FEEDING ECOLOGY OF THE FOUR-HORNED ANTELOPE (*Tetracerus quadricornis,* de Blainville 1816) IN BARDIA NATIONAL PARK, NEPAL

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DECLARATION

I hereby declare that the work embodied in this thesis entitled "**Feeding ecology of the four-horned antelope (*Tetracerus quadricornis*) in Bardia National Park, Nepal**" forms my own contribution to the research work carried out under the supervision of Dr. Tej Bahadur Thapa, Associate Professor, Central Department of Zoology, T.U. and has not been submitted for any other degree of this or any other University. Any literature and data cited within this dissertation have been specifically acknowledged by reference to the author(s) or institution(s) and help done by people during this period has been given due acknowledgement.

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RECOMMENDATION

This is to recommend that the thesis entitled **"Feeding ecology of the four-horned antelope (*Tetracerus quadricornis*) in Bardia National Park, Nepal"** has been carried out by **Mr. Amar Kunwar** for the partial fulfillment of Master's Degree of Science in Zoology with special paper 'Ecology and Environment'. This is his original work and has been carried out under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree(s) in any institution(s).

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LETTER OF APPROVAL

On the recommendation of the supervisor Tej Bahadur Thapa, Ph. D., Associate Professor, Central Department of Zoology, T.U. this thesis submitted by **Mr. Amar Kunwar** entitled "**Feeding ecology of the four horned antelope (*Tetracerus quadricornis*) in Bardia National Park, Nepal"**, is approved for the examination and submitted to the Tribhuvan University in partial fulfillment of the requirements for Master's Degree of Science in Zoology (Ecology and Environment).

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CERTIFICATE OF ACCEPTANCE

This thesis work submitted by **Mr. Amar Kunwar** entitled "**Feeding ecology of the four horned antelope (*Tetracerus quadricornis*) in Bardia National Park, Nepal."** has been approved as a partial fulfillment for the requirements of Master's Degree of Science in Zoology specializing in Ecology and Environment.

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ABSTRACT

Feeding ecology of Four-horned antelope *Tetracerus quadricornis* was assessed in Bardia National Park, Nepal during summer, monsoon and winter seasons to determine the diet composition, seasonal variation in diets and to assess niche breadth of food plants. Systematic belt transects were used in the field to collect reference plants' parts and FHA fecal samples while microhistologcal technique was used to determine diet. Microphotographs of different parts of 104 plants were prepared and 3000 fragments of 100 faecal samples (summer=60, monsoon=20, winter=20) were analyzed. Diet composition was expressed in terms of percent occurrence while Chi-square test was used to assess seasonal variation in diet and Levin's niche breadth to evaluate degree of selectivity of food plants.

The FHA was found to be a mixed feeder feeding on 15 tree species, 15 shrubs, 8 forbs, 5 grasses and 2 climbers belonging to 20 different families. It fed on 10 species of monocots and 35 species of dicots. Trees were the major food plants (25.87%), followed by shrubs (21.3 %), forbs (18.2 %), grasses (10.5 %) and climbers (4.36%). Plants of Gramineae family were consumed in highest proportion (17.64 %), followed by Acanthaceae (9.13 %) Rubiaceae (7.8 %), Asteraceae (6.56 %), Euphorbiaceae (6.4 %) and others. *Metragyna parviflora, Bridelia retusa, Bambusa vulgare, Hymenodictyon arixenese* and *Zizyphus mauritiana* were major tree species while *Berlaria cristata, Pogostemon benghalensis Achyranthus* sps, *Clerodendrum viscosum* were among shrubs. *Ageratum cristata* and *Blumea virens* were the main forbs. *Eulaliopsis binata* and *Imperata cylindrica* were the principal grass species. Climber *Trachetospermum lucidum* was consumed in small proportion. There was significant difference in consumption of functional plants (χ^2 = 112.20, d.f. = 10, p= < 2.2e-16) as well as species (χ^2= