranged between 0.456-1.454. Height of canopy base was mostly 1.5-3.0 m, although two grids showed extremely high canopy bases. Canopy volume ranged from 165.63m³ to 948.36m³, although the majority of the grids showed a high variation in canopy volume in terms of standard deviation (SE). The percent canopy cover ranged from 54.13% to 93.72%. Most of the NDVI values were high in the study area (>0.180), while one grid showed a low value of 0.143. For the standard deviation of slope, the values ranged from a low of 2.46 to a high of 8.46. The mean elevation of the study area ranged from 391-840m a.s.l.

Nutritional values estimated for most of the parameters in winter and summer from selected plant samples collected in the study area showed slight variations

between seasons. Percent nitrogen content indicated no seasonal difference ($P=0.98$, $p=0.05$, $df=11$). The percent acid detergent fibre indicated a difference ($P<0.05$, $df=11$) between the two seasons. Percent ash content was found not significantly different ($P=0.16$, $p=0.05$, $df=11$) between seasons. Amongst the macro and micro minerals, sodium content was significantly different across the two seasons. Potassium content was found to be significantly different across the seasons ($P<0.05$). Calcium content was also found to be significantly different between winter and summer ($P<0.05$). The copper content could not be compared across the seasons as in summer the levels present in plant samples were too low to be detected by the instrument. The difference in magnesium and zinc content across the two seasons were not significant ($P=0.16$ and $P=0.31$).

Dung density in the grids across both seasons was non-uniform and highly skewed ($P<0.05$, $df=47$). The dung densities in both seasons were related more with the habitat heterogeneity variables than nutritional values obtained in each grid. The relationship between dung density and the number of plants was positive in the winter seasons ($R^2= 0.2848$) and summer ($R^2= 0.4383$), indicating that elephants are highly selective towards areas with higher numbers of woody plants. Plant species diversity indicated no influence on dung density in winter ($R^2= 0.00005$), but showed a negative trend in summer ($R^2= 0.0154$). The height of canopy base was negatively related to dung density, with elephants selecting areas with a mean canopy base height between 1.5-3.0m during both winter ($R^2=0.2288$) and summer ($R^2=0.174$). Dung density showed a negative trend when related to canopy volume in both seasons, the R^2 value for winter is 0.2087 and in summer it is 0.1471. Percent canopy cover had a negative influence on the dung densities in winter ($R^2= 0.083$) and in summer ($R^2= 0.1524$). NDVI showed a negative relationship with dung densities in winter ($R^2=0.0111$) and a positive relationship in summer ($R^2= 0.1894$). The relationship between the standard deviation of slope and dung density showed a negative trend in both winter, ($R^2=0.0033$) as well as in summer ($R^2=0.0389$). The higher elevation grids show a lower dung density during both winter ($R^2=0.216$) and summer ($R^2=0.1443$). The relationship between dung density and proximity to water in winter is negative ($R^2=0.1575$) and the relationship remains negative ($R^2=0.1016$) in summer.

In relation to nitrogen content and dung density in winter there was a weak positive trend ($R^2=0.0256$), while in summer there was a weak negative trend

($R^2=0.032$). The relationship between dung densities and percent acid detergent fibre (ADF) in winter indicated a weak positive trend ($R^2=0.0012$) and during summer, indicated a weak negative trend ($R^2=0.0657$). In relation to percentage ash content (Fig. 4.29.), dung densities in winter indicated a weak positive trend ($R^2=0.0114$), while in summer there was a weak negative trend ($R^2=0.0641$). When compared with sodium, dung densities showed a very weak positive trend ($R^2=0.0092$) in winter and a negative trend in summer ($R^2=0.0834$). In winter, when compared with dung densities potassium showed no trend ($R^2=0.001$), but in summer, there was a weak negative trend ($R^2=0.0076$). In winter, calcium does not show any relationship with dung densities ($R^2=0.0002$), while in summer, there is a weak negative trend ($R^2=0.0511$). Magnesium content does not show any relationship with dung densities (Fig 4.33) in the winter season, ($R^2=0.0007$), while in summer, there is a weak negative trend ($R^2=0.004$). Zinc shows a weak positive trend ($R^2=0.0298$) in winter and a weak negative trend ($R^2=0.026$) in summer. Principal component analysis of nutritional parameters indicated nine components that were influencing dung density distribution in the study area in both the seasons, and hence no single parameter influenced elephant habitat use.

The study clearly indicates that the distribution of elephants in Chilla Range of Rajaji National Park is more related to abundance of woody species and proximity of water, than the nutritional content in plant species. Principal component analysis showed that there was no single parameter that influenced dung distribution in the study area. This could be due to the fact that plant species selected for foraging by elephants contained an adequate amount of nutrients in most species for meeting foraging requirements and they probably meet their daily requirements by foraging on varied proportions of plant species.

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CHAPTER 1.0. INTRODUCTION

1.1. Megaherbivores

Eight living species of terrestrial mammals fall into the megaherbivore category in terms of maximum body size attained. The consumptive demands of megaherbivores have a greater impact on vegetation than that of other herbivore species in a community, while they exert additional impact through breakage and trampling. Megaherbivores do not compete directly to any significant extent with other large herbivores. However, the vegetation changes that they induce may affect other herbivore species (Owen-Smith 1988).

Among megaherbivores, the evolution of elephants and related forms, collectively known as proboscideans, is one of the better recorded tales of mammalian evolution. Since its origin in the late Paleocene Epoch, some 60 million years ago, the order Proboscidea witnessed a spectacular radiation until the end of the Pleistocene Epoch, about 10,000 years ago. The evolutionary course of the proboscideans was marked by an overall increase in body size, also took many seemingly bizarre paths, including extreme dwarfism and morphologies that only the most daring palaeontologist could have otherwise imagined (Sukumar 2003). Of the over 30 species of elephant that ever existed, the African (*Loxodonta africana*) and Asian (*Elephas maximus*), still survive. In recent years, two additional species have been recognised from the earlier known two species, the African Forest Elephant (*Loxodonta cyclotis*) and the Borneo Pygmy Elephant (*Elephas borneensis*) (Roca *et al* 2001, Fernando *et al* 2003). The Asian elephant is sometimes called the Indian elephant, but this name obscures its wide distribution throughout tropical Asia.

Probably the most well-known among the wild animals of India is the Asian elephant. Only a small fraction of the population of over 900 million Indians may have seen it in the wild, but almost everyone has seen domesticated ones at sometime or other (Daniel 1998). It would be hard to find a more charismatic flagship species than the Asian elephant, *Elephas maximus*, which is identified by people across the length and breadth of the Indian subcontinent either as a conservation challenge, a cultural icon or as a pest (Christy *et al* 2005).

The elephant, the largest terrestrial mammal in Asia once ranged widely from the Tigris-Euphrates river system, throughout Asia south of the Himalayas, east to China. Today the distribution of Asian Elephant covers only a fraction of its former extensive range, and includes 13 countries from the Indian subcontinent in the west to Indo-China in the east. Asian elephants in the wild inhabit a land area of about 439,000 km², of which 132,000 km² (30%) are protected. Also, many populations are highly fragmented and endangered and optimistic estimates indicate that only eight populations of Asian elephants have more than 1000+ individuals in a contiguous area (Christy *et al* 2005). The Asian elephant today ranges over a wide spectrum of habitat types; hence its conservation can be integrated with the conservation of biological diversity (Sukumar 19892)

1.2. Introduction to Nutritional Ecology

Among the different aspects of ecology, nutritional ecology has been a major focus because animals continually interact with their environment for meeting their day-to-day food requirements. Forages consist of a proportion of cell contents which are wholly or largely digestible (Illius & Gordon 1992). The process of finding and harvesting food dominates the lives of mammalian herbivores. The rates of food

consumption by herbivores determine how much time they must invest in feeding to meet their metabolic requirements of energy and nutrients (Shipley *et al* 1994). The diet of a herbivore is influenced by the various anatomical and physiological characteristics of the animal, the structural and chemical constitution of the plants, and the community structure (Owen-Smith 1982). Herbivores have long been known to demonstrate preferences for different plant species and individual plants within a species. Also, the average food plant quality (i.e., protein, sugars) selected by different herbivores has been shown to be greater than the average found in the environment (Belovsky 1981). Food selection can take two main forms- plant species (quantity) and plant-parts (quality). Selection of plant species results in a characteristic composition of a species diet in a particular habitat, while the selection of plant-parts appears to be aimed at obtaining the component with the highest nutritive value in the plant (Leuthold 1977). Evolution of herbivores has followed that of plants and plant interactions with the animals. Many plants have utilized animal vectors for seed dispersal, while maintaining some quality as feed either as forage, seeds or fruit. However, plants also have evolved protection mechanisms against animals that lower availability of forage (Van Soest 1996). The delineation of elephant reserves has benefited greatly from past studies where the location of populations and the extent of available habitat for each population have been determined with some accuracy (Venkatraman *et al* 2002). The foundation of any wildlife habitat management plan is the ability to assess habitat quality accurately (Van Horne 1983).

1.3. Feeding Ecology of Elephants

The feeding ecology of the largest land mammals has attracted much attention, not only for the sheer quantity of food consumed, but also the variety of plants

selected and their impact on vegetation (Sukumar 2003). It is often mentioned that elephants are generalist feeders because they consume a wide variety of plants and plant parts. Many fossil forms of Proboscideans have been described which show a very extensive adaptive radiation, some being clearly very specialized (Sukumar 2003). The living species are relatively unspecialized in their ecology, but are essentially forest, woodland or bush and grassland forms. This is most evident in the case of the Asian elephant (*Elephas maximus*) and the forest race of *Loxodonta africana* (Eltringham 1977). While this is true when we compare the elephant to a specialized grazer or a frugivorous animal, the elephant also exercises considerable choice in the type of food it eats both on a short-term as well as on a seasonal basis. Feeding behaviour in the short-to-medium term of days or a few weeks essentially involves food selection within one or a few vegetation communities, while the seasonal changes in diet may involve complete shifts to different vegetation communities (Sukumar 2003). An elephant, when feeding, seldom spends much time feeding on one particular plant species (McKay 1973)

It is generally assumed that in the absence of hunting / poaching, habitat with high animal densities (i.e. highly selected habitat) is high quality habitat, and low densities indicate low quality habitat and that animal populations respond positively to the availability of highly selected habitat types (Railsback *et al* 2003). Elephants will choose the food that offers the highest rate of nutrient intake at any given place or time (Osborn 2004). It would appear that under optimal conditions, both species, *Loxodonta* as well as *Elephas*, show variability in their diet, taking both herbaceous and woody material (McKay 1973). Another study of an African megaherbivore, indicates that the Cape buffalo (*Syncerus caffer*) in Kruger National Park, South Africa range more widely to meet their daily foraging needs when forage quality is

low. Buffalo appear to forage in higher-quality areas when they are on granite, a substrate that is on average, lower quality than basalt. This result, when combined with the smaller average home range sizes on granite, suggests that buffalo are more selective foragers when they are on granite than when they are on basalt (Winnie *et al* 2006). The overall picture is that elephants have the capacity for wide roaming, opportunistic and flexible behaviour (Sukumar, 1989; Williams, 2001)

1.4. Habitat Quality

Habitat quality can conceptually be described as a measure of mean individual "fitness" per unit area. "Fitness" is as implied here is in a management rather than an evolutionary context, wherein it describes a mean group characteristic in a given habitat as compared to other habitats, rather than comparing an individual in a given population to other individuals of the population. The measure of habitat quality thus has components of density, offspring production, and survival. High density alone does not infer quality habitat. To give an extreme example, one could imagine a habitat in which all animals were immigrants and none emigrated or reproduced. The quality of such a habitat would be zero (Van Horne 1983).

1.5. Food Selection by Elephants

The diet of a herbivore is influenced by the various anatomical and physiological characteristics of the animal, the structural and chemical constitution of the plants, and the community structure (Owen-Smith 1982). In one of the early studies of elephants feeding, Peter Guy followed elephants at Sengwa in Zimbabwe in 1966, recording in detail the plants they ate and quantities consumed. In addition, he estimated tree densities and canopy volume to measure availability of potential food plants. Using this data, he calculated three indices of plant selectivity by elephants-

viz; based on tree canopy volumes, tree densities, and combining the two measures plus also factoring in plant availability below 6m height (the maximum reach of an elephant) (Sukumar 2003). Elephants are known to utilize a wide range of species when available, relying heavily on graminoids in the wet season and almost exclusively on woody browse during the dry season (Barnes 1996). In Sri Lanka's Gal Oya National Park, elephants spent the maximum time feeding on short grasses during the dry season (April-May) and post monsoon (July-August). While elephants invariably need large quantities of forage daily, most descriptions of elephant spatial foraging patterns have been limited to the substantial vegetation impacts observed in terms of broken trees within close vicinity to river fronts and other water sources during the dry season (Eltringham 1980), or to assessments of the diversity in diet composition within and between seasons (Barnes 1982, Nelleman *et al* 2002). It is well known that elephants prefer feeding on crops to wild forage because of the greater nutritive content and palatability of crops (Sukumar 1990). Since humans have selected their food crops primarily on considerations of sensory quality, digestibility, absence of toxins, productivity and, in recent times, for their nutritive value, it is not surprising that many such crops are also attractive to elephants especially as they are analogous to their wild counterparts. Degradation of the natural habitat is often mentioned as the primary cause of crop raiding. Here, the term degradation is used to describe any exploitation of the habitat that reduces the elephant's food resources. A qualitative ranking of habitat types around the villages when compared with the intensity of raiding showed no clear pattern (Sukumar 1989b). At the overall level, the strategy of habitat utilization conforms to the predictions of optimal foraging theory. However, elephants need not just food but also water in large quantities. Their

movement would also be governed by the spatial distribution and temporal availability of water (Sukumar 1989a)

A nutritional analysis of food plant species was carried out in Southern India (Sukumar 1989b). Important wild and cultivated food plants were analysed for crude protein by the standard Kjeldahl method and ashed samples for calcium, sodium, magnesium and iron by an atomic absorption spectrometer (Sukumar 1989b). Food quality estimates for elephants in South India indicates that crude protein content of browse leaves was found to be 6.0-18.0% in the dry season and 13-25% in the wet season and was generally higher than that of wild grass leaves (3.2-4.8% dry season, 6.8-9.9% wet season). Calcium content was lower in plants of the family Graminae (0.8-10.8 mg g⁻¹) than in other families (17.7-52.2 mg g⁻¹). Iron content was more variable, 0.03-0.48 mg g⁻¹. Sodium (0.11-0.36 mg g⁻¹) and Magnesium (0.53-2.12 mg g⁻¹) did not vary much in most plants (Sukumar 1989b). Analysis of stomach contents of African Elephants revealed that the amount of crude protein in the diet varied between 3.5-12.0% (Hudson & White, 1985)

The examination of the stomach contents revealed 25 plant species in the diet of African elephant (Buss 1961). Similar examination by B.R. Williamson of African Elephants identified 61 browse species (cited in Sukumar 2003). In Maputo Elephant Reserve, Mozambique, a total of 95 different plant species were identified in faecal samples. The percentage of grass was relatively low compared with other studies, increasing at the beginning of the rainy season. At the end of the dry season, elephants concentrated on the few available browse species with young leaves, but generally preferred grass species to browse species. Diet composition was mainly affected by season and less by habitat (De Boer & Douglas-Hamilton 2000). During the dry season, elephants in the Wet Zone of Sri Lanka did not show a preference to browse

(Iswaran 1993). In the case of grass, intake rates are higher (it is easier to harvest and handle), it is lower in toxins and when its nutrient content is high, its fibre content low (Lindsay, 1994). It also provides a return per unit time feeding that is higher than browse. It may, however, lack certain essential key nutrients and when it matures, its nutrient content becomes very low. Browse offers generally higher levels and diversity of nutrients, but toxin and lignin levels are also higher (Jachmann, 1989). Elephant damage to woody vegetation was positively correlated with leaf calcium, magnesium, potassium and protein concentration, but not with sodium, phosphorus or fibre (Holdø 2002). In addition bark and woody twigs require more handling time, especially when they are lignified or have thorns (Osborn 2004).

The selection of tall grasses by elephants is related to their phenophase and palatability (Field 1976). Heterogeneity in resource quality, coupled with adaptive response in diet selection, will cause the form of nutritional gain response to deviate from that of intake response. The form of gain response depends moreover on the extent to which digestive capacity is limiting (Owen-Smith 1988). Ultimately, the diet should provide all the nutrient requirements of the animal (Sukumar 1989²). Ungulates show a positive selection of plant species and plant parts with the highest protein value (Field 1976), or minerals such as sodium (Belovsky 1981). Some authors have put forth the assumption that the elephant increases the availability of its food by breaking or uprooting trees. The preferred habitat of the elephants being secondary forest (Eltringham 1977), opening the vegetation cover would be beneficial to them. In addition, it is stated that elephants browsing in tree-fall gaps often maintain the shrubby and herbaceous vegetation growth in a productive state, which is advantageous to browsing ungulates (Barnes 1996). The damage caused by elephants to the vegetation cover therefore has an indirect effect on other ungulate populations,

which has considerable implications for management authorities. From a spatial point of view, one can thus expect most severe damage in the densest zones of wooded savannah (Calenge *et al* 2002).

The elephant is a versatile feeder when it comes to handling various plant parts. In a study on Interview Island, Andaman and Nicobar, several species of trees were found debarked that were not recorded as eaten earlier (Ali 2000). Taking foliage from shrubs and trees is the most common way of feeding, contributing nourishment in the form of leaves, bark and fruits. Although fresh foliage is preferred, dry twigs and branches may be consumed in the dry season. Consumption of fruits is seasonal and elephants may spend long periods of time near a fruiting tree. (Sukumar 2003). Numerous studies on the feeding habits of African and Asian Elephants have shown that proportions of various food-plant categories in the diet vary widely from one region to another. A feeding pattern established for one area cannot be extrapolated to another area. Selection of forage by African Elephants according to tree species has been reported by several authors in other national parks (Laws 1970). Likewise, the intensity of damage by elephants has been found to vary among species. Most studies have shown that elephants cause slight damage to short trees more often than expected by chance (Caughley 1976, Laws 1970) and push over large trees from which leaves could not be reached (Caughley 1976). In small home ranges, elephants may use specific parts of their ranges more intensely than in large home ranges and therefore impact may be more intense. Thus, it may be more appropriate to define elephant impact in terms of range utilization functions or densities rather than population numbers *per se* (Junkers *et al* 2008). Other authors have stressed the importance of the proximity of water points in determining elephant damage. In the zones close to water, both the frequency and severity of the damage are generally

considerable (Calenge 2002). Presence of water is often the best predictor for elephants, especially for females, and particularly during dry seasons and in dry areas. This limits elephants to permanent water sources, including artificial water holes, in the dry season. If it is close enough to water an elephant seeks areas with high vegetation cover. Proximity to water is not merely the most important variable but the one that managers can more easily control (Harris *et al* 2008). It would appear then that under optimal conditions, both species show variability in their diet, taking both herbaceous and woody materials. These factors are of great importance for any consideration in conservation of the elephant (McKay 1973).

Elephants operate at the broad scale of plant and forest regeneration, though at finer scales, most plants can do without them. Elephants certainly have a profound influence on forest structure—they tend to make gaps and keep forest open, by trampling and debarking (Hawthorne & Parren 2000). Savanna elephants, *Loxodonta africana africana* are known to migrate according to vegetation changes (Vanleeuwe 1998). The proximate factor that influences the decision to consume or reject a plant is the palatability of the item as conveyed to the herbivore through the senses of smell, taste, sight and touch. The selection of dietary items obviously depends to a large degree on what is available. In the process of consuming an ideal diet from a natural environment, an elephant has to select from a changing mosaic of different plant species, phenological stages, structural types, chemical compositions, relative or absolute abundances and dispersion patterns (Sukumar 2003). On a daily scale, intake rates are limited by digestion and excretion, and the amount of time invested for foraging. On a finer scale, consumption rates are influenced by the morphological properties and spatial distribution of plants (Shipley *et al* 1994).

1.1.6 Elephant feeding studies in Asia

A study at Bardia National Park, Nepal, determined that major food tree species found to be eaten by Asian Elephants were *Mallotus philippinensis*, *Desmodium oojeinense* [syn. *Ougenia oojeinensis*] and *Dalbergia sissoo*. (Prajapati 2007). In a comparison with Rhino diets in the same region, elephants were observed in the study area feeding on wood and bark of *Acacia catechu* and bark from *Bombax ceiba* (Stenheim *et al* 2005). This was also confirmed by large, easily identifiable remnants in the fresh elephant dung, and signs of debarking on a number of these trees. Investigations revealed that the most preferred food tree species were *M. philippinensis* (61.54%) followed by *D. oojeinense* (30.77%) and *Dalbergia sissoo* (7.69%). In the Cat Tien National Park, Vietnam, elephants fed on at least 26 species of plants, both wild and cultivated. Of these, stems of 11 species, roots of 7, fruits of 4, and bark of 2 were eaten (Varma *et al* 2008). Supporting tissues such as stems, twigs, wood, roots and bark tend to be high in indigestible fibre, while fruits contain stores of soluble carbohydrates and leaves contain photosynthetic enzymes and are high in protein and minerals. In Kibale National Park, Uganda elephants fed on a diversity of plant items including leaves, floral structures, fruits, twigs, pith, roots, rhizomes, bark and wood. Twigs, flowers, young and mature leaves each made up 33.5, 0.9, 28.7 and 28.5% by frequency of elephant diet respectively (Chiyo *et al* 2005). The elephants did not exclusively consume the leaves of any plant species but these were consumed along with the stem, shoots or fruits. Grass dominated (57.7%) the diet, followed by cashew fruits (32.3%), rattan (5.8%) and bamboo (4.1%) (Varma *et al* 2008). In Rajaji National Park, 38 food plant species were recorded based on direct observations, of which 88% consisted of browse. *Mallotus philippensis* contributed to a major portion of the diet and was fed upon in all seasons. 50% of the

elephants' diet was constituted by six species, viz., - *M. philippensis*, *Ehretia laevis*, *Acacia catechu*, *Dalbergia sissoo*, *Ougenia oogenensis* and *Shorea robusta* (Christy *et al* 2005).

1.7. Nutritional Values

Biologically regulated whole-ecosystem stores and fluxes of elements and compounds, such as phosphorus, nitrogen, and carbon, are simply the sums of the stores and fluxes of the constituent organisms (Brown *et al* 2004). Micro-nutrients have been found to influence food selection by herbivores (Belovsky 1978). Digestion inhibitors consist of fibres and tannin. There is no doubt that fibre (often measured as Acid Detergent Fibre (ADF) is a major deterrent in food selection (Mole & Waterman 1987). The nitrogen content of a plant is only one of the many plant characteristics that are vitally important to herbivores. However, because of its central role in all metabolic processes as well as in cellular structure and genetic coding, nitrogen is a critical element in the growth of all organisms (Mattson 1980). Sodium requirements of elephants have not been directly measured, but rough estimates are possible if extrapolations are made from information available for other species. Daily sodium requirements for mammals vary iso-metrically with body mass (Holdø 2002). The elephant's strategy of alternating seasonally between grass and browse is related to the plant's protein content. Elephant' feeding on bark is not yet fully understood. Considerable amounts of bark were consumed during the dry season in southern India, while much less was observed in the wet season. The calcium content of dicotyledon bark is much higher (18-57mg/g) than grasses (1-5mg/g) (Sukumar 1989b). Although a diet of grasses alone could provide elephants with a sufficient intake of calcium, it is not known how much is physiologically unavailable. Supplementing the diet with

bark could increase calcium intake to a safe level. Bark may serve more than one purpose in an elephant's diet (Sukumar 1989b).

1.8. Context of the Study

In caricature, elephants prefer to move little, eat well, drink easily, and avoid people. If more space is made available for them, they will probably disperse to areas near water, with high vegetation cover, and relatively distant from humans. ^{The WL} Managers can make water accessible, but should anticipate high impacts on the vegetation nearby. As may be expected for such generalized feeders, that vegetation involves a wide variety of habitats (Harris *et al*). Wildlife managers managing large mammals such as elephants need access to information on their population densities, demographic data, distribution and their effect on vegetation. It is important to understand where the elephants are distributed in an area of interest, and the factors influencing the distribution. Knowledge of the distribution patterns becomes invaluable if there are distinct seasonal ranges. For example, the vegetation in a given area may be heavily damaged during the dry season because availability of water may be restricted to that area, resulting in high elephant use. Information on elephants, such as that given above, would assist wildlife managers in making informed management decisions (Christy *et al* 2005).

The Rajaji National Park and the adjoining forests host the northwest Indian elephant population and have been designated one of 11 elephant reserves in India (Singh 1995). While there have been many popular and scientific articles published on elephants in Rajaji National Park (Christy *et al* 2005), including on habitat utilisation, but none have focussed on foraging with respect to the nutritional aspect of food plants selected. Such information is important in understanding elephant-habitat interactions.

1.9 Objectives and Hypotheses

Objectives

- Determine the factors behind seasonality in food preferences between winter and summer.
- To determine how nutritional value of food species of woody plant influences elephant habitat use

Hypotheses

➤ Hypothesis 1:

Habitat quality and heterogeneity influence habitat use by elephants.

Questions

- Does the heterogeneity of the habitat influence its use by elephants?
- Does the quality of the habitat influence its use by elephants?
- Do both habitat quality and heterogeneity influence its use by elephants?

➤ Hypothesis 2:

Nutrient quality of selected food species varies across seasons

Questions

- Does the nutrient quality of selected food species differ between winter and summer in terms of crude protein, sodium, potassium, calcium, copper, magnesium, zinc, percentage ash and acid detergent fibre.
- How is the seasonal shift in the dietary profile of elephants compensated for by the nutrient quality of forage?

2.0. THE STUDY AREA

2.1 Location and Topography

The study was carried out in the Shivalik zone of northern India that lies in the sub-Himalayan tract. It forms a linear stretch of forested tract along the foothills of Uttarakhand state. This tract encompasses two protected areas, Rajaji National Park (proposed) and Corbett National Park & Tiger Reserve, and the Forest Divisions of Shiwalik, Dehra Dun and Landsdowne (Fig 2.1). The region is bounded by the extensively cultivated Upper Gangetic Plains in the south, river Yamuna in the West and river Kosi in the east. Biogeographically, the study area lies in Zone 7, the Upper Gangetic Plains, however, much of the area forms the transitional zone between the Western Himalayas and the Gangetic Plains (WII 2005, Rodgers & Panwar 1988)

The Rajaji National Park (820 km²) is divided by the Ganges into an eastern part comprising of Chilla and Gohri Ranges, and Motichur, Haridwar, Dholkhand East and West, Kansrao and Chillawali Ranges on the western side. This Protected Area is one of 11 designated elephant reserves in the country. It is situated in the *bhabar* tract of northern India. The altitude ranges from 400m – 1,300m. The Eastern and Western part of the Park are connected by the narrow Chilla – Motichur corridor (Johnsingh *et al.*, 1990).

Rajaji National Park and adjoining forested areas to the west up to River Yamuna forms the Northern-most limit in India for the ranges of the Tiger, Asian elephant, Great hornbill and King cobra (Ravi 2008).

The Intensive Study Area (ISA) selected for the present study and having an area of c.148km², lies at the junction of the Shivalik hills and the outer Himalayas, East of the Ganges, covering Chilla Range (29° 54" N to 30° 00" N and 77° 50" E to 78° 16" E) of Rajaji National Park. The range is bounded to the South by Shyampur

Range of Haridwar Forest Division and to the North by Pauri Forest Division. The area to the east comes under Lansdowne Forest Division, which forms a part of the important Rajaji-Corbett Elephant Corridor (Christy *et al* 2005).

The study area is characterised by a rugged terrain consist of hills ranging from 400m to 1300m in height. These are drained by several perennial and non-perennial rivulets and streams, known locally as *raus* and *sots*, respectively (Christy *et al* 2005).

The river Ganges forms the western boundary of Chilla (Banerjee 2006). There are three sub-basins of the Ganga within this range, Mundal, Ghasiram and Mithawali *raus* and associated non-perennial streams. Apart from these watercourses, several waterholes have been dug by the Forest Department to provide water for animals during the hot and dry summer months.

2.2 Climate

The region experiences three distinct seasons, *viz.*, winter, summer and monsoon. The period from November to February is the winter season, characterised by a minimum temperature of 3-5°C. There is minimal rainfall during the months of January and February. The summer season lasts from April to mid-June and is hot and dry with maximum temperatures reaching 44°C. Most watercourses dry up during this season and there are occasional thundershowers, usually during the months of March and April. The Monsoon season lasts from July till September. The mean annual rainfall is 1,600-1,800mm (WII 2005)

2.3 Flora

vegetation

The vegetation of the region is broadly classed under the Champion & Seth (1968) Classification into Moist Siwalik Sal Forest (3C/C2a), Moist Bhabar Sal Forest

(3C/C2b), Northern Secondary Moist Mixed Deciduous Forest (3C/C3/2S1), Khair-Sissoo Forest (5/1S2), Dry Sal-bearing Forest (5B/C1a) and Lower Shiwalik Chir Pine Forest (9/C1a) (Champion & Seth 1968). The region consists mostly of Sal mixed forest comprising of *Shorea robusta*, *Mallotus philippensis*, *Terminalia tomentosa*, *Ehretia laevis*, *Cordia dichotoma* and *Holharenna antidysenterica*. *Shorea robusta* is the dominant species on the northern slopes. There are also tracts of mixed forest comprising of *Bombax ceiba*, *Anogeissus latifolia*, *Ficus* spp., *Kydia calycina*, *Diospyros cordifolia*, *D. melanoxylon*, *Aegle marmelos*, *Limonia acidissima* and *Cassia fistula*. Riverine tracts of forest consist of *Zizyphus mauritiana*, *Z. xylopyrus*, *Dalbergia sissoo* and *Syzigium cuminii*. The hilly regions consist of mostly *Shorea robusta*, *Terminalia tomentosa*, *Mallotus philippensis*, *Ougenia oojenensis*, *Lannea coromandelica* and *Pinus roxburgii*. The hilly regions also have patches of *Dendrocalamus strictus*. Other grasses in the region consist of *Saccharum* spp., *Vetiveria zizanioides*, *Heteropogon contortus*, *Themeda arundinaria*, *Eulaliopsis binata*, *Cymbopogon* spp, Chrysopogon spp., and others (WII 2005).

2.4 Fauna

The region has a rich and diverse faunal assemblage. Important herbivores of this region include: Asian elephant (*Elephas maximus*), sambar (*Cervus unicolor*), chital (*Axis axis*), Nilgai (*Boselaphus tragocamelus*), barking deer (*Muntiacus muntjak*), wild pig (*Sus scrofa*) and goral (*Nemorhaedus goral*). Carnivores include: tiger (*Panthera tigris*), leopard (*Panthera pardus*), Asiatic black bear (*Ursus thibetanus*), sloth bear (*Melursus ursinus*), jungle cat (*Felis chaus*), striped hyena (*Hyaena hyaena*) and Himalayan yellow-throated marten (*Martes flavigula*). Two species of primates are found in the Park, viz., rhesus macaque (*Macaca mulatta*) and lesser hill langur (*Semnopithecus hector*) (Brandon-Jones 2004). Others include:

Indian porcupine (*Hystrix indica*), Indian pangolin (*Manis crassicaudata*), Rufous-tailed hare (*Lepus nigricollis ruficaudatus*). The region supports a diverse avifauna consisting of *c.*350 species of birds (Ravi 2008).

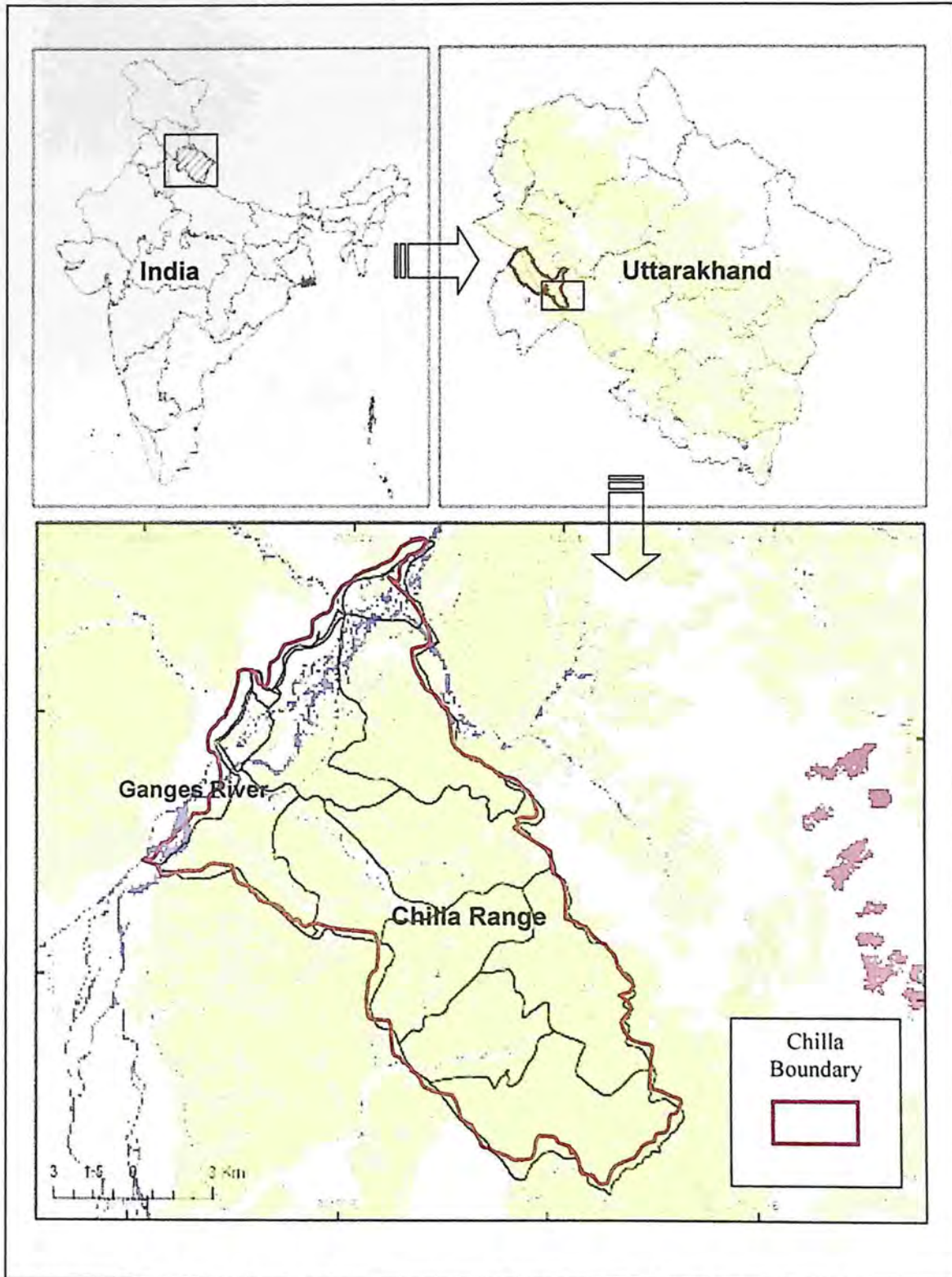


Figure 2.1. Map showing the location of the Intensive Study Area (ISA).



Figure 2.2. Grassland at Mundhal, Chilla Range, Rajaji National Park.



Figure 2.3. View from a high point looking northwards across Mundhal, Chilla Range, Rajaji National Park.



Figure 2.4. A *Shorea* forest in Chilla Range, Rajaji National Park.

CHAPTER- 3.0 METHODOLOGY

3.1. Reconnaissance

A reconnaissance of the study area was carried out during the month of December 2008 to become familiar with the terrain and establish the grids. The study period (December 2008 – May 2009) covered two seasons- Winter (December to March) and Summer (April to May).

3.2. Field Data Collection

The intensive study area (ISA) of 148km² in Rajaji National Park was overlaid with a 2x2km grid, placed in a checkerboard pattern on a Landsat FCC image (Fig 3.1). To maximise sampling, each grid was divided into four 1x1 km sub-grids. In total, there were 12 2x2km grids, which were divided into 48 1x1 km subgrids. These grids were then established on the ground using this reference image, a Garmin™ eTrex H hand-held Global Positioning System and a lensatic compass.

A 1km long open-width transect was laid in each sub-grid. These transects were walked once in each season and the perpendicular distance from the centre-line of the transect to dung-piles encountered was recorded using a measuring tape. Only week-old dung piles were counted, the age being determined by the amount of bleaching of the dung boli and moisture content within the bolus (Anon. 2004)

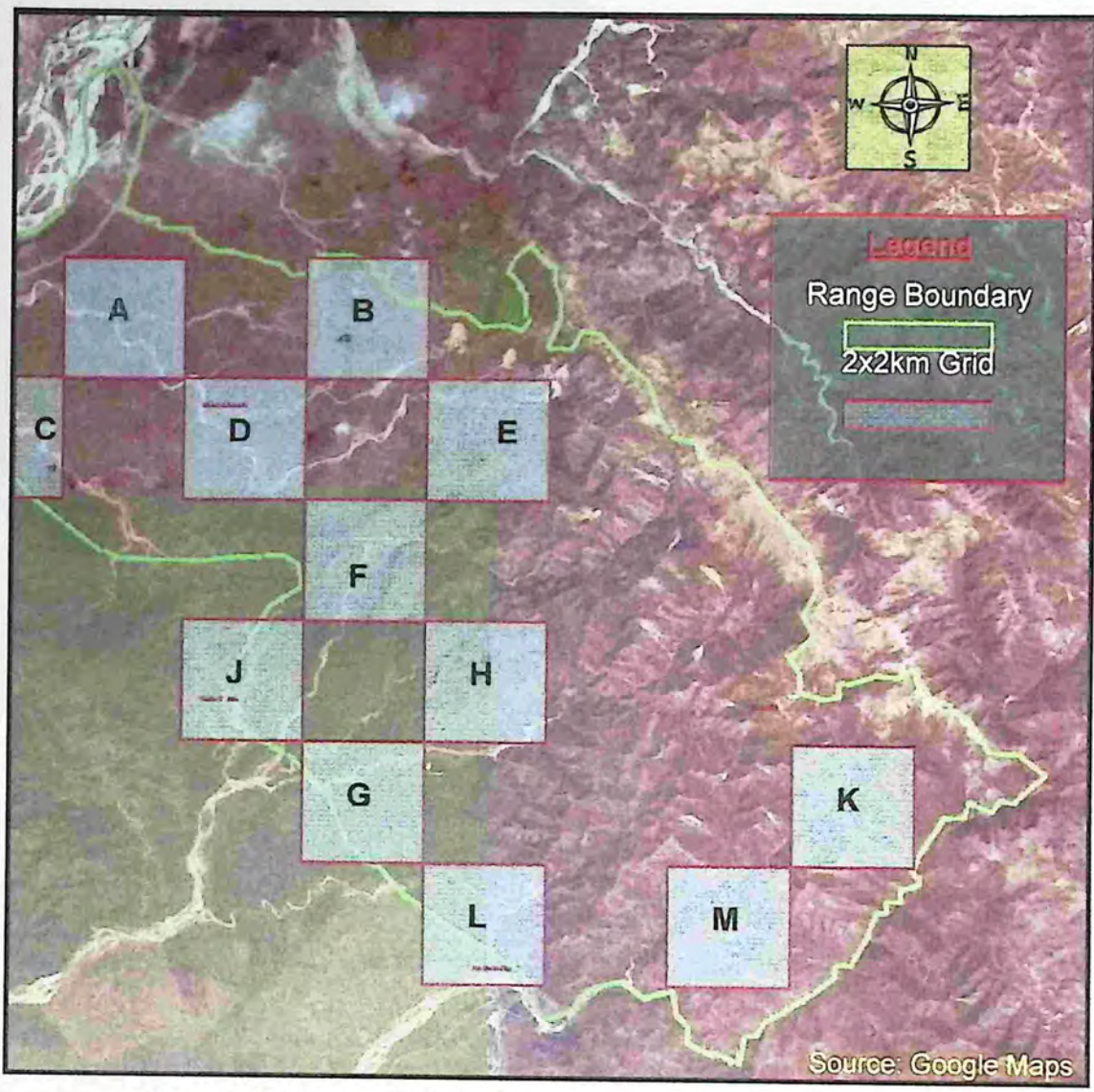


Figure 3.1. Map of Chilla Range showing placement of 2 km² grids.

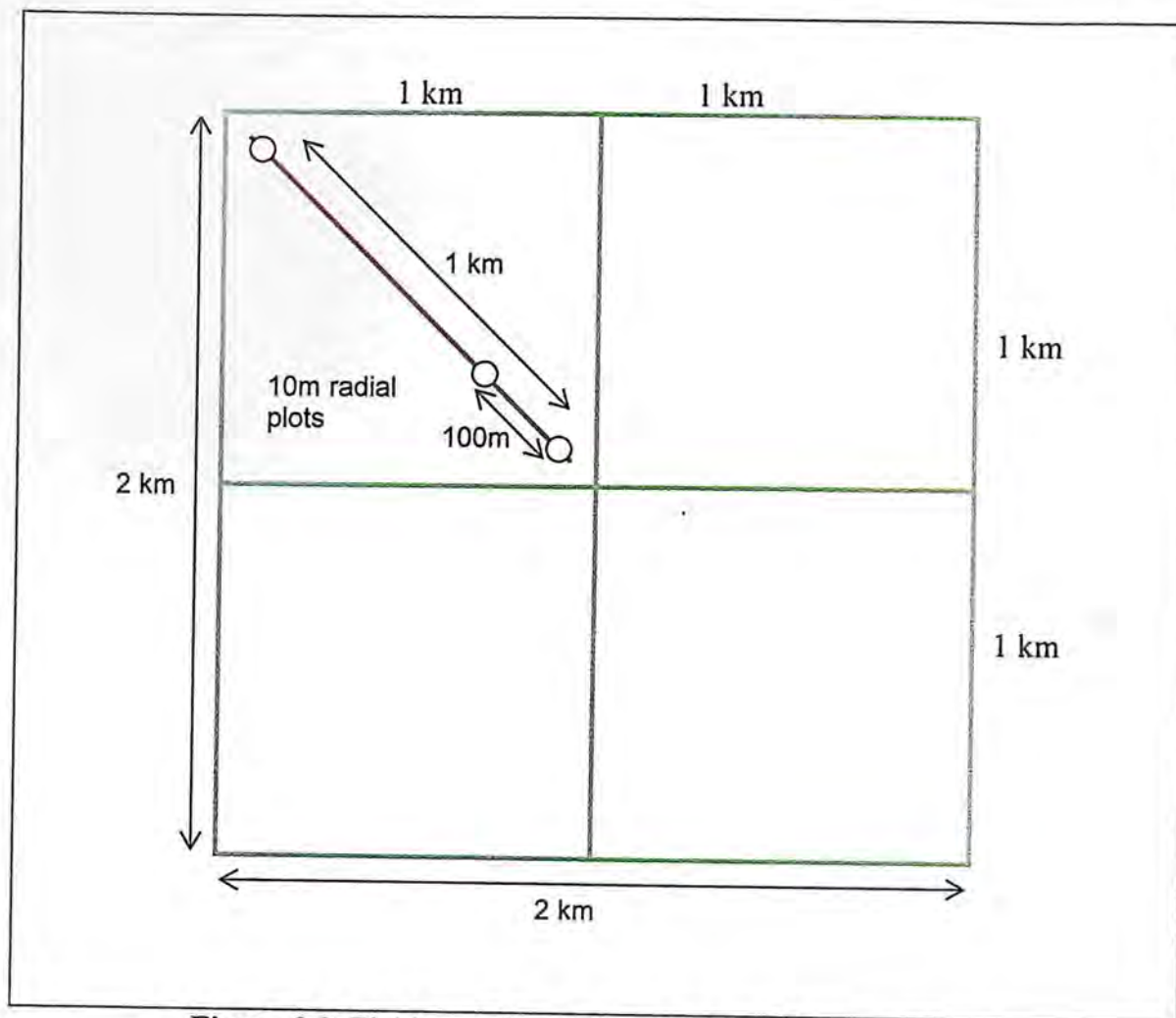


Figure 3.2. Field sampling design for the collection of data.

The density data collected for each season were pooled together to get a uniform estimate of encounter-rates (no. of dung-piles/km) and the dung density (no. of dung-piles/ km²) obtained by post-stratification by season, using the programme Distance 5.1™.

Vegetation data were collected to determine the structural heterogeneity of the habitat and were collected in 10m radial plots, placed at every 100m along the transect line (Fig 3.2). Twelve species of woody plants were chosen based on their preference as forage by elephants (^{Williams et al} Christy et al 2005) for quantification, while other species were not selected. These species are shown in Table 3.1. For the purpose of this study, woody plant is defined as having a GBH >10cm.

Table 3.1. Woody plant species selected for quantification in the present study, based on Christy (2005).

S. No.	Species
1.	<i>Mallotus philippensis</i>
2.	<i>Ehretia laevis</i>
3.	<i>Acacia catechu</i>
4.	<i>Dalbergia sissoo</i>
5.	<i>Ougenia oojenensis</i>
6.	<i>Shorea robusta</i>
7.	<i>Ficus benghalensis</i>
8.	<i>Lannea coromandelica</i>
9.	<i>Bauhinia variegata</i>
10.	<i>Acacia catechu</i>
11.	<i>Haplophragma heterophyllum</i>
12.	<i>Tectona grandis</i>

At sampling point, the number of selected tree species was recorded and GBH (Girth at Breast Height), height of the canopy base and canopy spread were measured using a measuring tape. Percentage canopy cover was recorded using a Spherical Densiometer (Forestry Suppliers, USA). Plant parts, viz.- bark, leaves and twigs for nutritional analysis were collected from each plot, stored in paper bags and brought to the WII Laboratory for nutrient analysis undertaken for content of Nitrogen, Acid Detergent Fibre, Sodium, Potassium, Calcium, Copper, Magnesium and Zinc. With the available time and resources the analysis was restricted to only those plant parts likely to influence diet selection for particular nutrients. These parts were selected based on direct observations of feeding and on the basis of data recorded by Christy (2005).

3.2. Laboratory Methods

Sample preparation

The methodology followed for analysing samples for nutritional parameters was according to standard (AOAC 1995).

The field-collected samples were first dried in an oven at 50°C for 48 hours to remove all moisture and then ground into powder using a commercial grinder. The powdered samples were stored in Zip-Loc™ bags.

Estimation of Percent Nitrogen

A FOSS Kjeltac™ 2300 Analyser (FOSS Inc., USA) was used to analyse the prepared sample for nitrogen content.

Sample Preparation for Kjeltac™ 2300 Analyser

1. 0.5gm of the sample was weighed and placed in a Kjeltac™ Tube.
2. 1 Kjeltab™ tablet ($\text{CuSO}_4 + \text{K}_2\text{SO}_4$) was placed in the tube.
3. 10ml of concentrated Sulphuric Acid (H_2SO_4) was added to the tube.
4. The tube was placed in a FOSS Digester™ 2400 (FOSS, Inc. USA) unit and heated to 400°C for 1hour, or until the contents became a clear, bluish liquid.

The samples were then placed in a FOSS Kjeltac™ unit to obtain percentage Nitrogen content.

Estimation of Na, Ca, Mg, K, Cu and Zn

For analysis of Sodium (Na) and Potassium (K), a standard Flame Photometer was used. For the analysis of Calcium, Magnesium Zinc and Copper, a Perkin-Elmer AAnalyst 700™ Atomic Absorption Spectrometer (Perkin-Elmer, USA) was used.

Sample preparation

For sample preparation, 1gm of the powdered samples was weighed and placed in Silica crucibles and heated in a Muffle Furnace to 500°C for 3hours. The resultant ash content was weighed for loss on ignition and used for further analysis.

N/10 Hydrochloric Acid (HCl) is added to the crucible and this was heated on a hot plate until the sample is fully dissolved.

The dissolved sample was filtered through a Whatman's[®] No 40/110mm filter paper into a 50ml volumetric flask. The volume was made up to 50ml and this aliquot was placed in sample tubes for the estimation of Sodium, Potassium, Calcium, Copper, Magnesium and Zinc.

Estimation of Sodium and Potassium

The samples were diluted 20 times using a solution of Lanthanum, as the usually high values of these elements are out of the detection range of the instrument.

The estimations of Na and K were carried out in a Systronics[™] Flame Photometer 123 (Systronics Analytical Instruments Ltd, India.). The values were estimated in parts per million (ppm).

Estimation of Calcium, Magnesium, Zinc and Copper

Estimations of Ca, Mg, Zn and Cu were carried out in a Perkin-Elmer[™] AAnalyst 700 unit. The values were estimated in parts per million (ppm).

Estimation of Ash content.

After the powdered samples were heated in the Muffle Furnace at 500°C, the resultant residue was weighed. The percentage Ash content was estimated using the formula,

$$\% \text{ Ash Content} = [(\text{Crucible Weight} + W_2) - W_3] \times 100,$$

where, W_2 = Sample Weight,

$$W_3 = \text{Crucible weight} + \text{Sample weight (after heating)}$$

Fibre Analysis

The estimation of Acid Detergent Fibre (ADF) was carried out using a Foss™ FiberTec 2010 (FOSS Inc. USA) unit.

A Foss Fibertec crucible was weighed and into this was added 0.5gm of sample, along with 0.3gms of Celite. Acetone was added to the crucible and the chlorophyll thus removed.

The crucible was then placed in the Fibertec unit and boiled and filtered in Acid Detergent Solution for 1 hour. After this, the crucibles were removed and placed in an oven at 80°C overnight.

After heating, the crucibles were weighed and this was noted as W_1 .

H_2SO_4 was added to the crucible and allowed to filter through for 1 hour. After the sample was filtered with distilled water and placed in an oven at 80°C overnight. The weight was taken the next day and noted as W_2 .

The next day, the crucibles were placed in a muffle furnace and ashed at 450°C for 3 hours and after this the weight was taken and noted as W_3 .

The percentage of ADF was calculated using the formula:

$$\%ADF = \frac{(\text{Crucible Weight} - W_1)}{\text{Sample Weight}} \times 100$$

3.3 Data Analysis

Data analysis was carried out using SPSS 8.0™ (SPSS Inc., USA) software, Distance 5.0™ ((Research Unit for Wildlife Population Assessment, Univ. of S^t. Andrews, UK), Primer 6.0 (PRIMER-E Ltd., UK) and Microsoft™ Excel (Microsoft Corporation, USA).

Initial data analysis involved running Principal Component Analysis to reduce the dimensionality of the nutritional variables using SPSS™ 8.0. The programme

Distance 5.0™ was used for estimating dung densities. Comparison of dung densities with structural, geo-spatial and nutritional variables was done by running Linear Regression on SPSS 8.0™ software. The uniformity of dung density distribution in the two seasons in the study area was tested using Kolmogorov-Smirnov one-sample test.

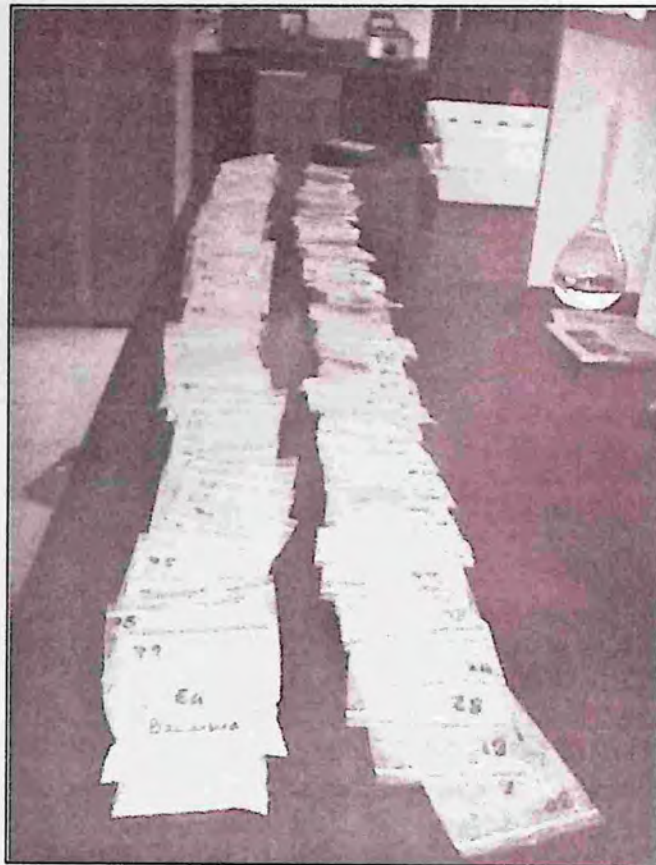


Figure 3.3. Powdered samples, catalogued and stored in Zip-Loc™ bags before analysis.

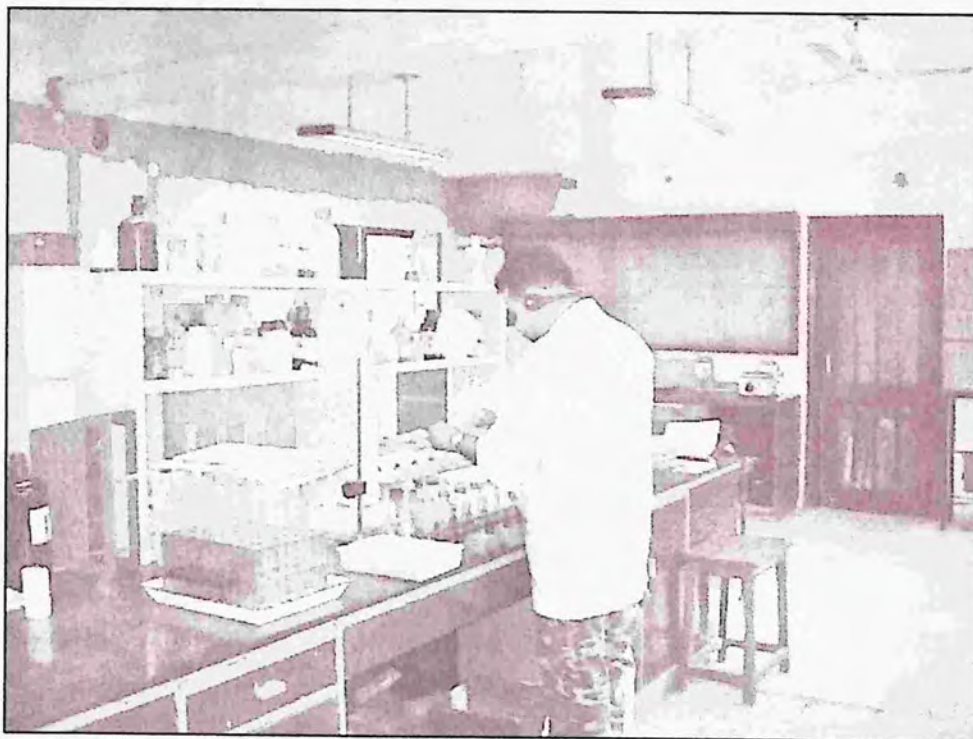


Figure 3.4. Aliquot being filtered before analysis for nutrients.

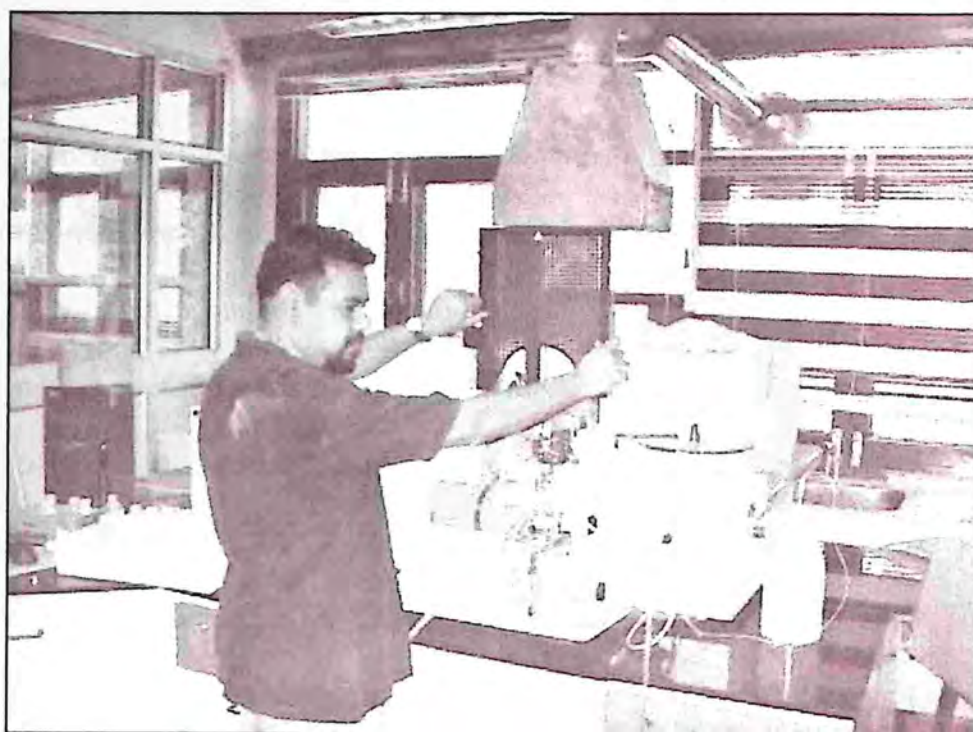


Figure 3.5. Samples being analysed in the Perkin-Elmer™ AAAnalyst Atomic Absorption Spectrometer.

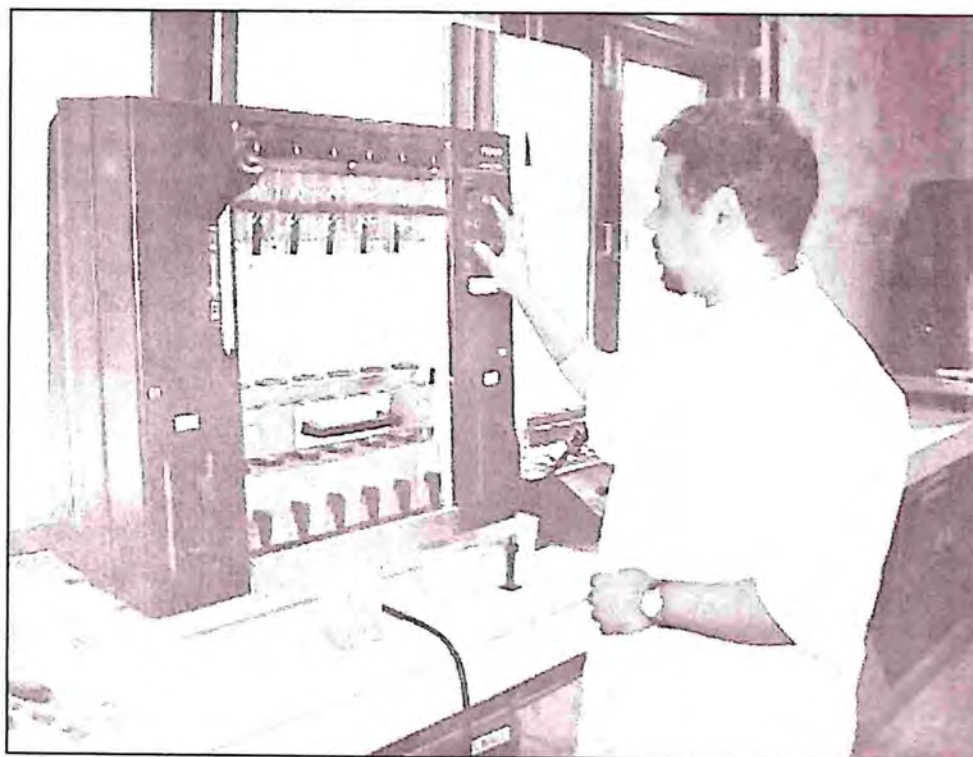


Figure 3.6. Samples being analysed for acid detergent fibre in FOSS™ Fibertec 2010 fibre analyser.

CHAPTER 4.0 RESULTS

The data collected in the study area and the results obtained from laboratory analysis have been presented in three sections, viz.- heterogeneity in habitat, variations in nutritional content in food plant species and distribution of dung in relation to habitat heterogeneity and nutritional quality of plants.

In total, structural variables were quantified from 2365 trees sampled in 480 10-metre radial plots, spread across 48 sub-grids. For nutritional analysis, 154 samples were collected for the 12 selected plant species commonly used by elephants during summer and winter. These were reduced to a maximum of six randomly chosen samples per species, amounting to 54 species per season. For uniformity in comparison, the same number of species was collected randomly from each grid during summer, and winter.

4.2. Heterogeneity in the habitat

The total number of woody plant species in each grid is depicted in Fig 4.1. The number of trees in the grids varied from 268 in Grid 'C', to 124 in Grid E (Table 4.1). Grids 'E', 'G' and 'K' had a lower number of trees (>141trees).

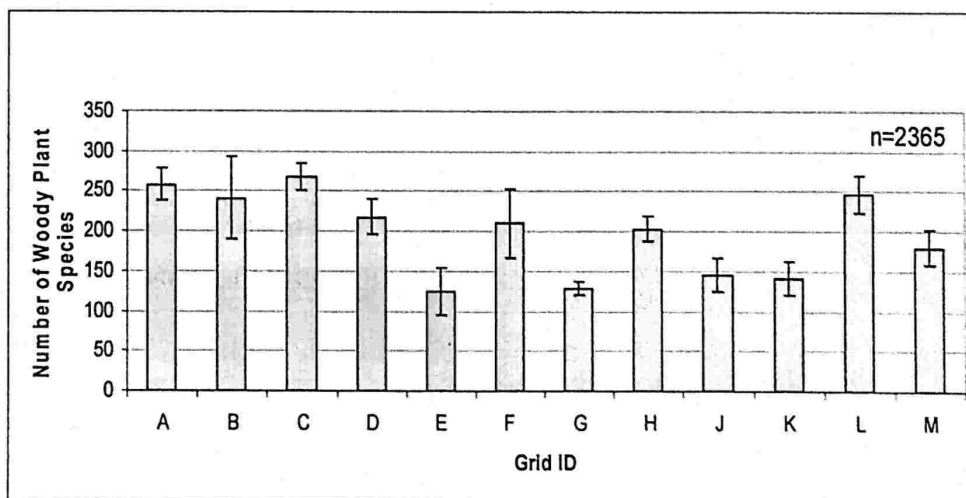


Figure 4.1. Total number of woody plant species quantified in each grid of the Intensive Study Area.

Table 4.1. Plant species representation in each grid of the Intensive Study Area.

Grid ID	# of trees	Number of trees of each species represented in the sampled grid.											
		<i>Acacia</i>	<i>Bauhinia</i>	<i>Dalbergia</i>	<i>Ehretia</i>	<i>Ficus</i>	<i>Haplophragma</i>	<i>Holharrenna</i>	<i>Lannea</i>	<i>Mallotus</i>	<i>Ougenia</i>	<i>Shorea</i>	<i>Tectona</i>
A	258	2	1	0	62	0	0	118	0	70	0	5	0
B	241	0	0	0	12	0	0	5	0	216	0	8	0
C	268	1	0	0	19	0	6	67	0	117	0	51	0
D	218	0	0	1	24	1	0	50	0	138	0	4	0
E	124	0	1	0	0	0	0	2	0	90	0	31	0
F	210	0	0	0	19	0	0	10	0	180	0	1	0
G	129	1	0	0	12	0	20	15	0	66	0	3	0
H	203	1	0	0	43	0	0	46	0	101	0	11	0
J	146	0	0	0	17	0	0	10	0	112	0	5	2
K	141	0	3	0	0	0	0		1	29	1	107	0
L	247	0	0	0	0	0	113	4	0	83	0	0	47
M	180	1	0	0	0	0	0	32	0	122	1	24	0

Grids 'A', 'B', 'C' and 'L' had a higher numbers of trees (>240 trees). Standard Error (SE) values for each grid reveals that in grids 'B' and 'F', there is a high variation in the number of woody plant species, while in the rest of the plots of grids, the variation is mostly uniformly minimal.

The average Shannon index of diversity of selected plant species is shown for each grid in Fig. 4.2. Grids 'A', 'C', 'G' and 'H' (1.190 -1.454), showed a high diversity index in comparison to grids 'D', 'E', 'J' and 'M' (0.821-1.049) having a moderate diversity index. Grids 'B' and 'F' (0.456-0.693) showed a low index of diversity, as these grids are dominated by *Mallotus philippensis* while grid 'K' (0.693) is dominated by *Shorea robusta* (Table 4.1).

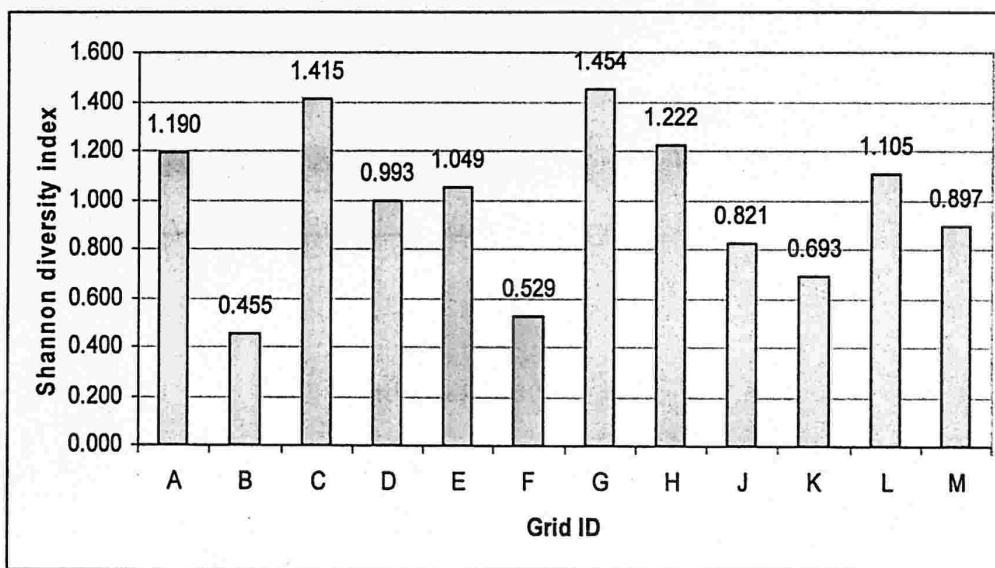


Figure 4.2. Average Shannon diversity of plants species in grids sampled in the ISA, Rajaji National Park.

In each grid, the height of the canopy base was measured (Fig. 4.3.), where ten grids showed a moderate canopy height from 1.57m in grid 'F' to 2.39m in grid 'C'. Two grids, 'E' (4.29m) and 'K' (6.08m), show very high canopy base height, as these grids contained tall stands of *Shorea* trees. Grids, 'B', 'E', 'F', 'H' and 'M' showed a very high variability in the height of the canopy base, based on the SE value.

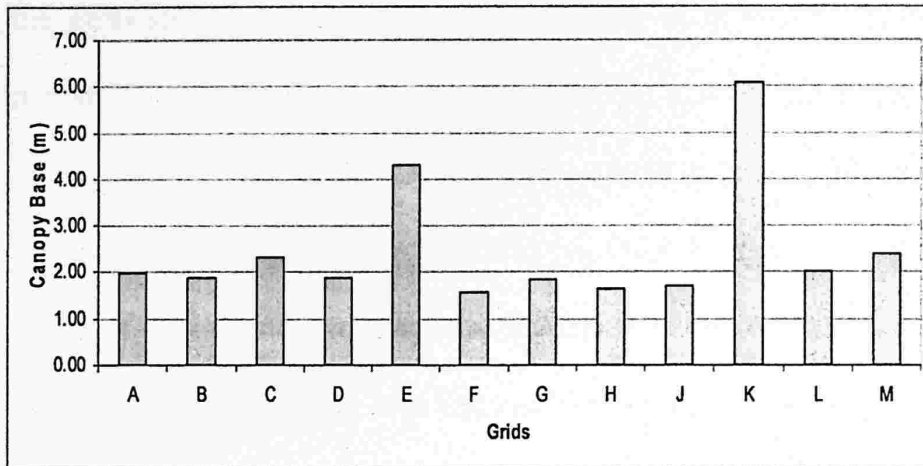


Figure 4.3. Average height of canopy base (m) measured in each grid in the Intensive Study Area, Rajaji National Park.

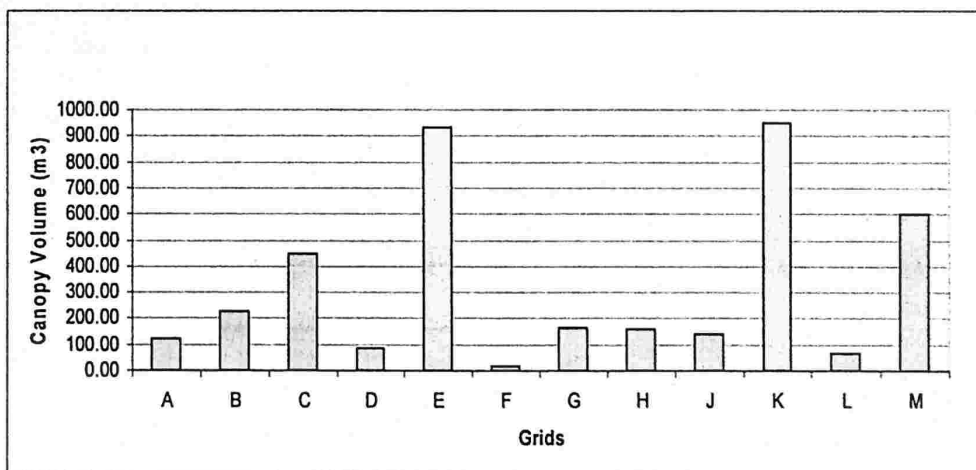


Figure 4.4. Average canopy volume (m³) measured in each grid in the ISA, Rajaji National Park.

Average canopy volume is a product of the canopy length, canopy width and tree height, minus the height of canopy base. Fig 4.4. indicates the average canopy volume in each grid. Most grids in the study area showed a low to moderate canopy volume, with a minimum of 165.63m³ to a maximum of 446.77m³. Two grids, 'E' and

'K' showed a very high canopy volume of 933.05m^3 and 948.36m^3 , respectively. As mentioned above, this was probably because these grids had tall stands of *Shorea* trees. Grids 'B', 'D', 'E', 'G', 'J', 'K' and 'M' indicate a high variation in canopy volume.

Fig 4.5. shows the average percentage canopy cover in the sampled grids. Most of the grids show a high canopy cover, ranging from 93.72% in grid 'B' to 69.28% in grid 'H'. However, two grids-'G' (54.13%) and 'J' (55.13%) indicate a lower percentage canopy cover as these are on the southern fringes of the study area with a lower number of trees in the grid. Although, Grid 'L' shows a higher number of trees (Fig. 4.1), the overall percentage canopy cover is low (62.12%) as this grid is on the southern fringe of the study area and bordered by Rasulpur village. Therefore, most of the trees in this area are probably subjected to lopping.

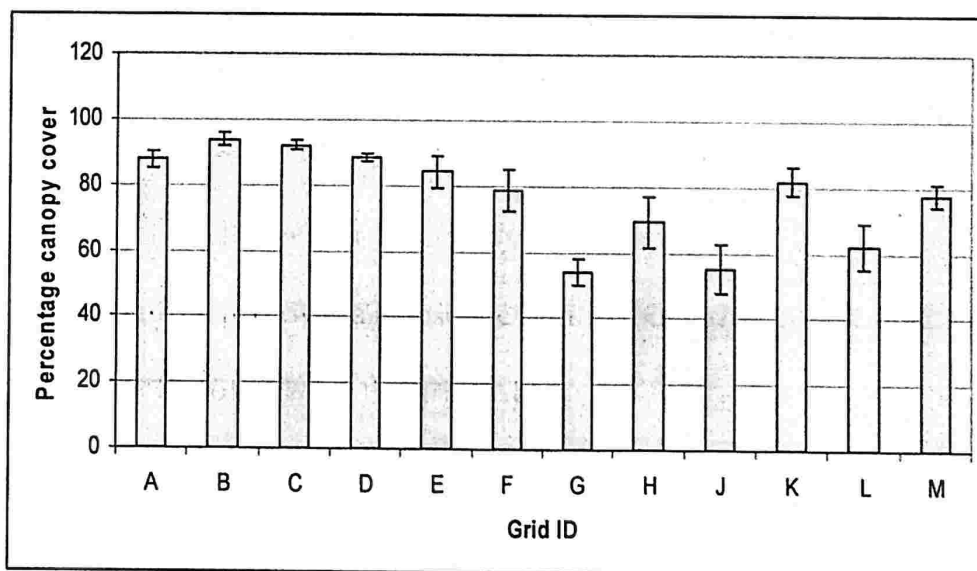


Figure. 4.5. Average percentage canopy cover in the grids sampled in the ISA, Rajaji National Park.

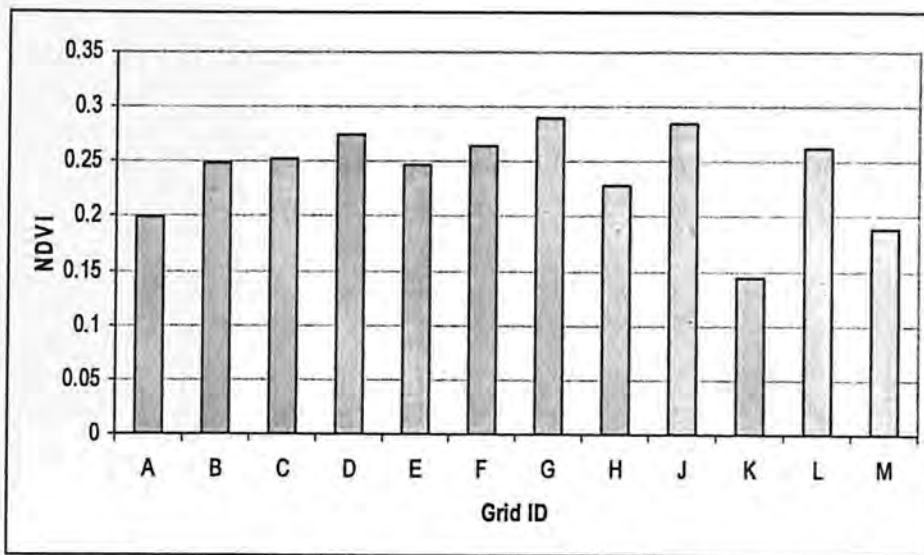


Figure 4.6. Average NDVI values for each sampled grid in the ISA, Rajaji National Park.

The data on Normalised Difference Vegetation Index (NDVI) recorded in March 2007 (Fig.4.6) for each sampled grid indicates that most of the grids had a uniformly high value (0.189-0.289), whereas grid 'K' had a low value (0.143), as this was situated at an elevation in the north-eastern corner of the study area, where there were many barren patches.

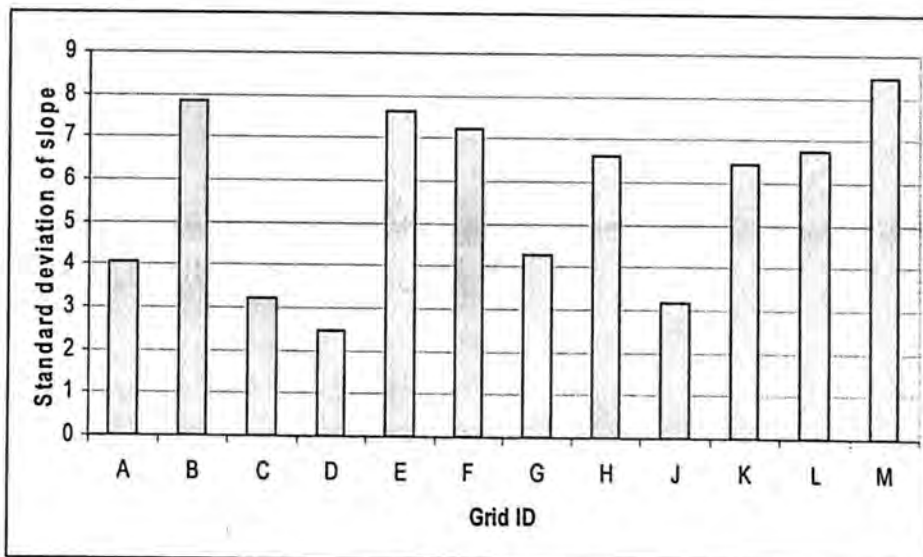


Figure 4.7. Average standard deviation of slope values per sampled grid in the ISA, Rajaji National Park.

The average standard deviation of slope in each sampled grid is shown in Fig. 4.7. where higher values indicate steep terrain. The grids 'B', 'E', 'F', 'H', and 'M'

(6.62-8.46) have very high values as these grids were situated in areas with very steep terrain. In comparison, the grids 'C', 'D', 'G' and 'J' were in plain areas, hence the values are low (2.46-4.28).

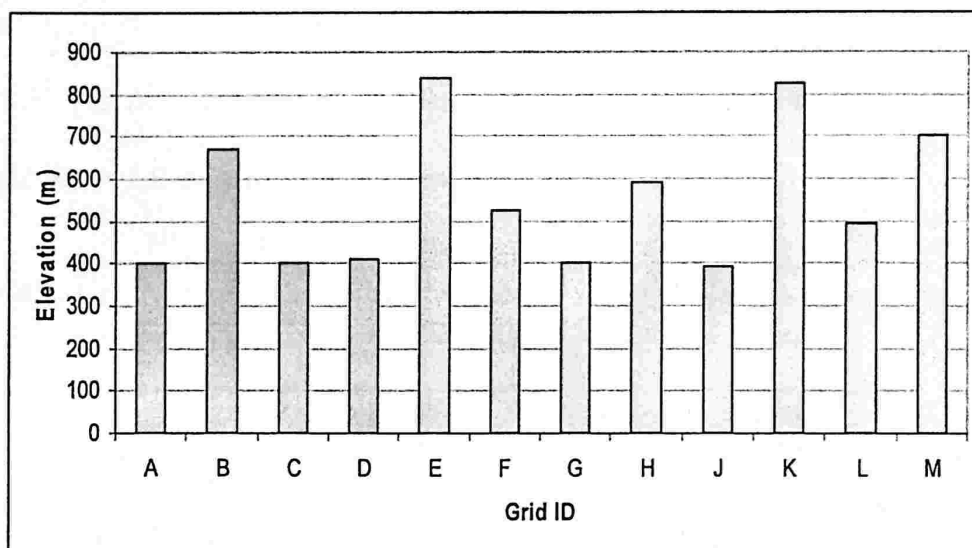


Figure 4.8. Average elevation for each sampled grid in the ISA, Rajaji National Park.

The average elevation of the sampled grids (Fig. 4.8) was moderate (391m - 526m a.s.l), however, grids 'B', 'E', 'H', 'K' and 'M' were situated at higher elevations (669-840m).

4.3 Variation in the nutritional contents in selected food plant species

In the present study, the nutritional relationship has been compared by correlating seasonal variation in the proximate factors like percent nitrogen, percent acid detergent fibre and percent ash, and macro- and micro-nutrients such as sodium, potassium, calcium, copper, magnesium and zinc in plant species. Table 4.2 indicates the basic data on the various parameters used in this study

Table 4.2. Gridwise mean nutritional values of selected plant samples collected from the ISA, Rajaji National Park during winter and summer.

a) Winter

Grid ID	% N	% Ash	% ADF	ppm Na	ppm K	ppm Ca	ppm Cu	ppm Mg	ppm Zn
A	0.535	45.420	81.030	1.551	21.095	9.800	0.047	1.810	0.038
B	0.494	42.739	88.407	0.740	13.574	8.589	0.045	1.974	0.028
C	0.602	53.377	73.563	1.747	21.710	10.526	0.057	2.079	0.043
D	0.377	25.962	85.975	0.612	6.511	5.279	0.038	1.039	0.046
E	0.374	48.177	41.889	3.716	29.862	12.549	0.043	0.748	0.044
F	0.210	18.140	88.407	0.314	5.761	3.646	0.019	0.838	0.012
G	0.234	19.584	86.023	0.606	9.507	3.985	0.021	0.835	0.016
H	0.526	44.830	86.023	1.044	17.525	9.058	0.047	2.001	0.032
J	0.447	44.027	75.946	2.266	17.960	8.171	0.048	1.178	0.043
K	0.346	38.498	39.818	2.476	19.350	10.773	0.033	0.790	0.034
L	0.430	34.484	54.753	1.812	12.189	5.955	0.054	0.920	0.135
M	0.550	79.092	34.793	6.304	38.857	16.795	0.077	1.049	0.090

b) Summer

Grid ID	% N	% Ash	% ADF	Na ppm	K ppm	Ca ppm	Cu ppm	Mg ppm	Zn ppm
A	0.015	0.976	14.00	0.087	0.085	0.012	BDL	0.056	0.001
B	0.012	0.768	5.20	0.067	0.080	0.009	BDL	0.046	0.000
C	0.017	1.255	12.80	0.098	0.074	0.016	0.0002	0.032	0.002
D	0.021	1.349	9.80	0.115	0.134	0.016	BDL	0.079	0.001
E	0.014	3.668	4.49	0.242	0.044	0.219	0.0001	0.032	0.001
F	0.019	1.216	8.20	0.106	0.127	0.014	BDL	0.073	0.000
G	0.012	0.774	8.81	0.068	0.075	0.009	BDL	0.046	0.000
H	0.033	2.118	17.80	0.185	0.215	0.025	BDL	0.127	0.001
J	0.019	1.307	9.00	0.110	0.122	0.015	0.0008	0.067	0.001
K	0.006	1.407	16.60	0.095	0.020	0.077	BDL	0.016	0.000
L	0.041	8.031	8.81	0.366	0.581	0.464	0.0082	0.119	0.009
M	0.033	3.947	42.00	0.275	0.107	0.137	0.0004	0.033	0.006

4.3.1. Percent Nitrogen

In the present study, the nutritional relationship has been compared by correlating seasonal variation in the proximate factors like percent nitrogen, percent acid detergent fibre and percent ash, and macro- and micro-nutrients such as sodium, potassium, calcium, copper, magnesium and zinc in plant species. Table 4.2 indicates the basic data on the various parameters used in this study.

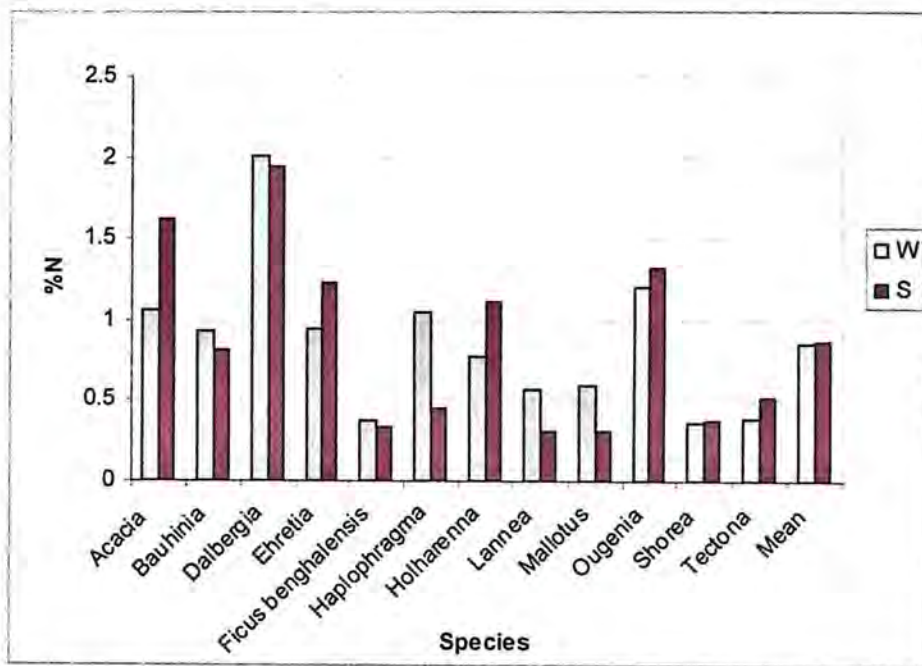


Figure 4.9. Species-wise seasonal variations in percent nitrogen in selected plant species in the ISA, Rajaji National Park. (W=winter; S=summer).

The species-wise variation in the percentage nitrogen content is depicted in Fig. 4.9. A Student's 't' test was performed, $P=0.98$ ($p=0.05$, $df=11$) and indicates that there is no significant difference between the mean nitrogen content of plant species between the two seasons, among most species. The mean value of percent nitrogen in *Dalbergia sissoo* is consistently high across both seasons (0.85%-0.860%), while the lowest value was for *Ficus benghalensis*, which had a mean value between 0.33%-0.37%. *Acacia catechu* showed a high variation in nitrogen content across the seasons, with a winter value of 1.06% and a summer value of 1.62%.

4.3.2 Percent acid detergent fibre (ADF)

The mean value of acid detergent fibre (ADF) for winter is 55.21%, while in summer it falls to 18.22% in all plant species. The percent content of ADF was significantly different between the two seasons ($P=0.0001$).

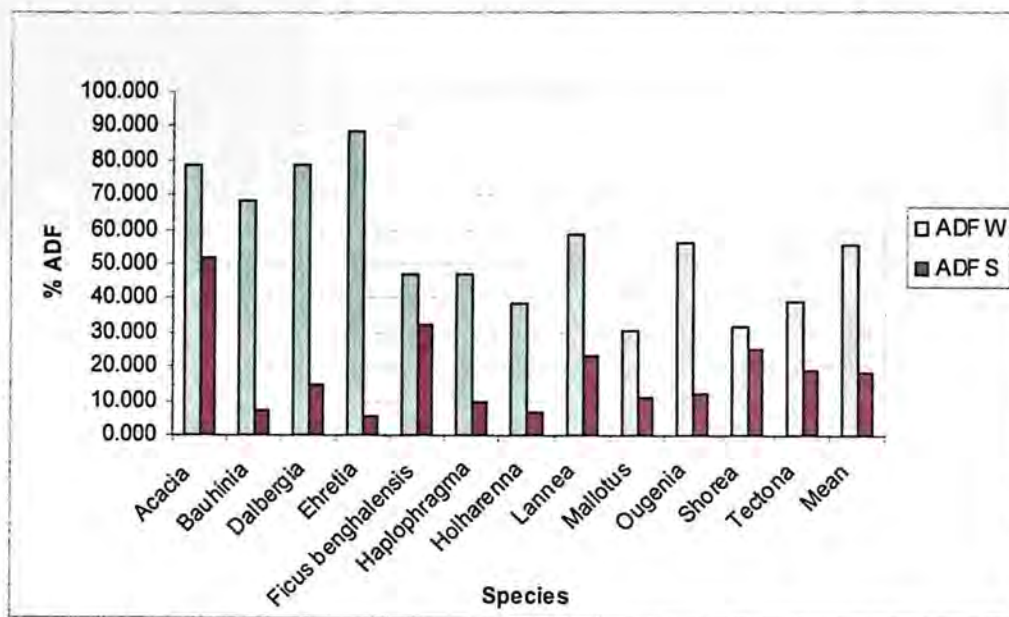


Figure 4.10. Species-wise seasonal variations in percent acid detergent fibre content in samples in the ISA, Rajaji National Park. (W=winter; S=summer)

Amongst the plant species, *Bauhinia variegata* (7.36%-68.43%), *Dalbergia sissoo* (14.84%-78.68%) and *Ehretia laevis* (5.39%- 88.40%) showed a high variation between the two seasons. The highest value for percentage ADF in winter was found in *Ehretia laevis* (88.40%), while the lowest value was for *Mallotus philippensis* (30.28%). In the summer, the highest value was in *Acacia catechu* (51.59%), while the lowest was in *Ehretia laevis* (5.39%).

4.3.3 Percentage ash content

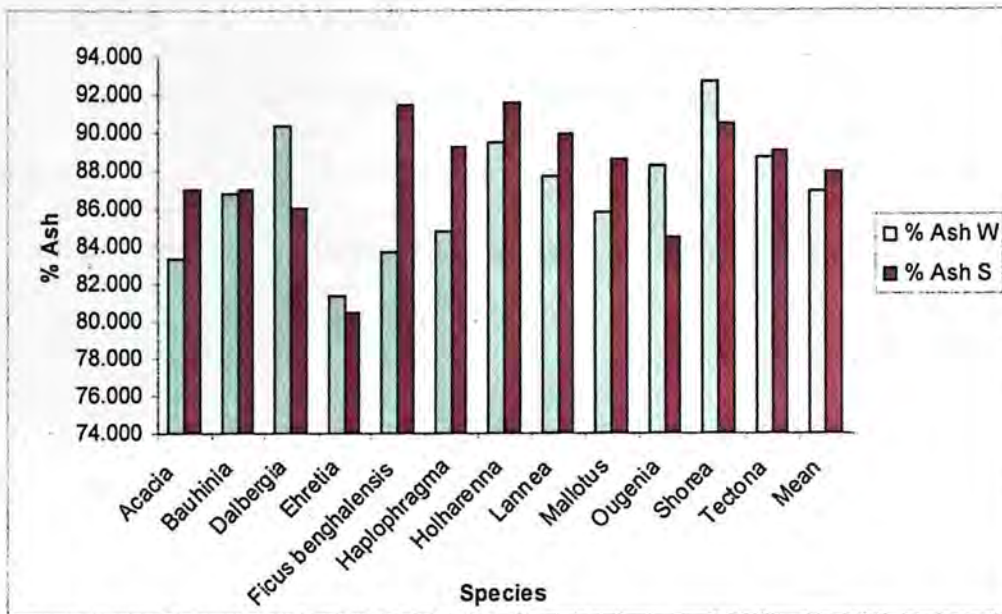


Figure 4.11. Species-wise seasonal variations in percentage ash content in selected plant species in the ISA, Rajaji National Park. (W=winter; S=summer)

The winter values of ash content showed a lower mean value of 86.88%, while in summer, the mean was higher at 87.92%. The highest winter value was in *Shorea robusta* (92.62%), while the lowest was in *Ehretia laevis* (81.30%). During summer, the highest value was in *Holharenma antidysenterica* (91.58%), while the lowest was in *Ehretia laevis* (80.41%). The variation across the seasons in percentage ash content is shown in Fig. 4.11. When Student's 't' test was performed on this data, the mean variation in ash content of all tree species was found to be only non-significantly different ($P=0.16$, $p=0.05$, $df=11$).

4.3.4. Macro and Micro mineral contents

Macro and micro mineral contents were analysed in the plant samples were sodium, potassium, calcium, copper, magnesium and zinc.

Sodium

Mean sodium (Fig. 4.12) content variation in selected plant species across the seasons was found to be significantly different, ($p=0.05$, $df=11$). The highest overall value was found in summer in *Acacia catechu* (8.92 ppm), while the lowest overall value was in summer in *Ehretia laevis* (1.40 ppm). The mean value in winter was 4.69 ppm, while in summer it was 6.33 ppm.

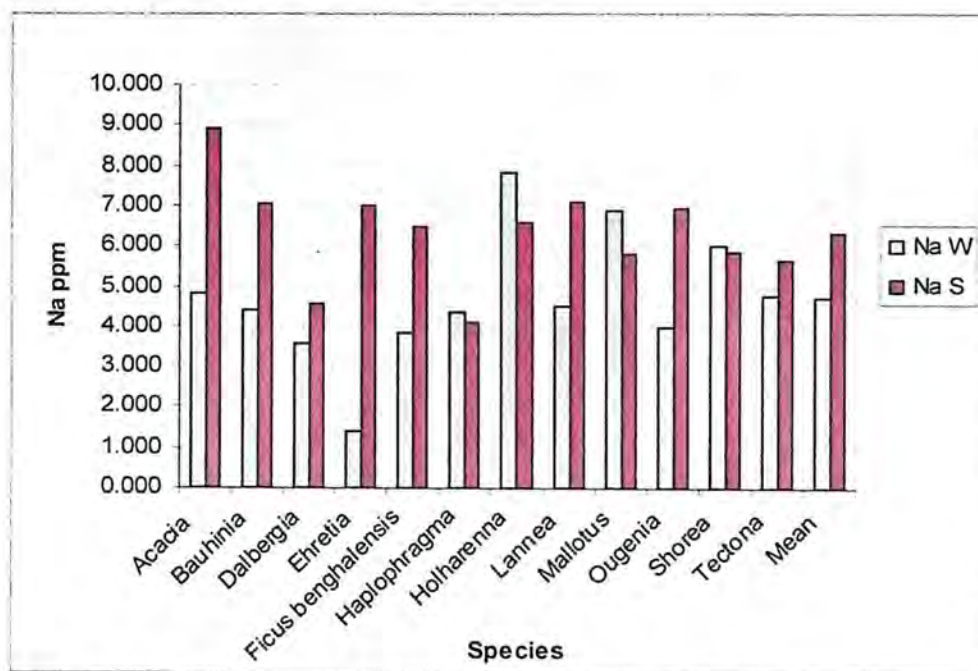


Figure 4.12. Species-wise seasonal variation in the content of sodium in selected plant species in the ISA, Rajaji National Park. (W=winter; S=summer)

Potassium

The mean value of potassium content for all plant species was higher in winter (32.13 ppm) than in summer (3.53 ppm). The difference in potassium content in plant species (Fig. 4.13) was found to be highly significant ($P=0.0003$, $p=0.05$, $df=11$) across the seasons.. The highest value in winter was in *Acacia catechu* (67.67 ppm),

while the lowest was in *Dalbergia sissoo* (6.89 ppm). During the summer season the highest value was found to be in *Ehretia laevis* (8.39 ppm) while *Mallotus philippensis* (0.97 ppm) had the lowest content.

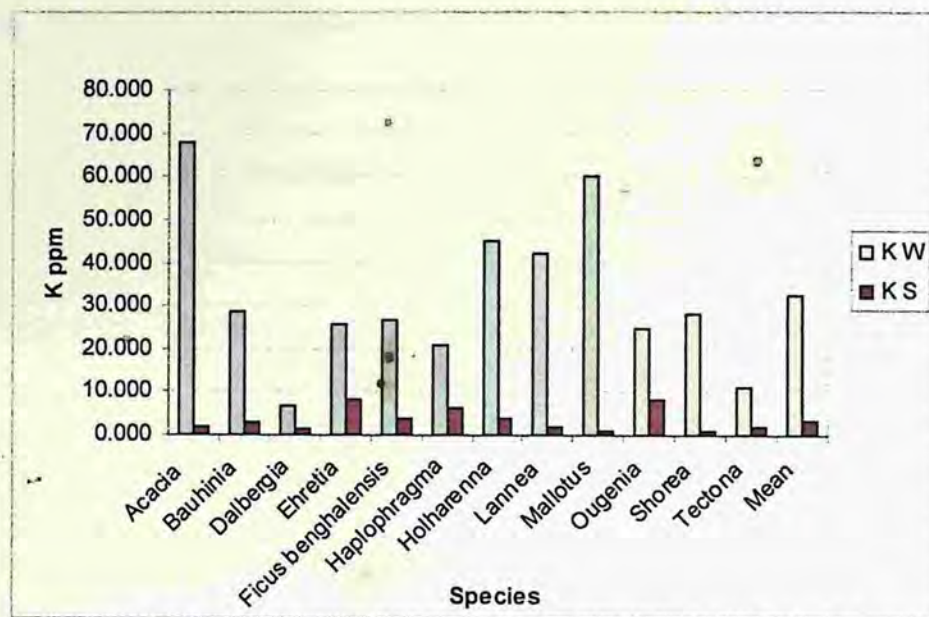


Figure 4.13. Species-wise seasonal variation in the content of potassium in selected plants species in the ISA, Rajaji National Park. (W=winter; S=summer)

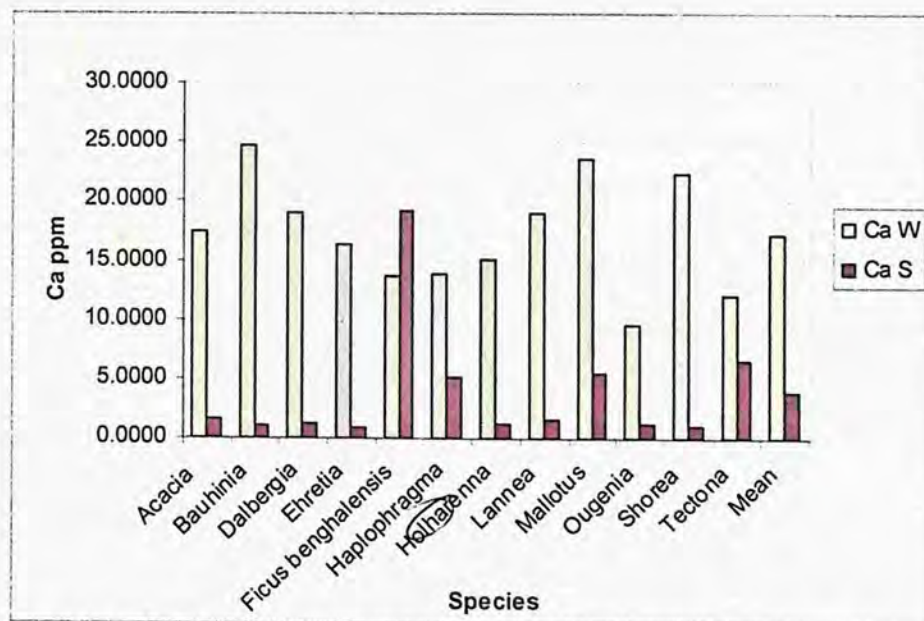


Figure 4.14. Species-wise seasonal variation in the content of calcium in selected plants species in the ISA, Rajaji National Park. (W=winter; S=summer)

Calcium

The content of calcium in the plant samples (Fig. 4.14) was found to be consistently high in the winter, with a mean value of 17.22 ppm. In the summer, the mean was 3.89 ppm, and hence when a Student's 't' test was performed, the difference was significant at $P=0.0001$. Although the summer values were consistently low, one species, *Ficus benghalensis* had a very high value at 19.23 ppm, higher than the mean value for winter. This phenomenon could be explained by the fact that most *Ficus benghalensis* were fruiting during this season.

Copper

The comparison between the content of copper in plant samples between the seasons could not be made as the summer concentrations were too low to be detected by the instrument (Table 4.1). However, the mean content in winter was low, at 0.11 ppm, with the highest content being found in *Haplophragma heterophyllum* (0.14 ppm) and the lowest found in *Mallotus philippensis* (0.072).

Magnesium

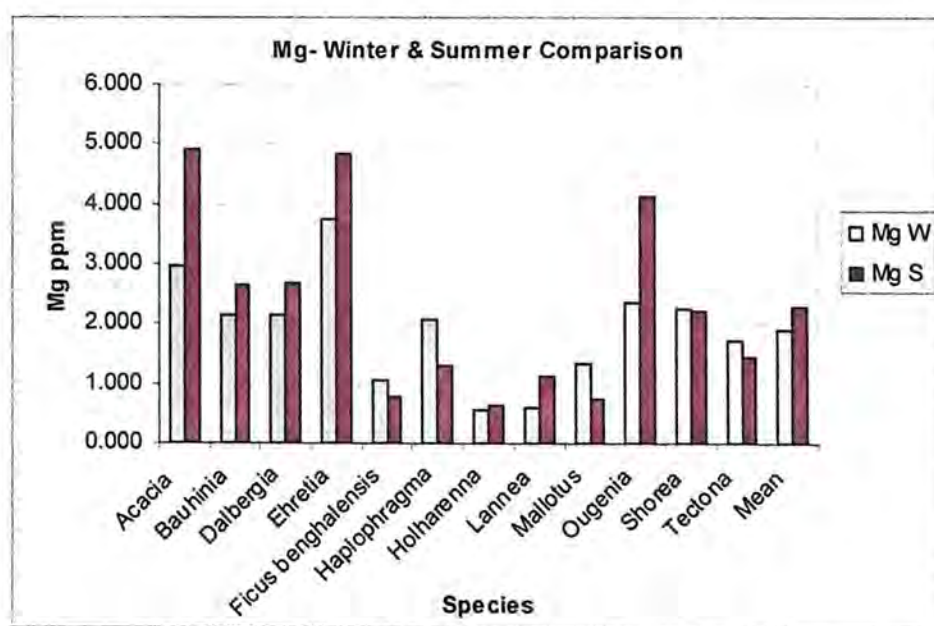


Figure 4.15. Species-wise seasonal variation in the content of magnesium in selected plants species in the ISA, Rajaji National Park. (W=winter; S=summer)

The mean value for magnesium content in winter was 1.91 ppm, while in summer, it was 2.29 ppm. The variation in the content of magnesium (Fig 4.15) in the selected plant species was not significant ($P=0.16$, $p=0.05$, $df= 11$) across the seasons. In winter, while all other values were below 3.00 ppm, only *Ehretia laevis* had a high magnesium content of 3.75 ppm. Three species in summer showed extremely high values, viz; *Acacia catechu* (4.92 ppm), *Ehretia laevis* (4.82 ppm) and *Ougenia oojenensis* (4.13 ppm).

Zinc

The content of zinc in the plant samples in both seasons (Fig 4.16) was generally low, with a mean winter content of 0.14 ppm and a mean summer content of 0.23 ppm. The difference between the two seasons was found to be not significant with $P= 0.31$ ($p=0.05$, $d=11$). However, during the winter season, two species showed high values, viz; *Dalbergia sissoo* (0.42 ppm) and *Haplophragma heterophyllum* (0.387 ppm). Similarly, in summer, while all other species showed values below 0.2 ppm, *Dalbergia sissoo* had a zinc content of 0.60 ppm and *Ougenia oojenensis* had a content of 0.88 ppm.

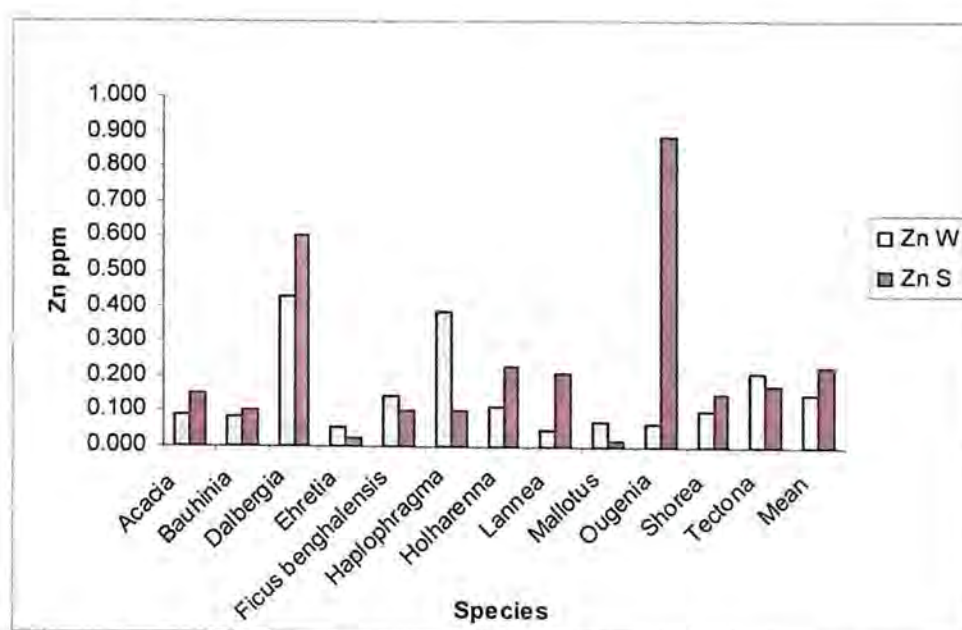


Figure 4.16. Species-wise seasonal variation in the content of zinc in selected plants species in the ISA, Rajaji National Park.

4.4. Distribution of dung density in relation to habitat heterogeneity and plant nutritional quality

4.4.1. Dung density

Fig. 4.17 indicates the grid-wise dung density in the winter and summer season.

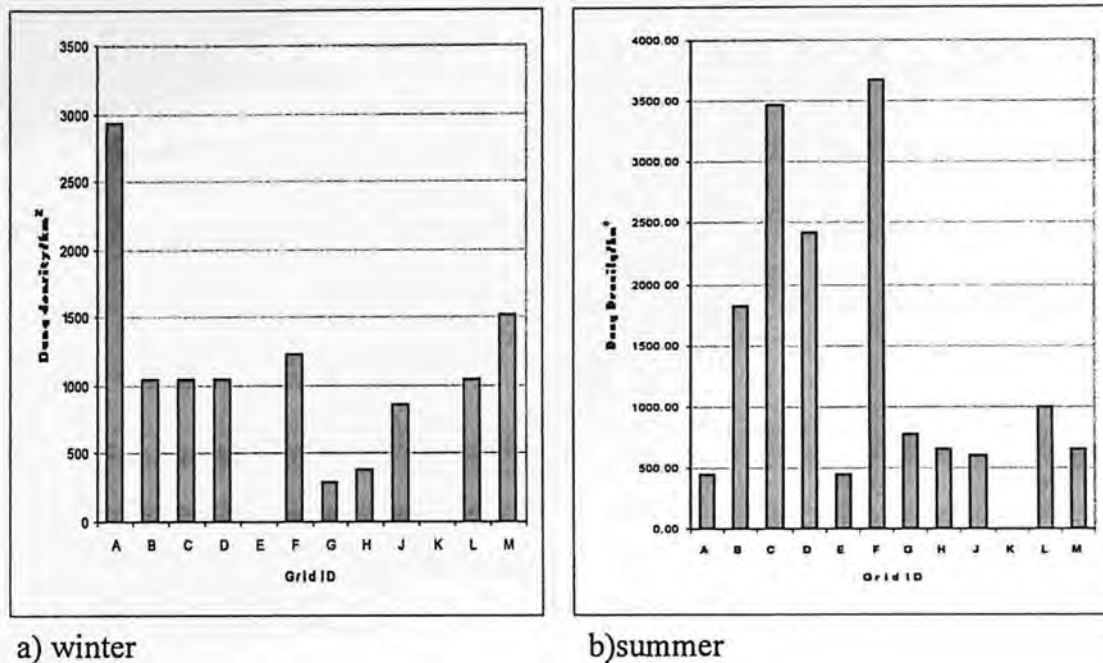


Figure 4.17. The distribution of dung density (no./km²) in sampled grids during winter and summer in the ISA, Rajaji National Park.

The dung density in both winter and summer seasons, when tested for uniformity found to be non-uniform, with a significance of ($p < 0.05$, $df = 47$). The data reveals that the habitat use by elephants in the ISA in both seasons was skewed towards some grids, while others had lower use.

During the winter, the majority of the grids ($n = 6$) had been evenly used as dung density was around 1000 dung piles/km², except grids 'A' and 'M'. However, grids 'G' and 'H' were used in very low proportions.

In summer, 7 of the 12 grids show a dung density below 1000 dung piles/km². However, grids 'B' (1813.11 dung piles/km²), 'C' (3461.39 dung piles/km²), 'D' (2417.48 dung piles/km²) and 'F' (3681.16 dung piles/km²) show high dung densities.

In winter, grids 'E' and 'K' had no dung while in summer, grid 'K' had no dung.

4.4.2. Distribution of dung density in relation to habitat heterogeneity.

The seasonal relationship between dung density distribution in the grids and the number of plants in those grids is depicted in Fig. 4.18. As can be seen, in both the seasons, there is a strong positive relationship between elephant habitat use and the number of plants in the grids.

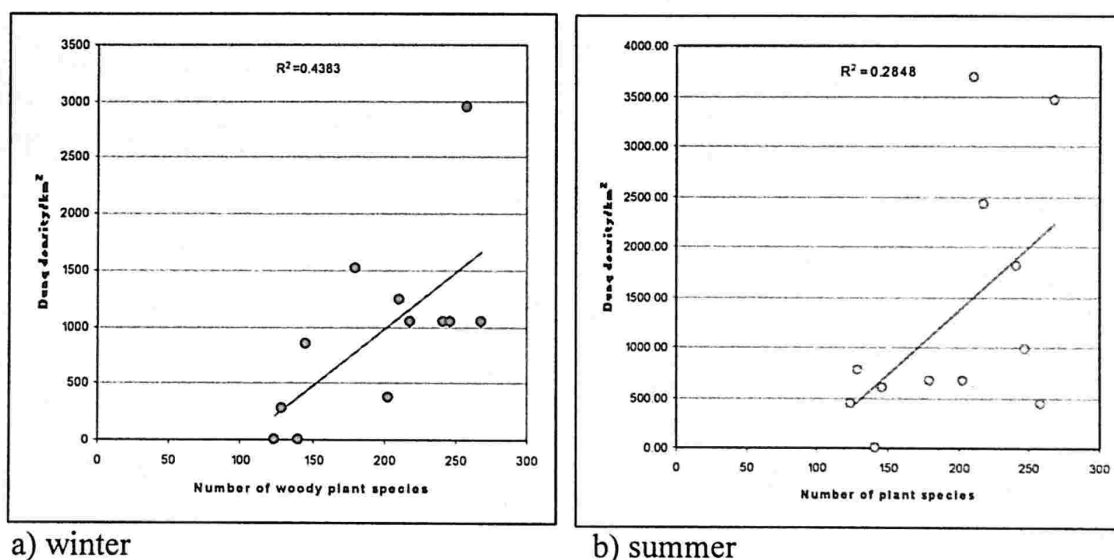
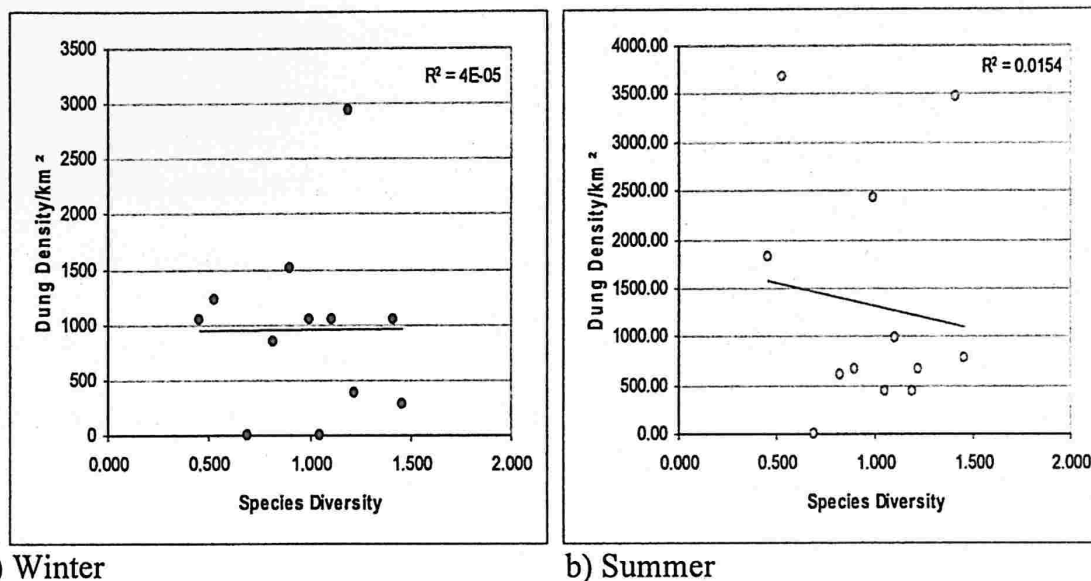


Figure 4.18. Relationship between dung densities and number of woody plant species sampled in each grid during summer and winter in the ISA, Rajaji National Park.

The relationship between dung density and number of plant species was significant in both winter ($R^2 = 0.2848$) and summer ($R^2 = 0.4383$). The relationship in both seasons shows that elephants select for areas that have a higher number of woody plants.

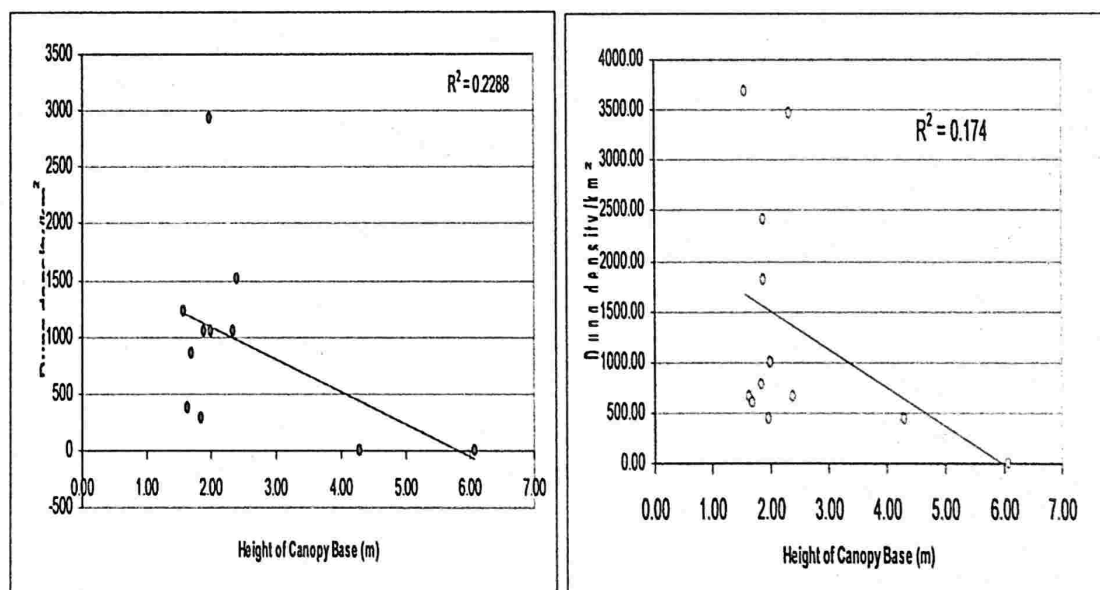
The relationship between the diversity of preferred plant species and dung density (Fig. 4.19) in winter showed no particular relationship ($R^2 = 0.00005$). However, in the summer, the dung density decreases with increasing plant species diversity ($R^2 = 0.0154$).



a) Winter

b) Summer

Figure 4.19. Relationship between dung densities and species diversity of preferred plant species in each grid in winter and summer, in the ISA, Rajaji National Park.



a) Winter

b) Summer

Figure 4.20. Relationship between dung densities and height of canopy base in each grid during summer and winter in the ISA, Rajaji National Park.

Fig 4.20 indicates the relationship between the average height of canopy base and dung density during winter and summer.

Dung densities indicate that the animals used areas having a narrow range of height of canopy base (1.5m-3.0m). Dung densities in both seasons show a sharp decrease in relation to the height of canopy base. R^2 in winter is 0.2288, while in summer the value is 0.174. This could be because a higher canopy base would be out of reach of an elephant for foraging.

The relationship between dung density and canopy volume (Fig. 4.21) indicates that for winter and summer, there is a fall in dung densities as the volume of the canopy increases. The R^2 value for winter is 0.2087 and in summer it is 0.1471.

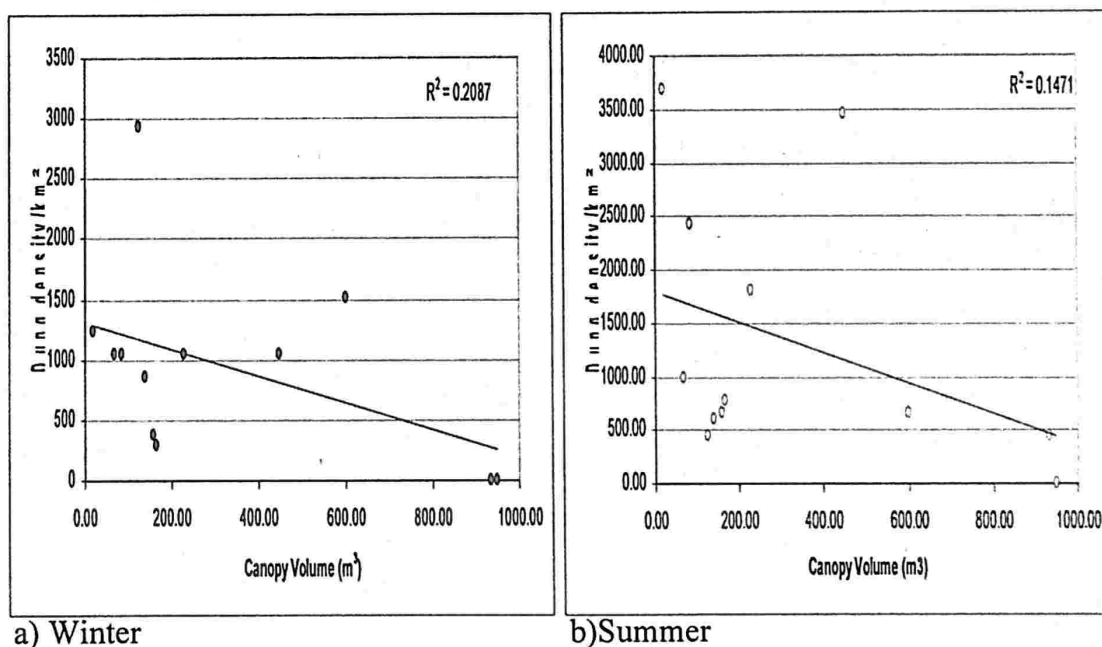


Figure 4.21. Relationship between dung densities and canopy volume in each grid in winter and summer in the ISA, Rajaji National Park.

The relationship between dung density and percentage canopy cover is shown in Fig. 4.22. The relationship is positive in both winter ($R^2 = 0.083$) and in summer

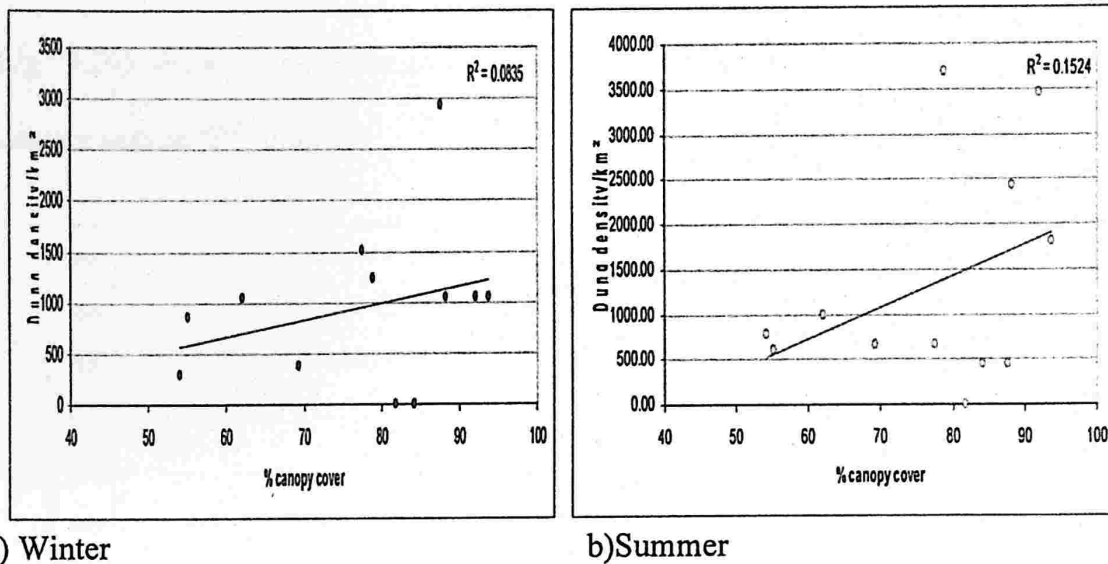


Figure 4.22. Relationship between dung densities and percent canopy cover in each grid in winter and summer in the ISA, Rajaji National Park.

($R^2 = 0.1524$) This is possibly because the higher canopy cover would afford more forage for an elephant as well as more shade during summer.

The relationship between NDVI and dung density (Fig. 4.23.) shows a negative trend ($R^2 = 0.0111$) in winter, but a strong positive trend ($R^2 = 0.1894$) in the summer season.

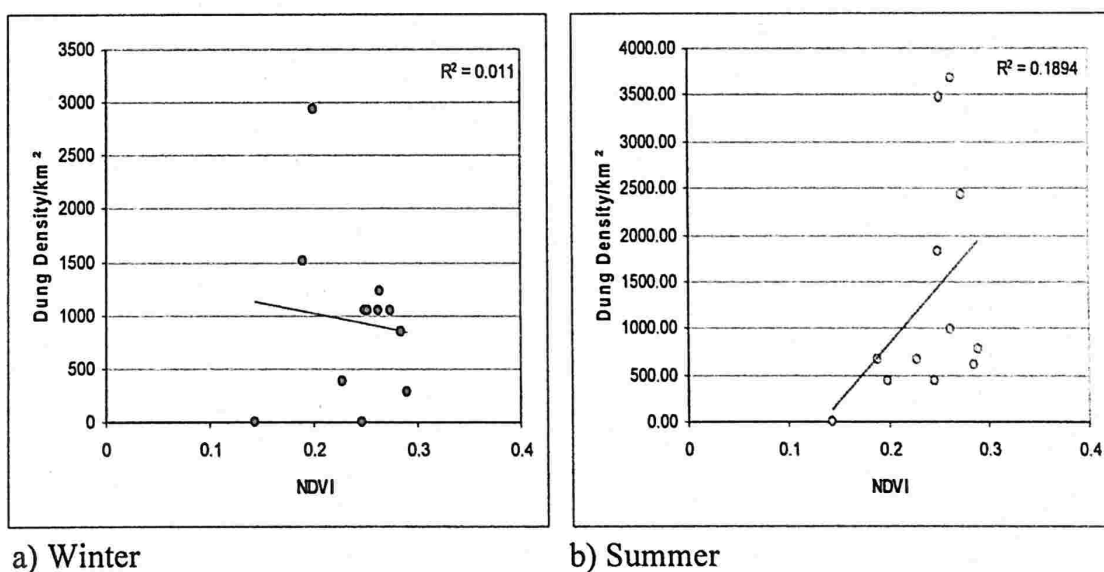


Figure 4.23. Relationship between dung densities and NDVI in each grid during winter and summer in the ISA, Rajaji National Park.

The relationship between the standard deviation of slope and dung density (Fig. 4.24) shows a negative trend in both winter, ($R^2=0.0333$) as well as in the summer season ($R^2=0.0389$).

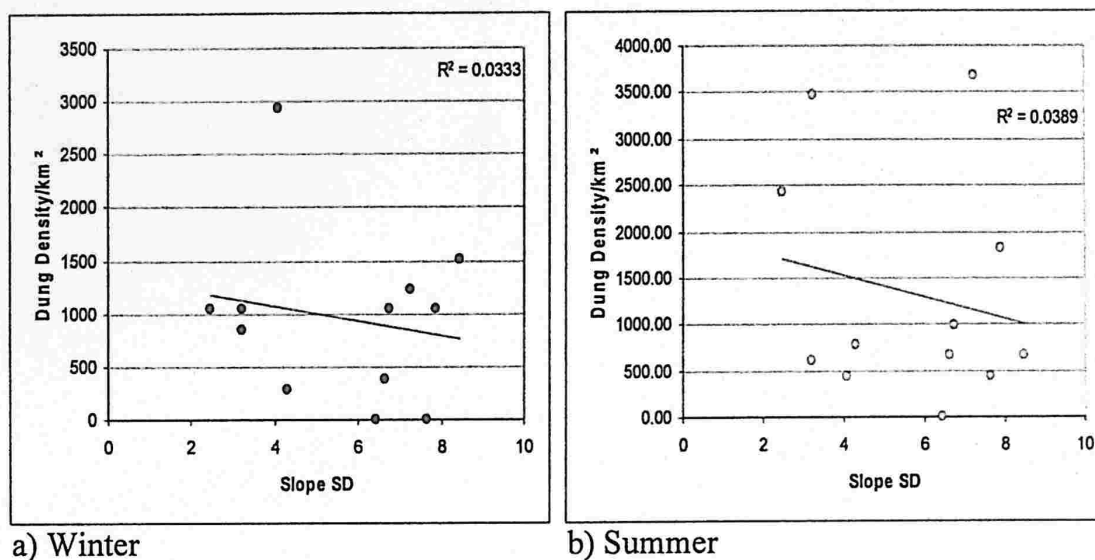


Figure 4.24. Relationship between dung densities and standard deviation of slope in each grid in winter and summer in the ISA, Rajaji National Park.

The higher elevation grids (Fig. 4.25.) show a lower dung density during winter ($R^2=0.216$) and summer ($R^2=0.1443$).

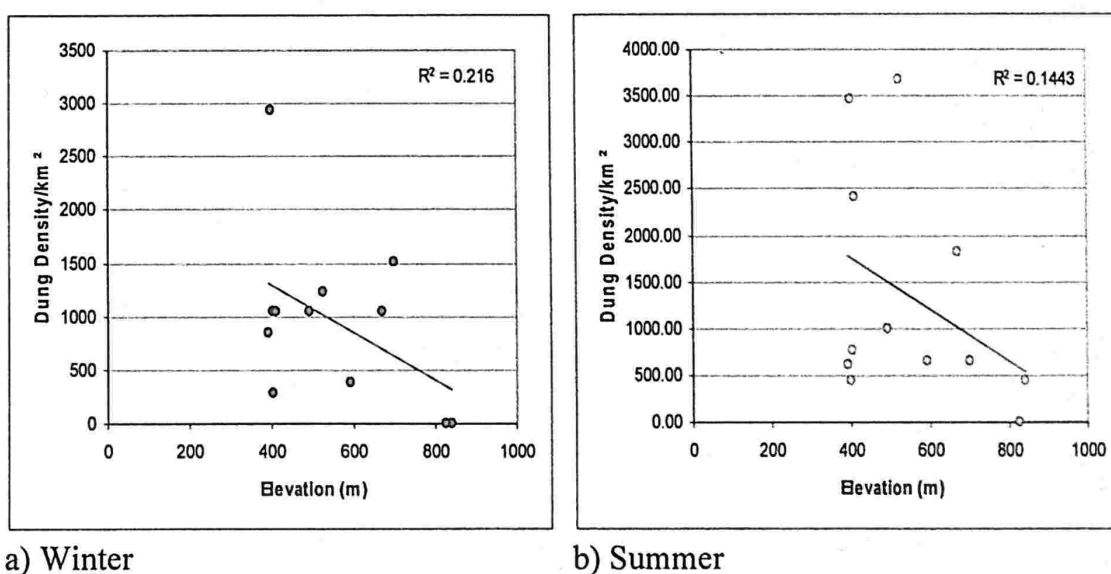


Figure 4.25. Relationship between dung densities and elevation in each grid in winter and summer in the ISA, Rajaji National Park.

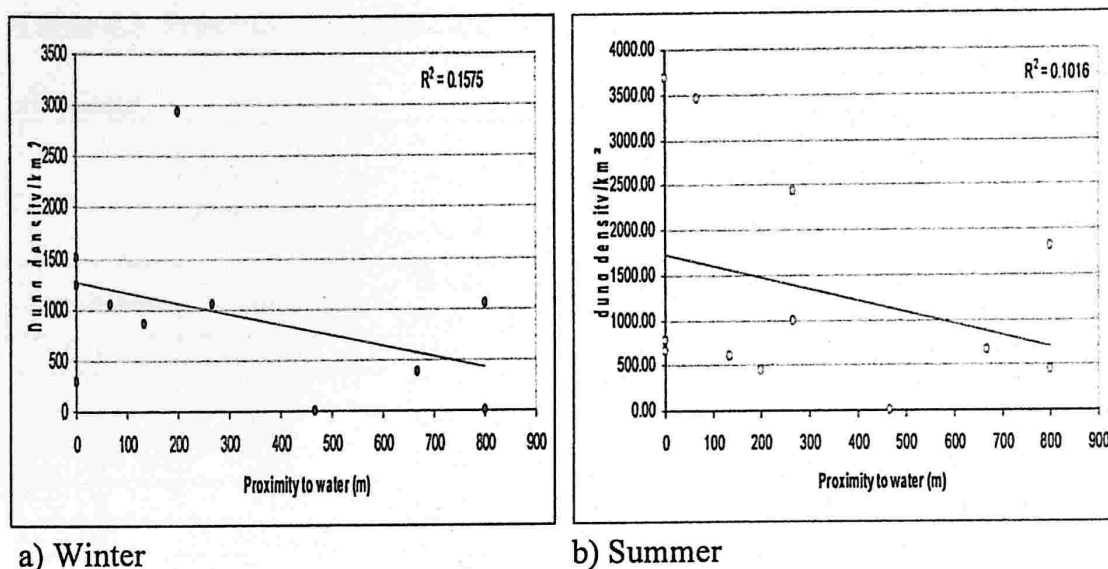


Figure 4.26. Relationship between dung densities and proximity to water of each grid in winter and summer in the ISA, Rajaji National Park.

The proximity to water is a major factor in determining the distribution of elephants in the study area (Fig 4.26). In winter, the relationship is negative ($R^2=0.1575$) with dung densities decreasing with increasing distance from water. In summer, the relationship remains negative ($R^2=0.1016$).

4.4.3 Distribution of dung density in relation to nutritional quality of plants

The mean grid-wise nutritive values of plant samples collected were tested with a principal component analysis for both winter (Table 4.3) and summer (Table 4.4). These show that there was no particular nutrient that could be used as a factor for explaining dung density distribution across the grids in the study area. Nine components were extracted in winter and seven components in summer.

Table 4.3. Principal component analysis of nutritional data.

a) Winter

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.569	61.875	61.875	5.569	61.875	61.875
2	2.057	22.855	84.730	2.057	22.855	84.730
3	.887	9.850	94.581			
4	.243	2.696	97.276			
5	.112	1.248	98.524			
6	7.944E-02	.883	99.407			
7	4.784E-02	.532	99.938			
8	4.721E-03	5.245E-02	99.991			
9	8.500E-04	9.444E-03	100.000			

Extraction Method: Principal Component Analysis.

b) Summer

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.478	78.254	78.254	5.478	78.254	78.254
2	.852	12.174	90.429			
3	.462	6.604	97.033			
4	.188	2.693	99.726			
5	1.861E-02	.266	99.991			
6	5.914E-04	8.449E-03	100.000			
7	9.094E-06	1.299E-04	100.000			

Extraction Method: Principal Component Analysis.

When dung density distribution was compared with percentage nitrogen (Fig. 4.27) in winter, there was a weak positive trend ($R^2=0.0256$). A weak negative trend ($R^2=0.032$), during summer indicated that dung densities decreased with increasing percentage nitrogen. Thus there is no clear relationship between the percent of nitrogen and the habitat use by elephants in this landscape.

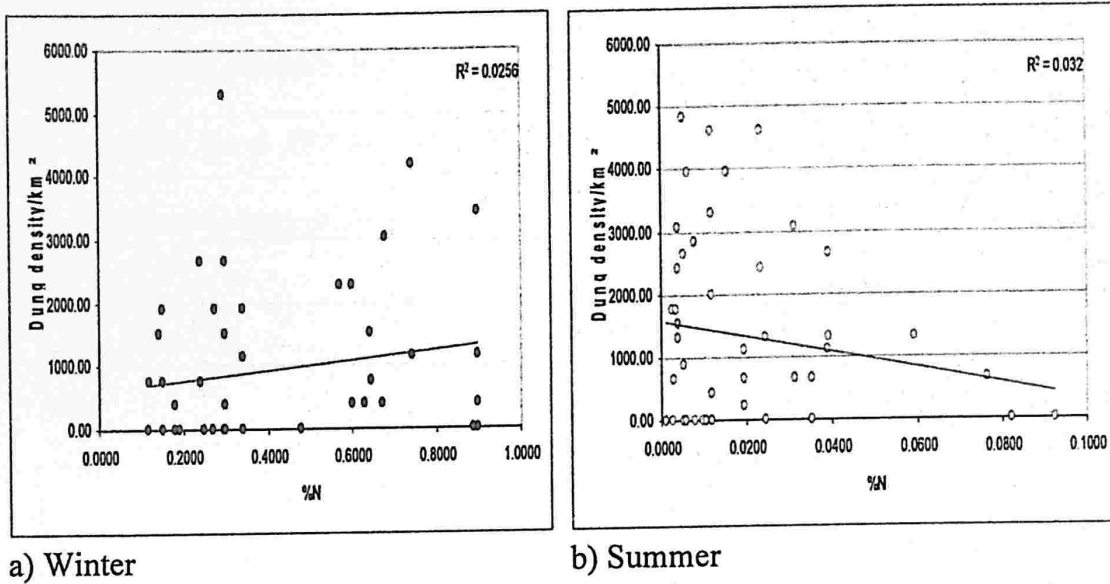


Figure 4.27. Relationship between dung densities and percent nitrogen content during winter and summer, in the ISA, Rajaji National Park.

The relationship between dung densities and percentage acid detergent fibre (ADF) (Fig 4.28) in winter indicated a weak positive trend ($R^2=0.0012$). During the summer season, there was a weak negative trend ($R^2=0.0657$). Hence, there is no clear relationship between percentages ADF in both seasons in the study area.

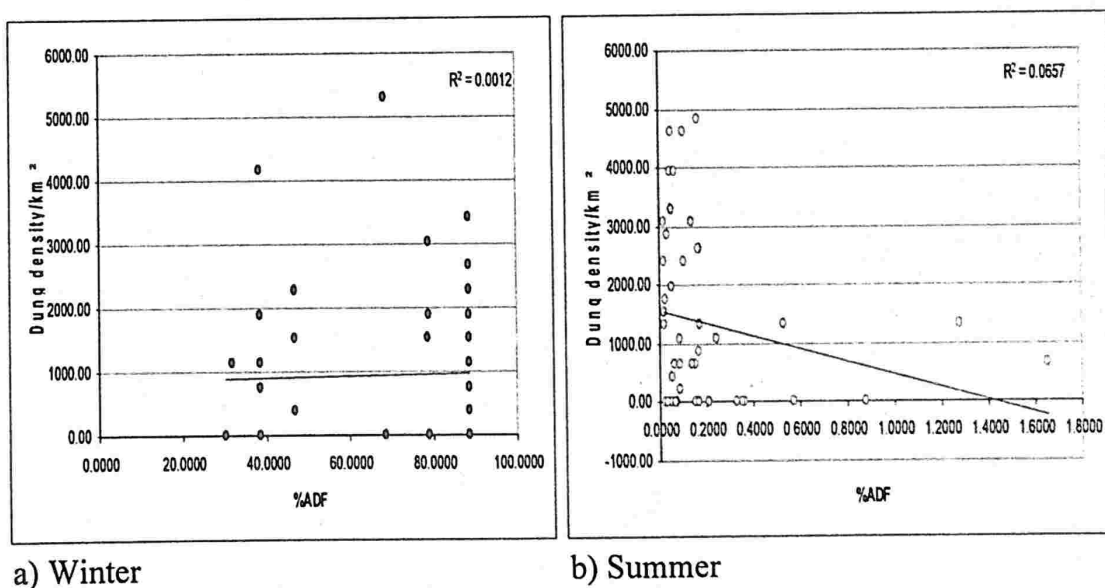


Figure 4.28. Relationship between dung densities and percent acid detergent fibre content during winter and summer in the ISA, Rajaji National Park.

In relation to percentage ash content (Fig. 4.29.), dung densities in winter indicated a weak positive trend ($R^2=0.0114$). During the summer season, there is a weak negative trend ($R^2=0.0641$). This also shows that in neither season is do elephants select against percentage of ash in their forage in the study area.

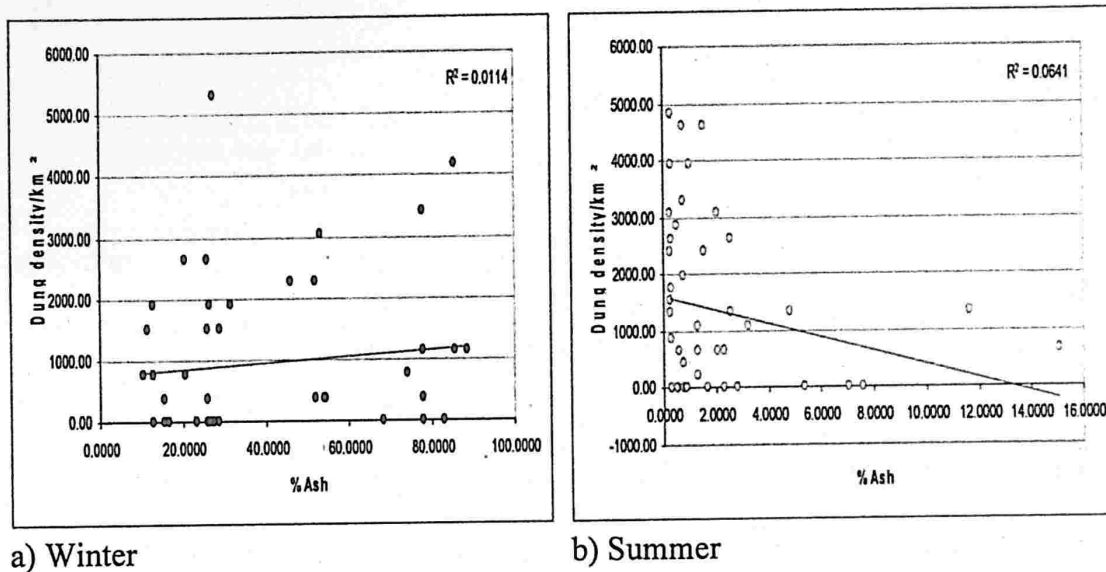


Figure 4.29. Relationship between dung density and percent ash content during winter and summer in the ISA, Rajaji National Park.

When compared with sodium (Fig 4.30.), dung densities showed a very weak positive trend ($R^2=0.0092$) in winter. In summer, the trend was negative ($R^2=0.0834$). This shows that sodium is not an important factor governing the distribution of elephants in both winter and summer in the study area.

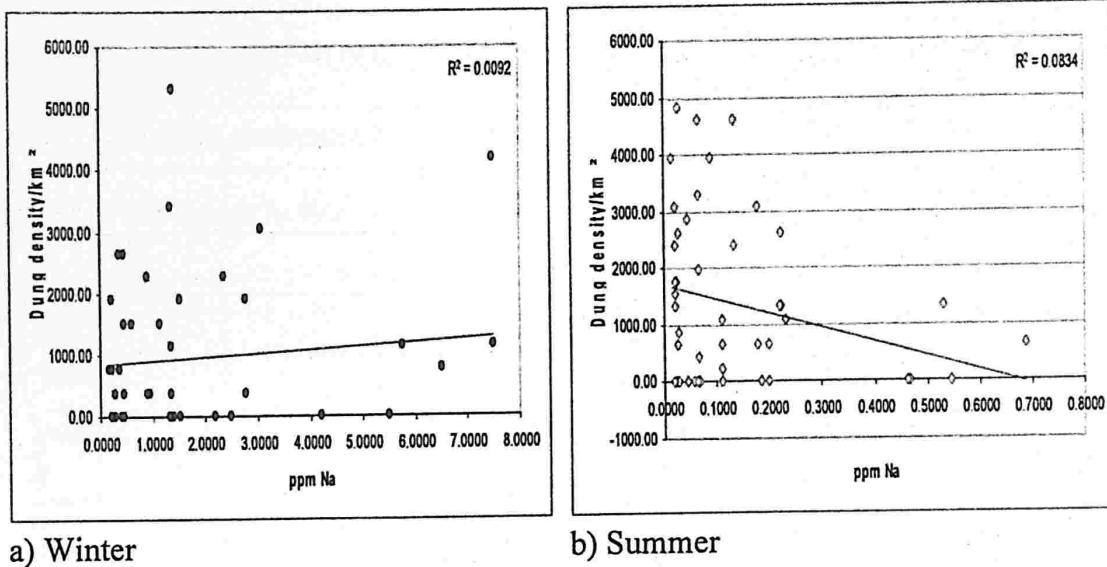


Figure 4.30. Relationship between dung density and sodium content in winter and summer in the ISA, Rajaji National Park.

In the winter season, when compared with dung densities (Fig 4.31), potassium showed no trend ($R^2=0.001$), but in summer, there was a weakly negative trend ($R^2=0.0076$). Thus, the present level of potassium content in plants does not role influence the distribution of elephants in the study area, in either winter or summer.

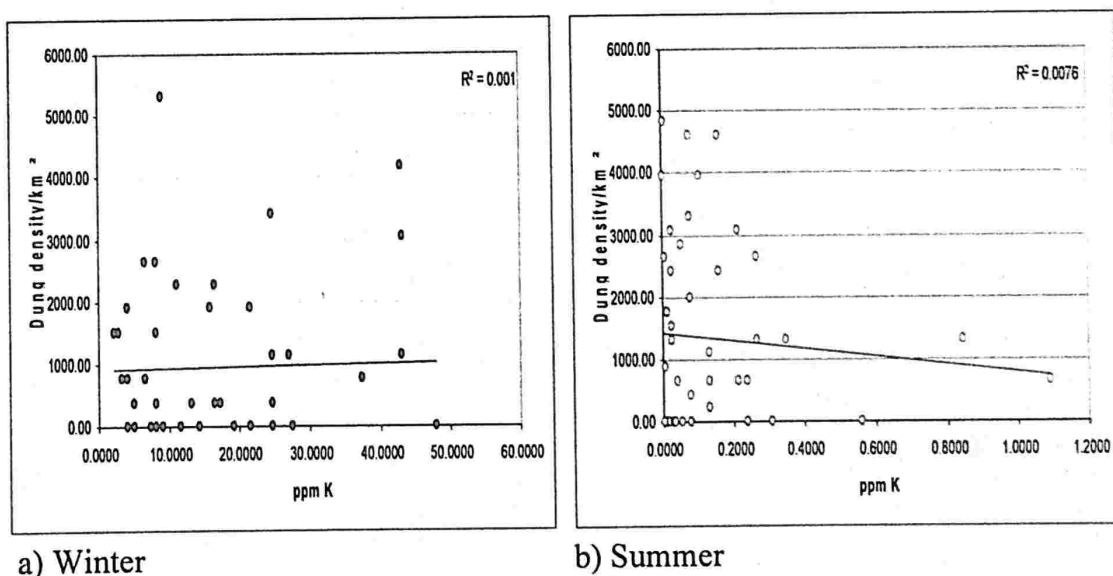


Figure 4.31. Relationship between dung density and potassium content in winter and summer in the ISA, Rajaji National Park.

During the winter season, calcium (Fig 4.32) does not show any relationship with dung densities ($R^2=0.0002$). In the summer, it shows a weak negative trend ($R^2=0.0511$). Elephant movements are hence not influenced by the presence of calcium content in the forage in this landscape.

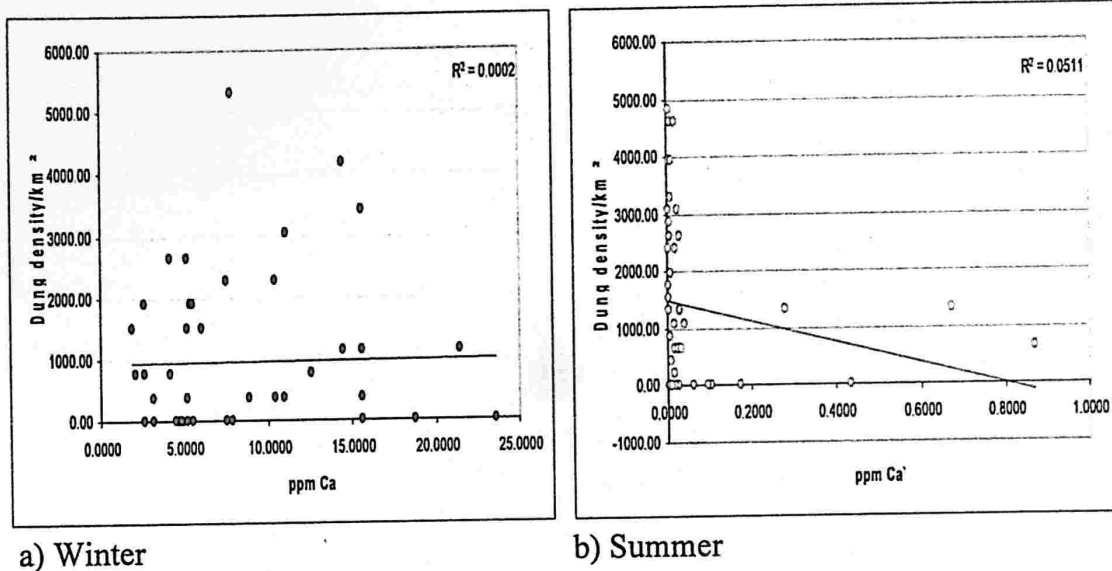


Figure 4.32. Relationship between dung density and calcium content during winter and summer in the ISA, Rajaji National Park.

The presence of magnesium in forage plants does not show any relationship with dung densities (Fig 4.33) in the winter season, $R^2=0.0007$. In summer, there is a weak negative trend ($R^2=0.004$). Hence, this nutrient has no influence on elephant use in any of the grids in the study area.

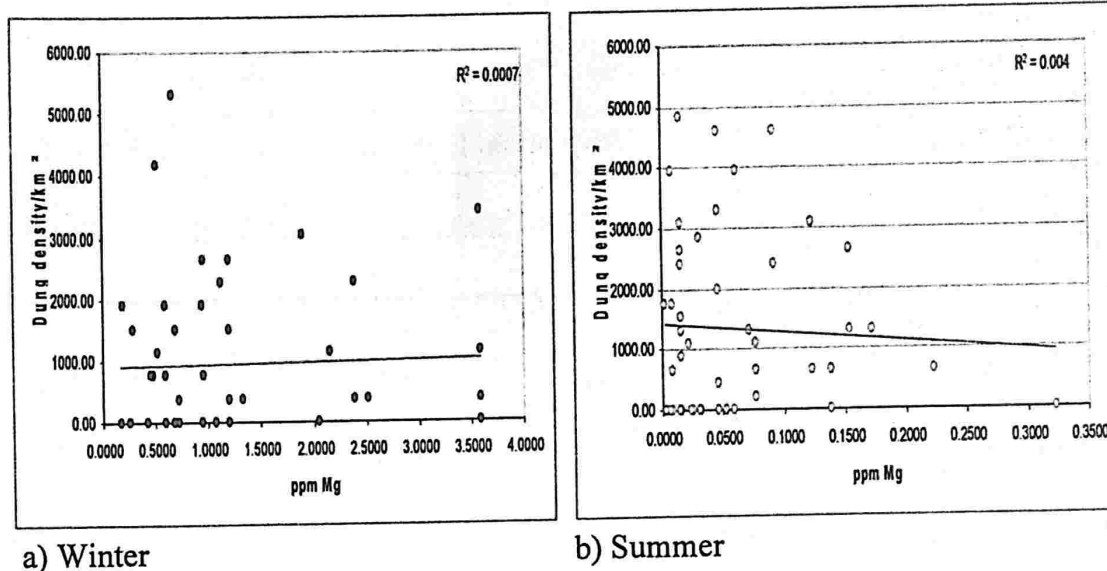


Figure 4.33. Relationship between dung density and magnesium content during winter and summer in the ISA, Rajaji National Park.

Zinc, present in extremely small concentrations in the plant samples of preferred species collected in the study area (Fig. 4.16, Table 4.1) and shows a weak positive trend ($R^2=0.0298$) in winter and a weak negative trend ($R^2=0.026$) in the summer (Fig. 4.33.). Thus the present micro-nutrient level in plants has no influence on the distribution of elephants in the study area during both the seasons.

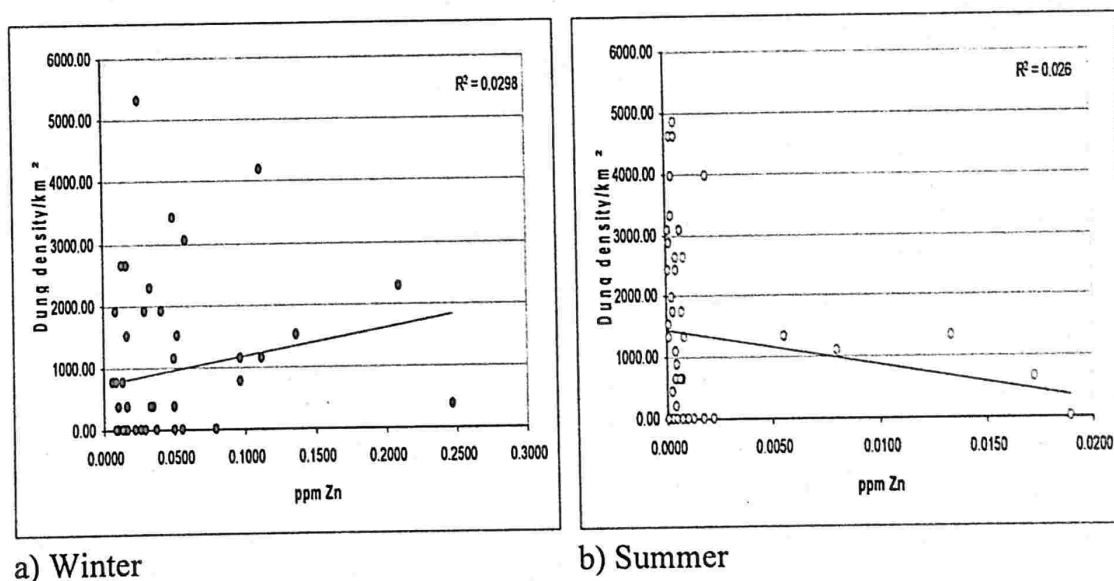


Figure 4.34. Relationship between dung density and zinc content during winter and summer in the ISA, Rajaji National Park.

CHAPTER 5.0. DISCUSSION

Herbivores have long been known to demonstrate preferences for different plant species and individual plant parts within a species (Belovsky 1981). Food selection can take two main forms- plant species and plant-parts. Selection of plant species results in a characteristic composition of a species diet in a particular habitat, while the selection of plant-parts appears to be aimed at obtaining the component with the highest nutritive value in the plant (Leuthold 1977). It is often mentioned that elephants are generalist feeders because they consume a wide variety of plants and plant parts (Sukumar 2003). Feeding behaviour in the short-to-medium term of days or a few weeks essentially involves food selection within one or a few vegetation communities, while the seasonal changes in diet may involve complete shifts to different vegetation communities (Sukumar 2003). An elephant, when feeding, seldom spends much time feeding on one particular plant species (McKay 1973). The proximate factor that influences the decision to consume or reject a plant is the palatability of the item as conveyed to the herbivore through the senses of smell, taste, sight and touch. The selection of dietary items obviously depends to a large degree on what is available and its quantity. Heterogeneity in resource quality, coupled with adaptive response in diet selection, will cause the form of nutritional gain response to deviate from that of intake response. The form of gain response depends moreover on the extent to which digestive capacity is limiting (Owen-Smith 1988).

Elephant foraging behaviour was studied in Chilla Range of Rajaji National Park in relation to habitat heterogeneity and plant nutritional value. Data on elephant distribution determined by dung density indicates that animals are non-uniformly distributed during summer and winter. This may be due to variation in habitat quality.

The examination of the stomach contents revealed 25 plant species in the diet of African elephant (Buss 1961). Similar examination by B.R. Williamson of African Elephants identified 61 browse species (cited in Sukumar 2003). In Maputo Elephant Reserve, Mozambique, a total of 95 different plant species were identified in faecal samples. (Douglas-Hamilton 1972, De Boer 2000). Also as elephants are known to utilize a wide range of species when available, relying heavily on graminoids in the wet season and almost exclusively on woody browse during the dry season (Barnes 1996), therefore they would select areas with more woody plant species during the hot, dry season, rather than grassy patches. In Maputo Elephant Reserve, Mozambique, a total of 95 different plant species were identified in faecal samples. The percentage of grass was relatively low compared with other studies, increasing at the beginning of the rainy season. At the end of the dry season, elephants concentrated on the few available browse species with young leaves, but generally preferred grass species to browse species. The habitat in Rajaji National Park being Shiwalik forest ecosystem where availability of grasses is very limited, elephants prefer to select browse species throughout the year. The relatively less number of observed major food plants in the diet of elephants in this area in comparison to what has been observed from Africa could be due to the relatively high abundance of these forage plant species. This could be one of the reasons that elephant distribution is strongly related with the abundance of woody plants.

| ref??

These data indicate that diet composition studied in African elephant was mainly affected by season and less by habitat (De Boer & Douglas-Hamilton 2000). In Rajaji National Park, 38 food plant species were recorded based on direct observations, of which 88% consisted of browse. *Mallotus philippensis* contributed to a major portion of the diet and was fed upon in all seasons. 50% of the elephants' diet

was constituted by six species, viz., *M. philippensis*, *Ehretia laevis*, *Acacia catechu*, *Dalbergia sissoo*, *Ougenia oogenensis* and *Shorea robusta* (Christy *et al* 2005). These species were amongst the 12 woody plant species selected for quantification in this study (Table 3.1).

The increasing height of canopy base has a negative effect on elephant habitat use in both the seasons (Fig. 4.19) since a higher canopy base would mean inability to reach browse and the animal would rely on pushing down trees to access browse. Most studies have shown that elephants cause slight damage to short trees more often than expected by chance (Caughley 1976, Laws 1970) and push over large trees from which leaves could not be reached (Caughley 1976). A study in Sengwa, Zimbabwe indicated that elephants selected for tree canopy base heights of 6m, the maximum reach for an elephant (Sukumar 2003). In the present study, most of the grids selected by elephants had a height of canopy base in the range of 1.5m – 3.0m and would indicate preference of more foraging species in the middle level of canopy.

Canopy volume showed a negative trend to dung density (Fig. 4.20). This could be a result peculiar to this study area, as most other studies have shown that tree canopy volumes to be a factor in the selectivity of plant species in Sengwa, Zimbabwe (Sukumar 2003).

Canopy cover showed a positive trend to dung density (Fig 4.21) during winter than summer. This would be due to the greater availability of browse in areas having a higher average canopy cover. Data indicates a positive relationship between canopy cover and the number of woody plant species ($R^2=0.23$). Other studies in Africa however, indicate that the preferred habitat of the elephants being secondary forest (Eltringham 1977), opening the vegetation cover would be beneficial to them. Some authors have put forth the assumption that the elephant increases the availability

of its food by breaking or uprooting trees (Eltringham 1977). This would cause more areas to become available for grasses in comparison to browse species, which are more sparsely distributed.

The selection of dietary items obviously depends to a large degree on what is available. In the processing of consuming an ideal diet from a natural environment, an elephant has to select from a changing mosaic of different plant species, phenological stages, structural types, chemical compositions, relative or absolute abundances and dispersion patterns (Sukumar 2003). In the study area, results show that in winter, when resources are abundant, there is no selection of foraging areas with higher species diversity (Fig. 4.22). In the summer, this shows a negative trend, which is probably due to the availability of certain species of preferred plant species in pure stands, such a *Mallotus philippensis* (Christy *et al* 2005, Prajapati 2007). In this study, it is evident that elephants meet the majority of their nutritional requirements from all the 12 selected woody plant species during the winter and summer seasons. As the nutritional content of most of these plants seems to be higher than the threshold required by elephants, therefore there was no selection of any one plant species in any particular season.

The relationship between dung density and Normalised Difference Vegetation Index (NDVI) (Fig 4.23) shows that there is a negative trend of dung densities with NDVI in winter, while there is a strong positive trend in summer. This could be because elephants select areas with greener vegetation in summer, rather than in winter when most of the plants have abundant green leaves. On a daily scale, intake rates are limited by digestion and excretion, and the amount of time invested for foraging (Shipley *et al* 1994). Hence, elephants in the study area have to follow the patterns of phenology across the season to obtain optimal forage. Data has clearly

indicated the spatial variation in habitat use by elephants during winter and summer (Fig. 4.17.)

It is evident from the results that the slope has a negative effect on the dung densities in the study area in both seasons (Fig. 4.24). Steeper terrain would limit the amount of forage available to elephants and most of such areas have a very low canopy cover which does not provide adequate thermal cover.

Elevation is also a limiting factor in the distribution of elephants in the study area. The higher elevation grids had higher canopy base heights, which as has been mentioned before, is a limiting factor in elephant habitat use.

Elephants need not just food but also water in large quantities. Their movement would also be governed by the spatial distribution and temporal availability of water (Sukumar 1989a). The presence of water is often the best predictor for elephants, especially for females, and particularly during dry seasons and in dry areas. This limits elephants to permanent water sources, including artificial water holes, in the dry season (Harris *et al* 2008). Most descriptions of elephant spatial foraging patterns have been limited to the substantial vegetation impacts observed in terms of broken trees within close vicinity to river fronts and other water sources during the dry season (Eltringham 1980). This may be seen in the study area, the proximity to water influences the presence of elephants in an area (Fig. 4.26) in both seasons and could be because the *bhabar terai* tract where the study area is located is hot and dry and most precipitation that occurs percolates into the soil, leaving not much available surface water.

The nitrogen content of a plant is only one of the many plant characteristics that are vitally important to herbivores. Because of its central role in all metabolic processes as well as in cellular structure and genetic coding, nitrogen is a critical

element in the growth of all organisms (Mattson 1980). While nitrogen, as a surrogate for crude protein did not play a major role in influencing the dung density in grids (Fig. 4.27), this is not so in other studies. The elephant's strategy of alternating seasonally between grass and browse is related to the plant's protein content (Sukumar 1989b). The levels of nitrogen in most plants used for foraging by elephants in the study area are high in both seasons (Fig. 4.9), and hence they do not need to compensate with a shift in diet between seasons to maintain minimum levels of intake.

Digestion inhibitors consist of fibres and tannin. There is no doubt that fibre (often measured as acid detergent fibre (ADF)) is a major deterrent in food selection (Mole & Waterman 1987). The elephant habitat use in the study area was however, not influenced by the amount of ADF in the preferred plant species (Fig. 4.28) and this may be due to the elephant being a hind-gut fermenter, they extract nutrients by feeding on large amounts of forage containing fibre.

The content of ash in the selected plant samples was not a criterion for high dung densities (Fig 4.29).

Sodium requirements of elephants have not been directly measured, but rough estimates are possible if extrapolations are made from information available for other species. Daily sodium requirements for mammals vary isometrically with body mass (Holdø 2002). The amount of sodium in selected plant species in the study area had no influence on the distribution of elephants in the study area (Fig. 4.30). Since there is a seasonal difference in the sodium content in most selected plant species in the study area, the sodium intake could be compensated for by foraging on *Holharena antidysenterica* and by *Acacia catechu* in summer, or by using natural salt-licks which are considered to be rich in sodium content (McKay 1973).

Potassium had no influence in the distribution of dung densities across the grids sampled in the study area (Fig. 4.31). The levels of potassium are low in the summer season (Fig. 4.13) and this probably compensated for by higher consumption of *Ehretia laevis* and *Ougenia oojenensis*. In winter, all plant species have a relatively high concentration of potassium.

Considerable amounts of bark were consumed during the dry season in southern India, while much less was observed in the wet season. The calcium content of dicotyledonous bark is much higher than in grasses. Although a diet of grasses alone could provide elephants with a sufficient intake of calcium, it is not known how much is physiologically unavailable. Supplementing the diet with bark could increase calcium intake to a safe level (Sukumar 1989b). In the study area, while calcium content in plants played a very minimal role in influencing the distribution of elephants in the sampled grids (Fig 4.32) in both seasons, the concentration of calcium in selected plant species was very high in winter (Fig. 4.14), while in summer, it was uniformly low, except in *Ficus benghalensis*. Feeding on the bark of this species has been observed during the summer season, in addition to other species.

The presence of magnesium in amount in plant species did not have any effect on the distribution of elephants in either season (Fig. 4.33). However, as the concentration of magnesium was almost uniform in both seasons (Fig. 4.15), there is no requirement for elephants to compensate for this mineral.

While Zinc did not influence the use of any particular habitat in either winter or summer (Fig. 4.34), the variation between the two seasons was significant (Fig. 4.16). The high winter values for the nutrient in selected plant species in *Dalbergia sissoo* and *Haplophragma heterophyllum* is compensated during the summer months by the high concentrations of zinc in *Dalbergia sissoo* and *Ougenia oojenensis*.

The nutrient levels of most of the food species are different across the two seasons, with the exception percentage nitrogen and magnesium. A principal component analysis of nutrient data gave 9 components and hence there was no single parameter that influenced dung distribution. The seasonal variation is compensated for by high levels of nutrients in certain plants in each season. In the case of calcium (Fig. 4.14.), while the content in most plants in winter is high, only *Ficus benghalensis* contains high calcium content in the summer. Similarly, while elephants may meet their potassium requirements from a variety of plants in winter (Fig. 4.13.), only *Dalbergia sissoo* and *Ougenia oojenensis* have relatively high values. Zinc (Fig. 4.16.) is present in all plants in moderate levels during winter, but this seasonal shift in habitat use in the study area is indicated by the high use by elephants of certain grids in winter, while using other grids in summer. The number of plants in each grid had a positive influence on the distribution of elephants (Fig. 4.18). This is could be explained by the fact that elephants would select areas that have a higher number of trees rather than barren areas. This would facilitate the animal to gain higher energy / search than foraging in areas having sparse trees. Fig. 4.17. indicates that during winter, the grids with the highest dung densities were 'A' (2939.75 dung piles/km²), 'M' (1517.198 dung piles/km²), 'F' (1232.72 dung piles/km²). 'B', 'C' 'D' and 'L' had dung densities of 1043.75 dung piles/km²). During the summer season, grids 'F' (3681.16 dung piles/km²), 'C' (3469.31 dung piles/km²), 'D' (2417.48 dung piles/km²) and 'B' (1813.11 dung piles/km²).

In conclusion, it may be surmised ~~from the results~~ that habitat use by elephants in the study area directly proportional to abundance and wood plant species, canopy cover and proximity to water and seasonal variation in plant nutrients and PCA clearly indicates that habitat use by elephants in the study area is not influenced by the

nutritional quality of selected plant species and probably meets its nutritional requirements by foraging on different species during the summer and winter seasons.

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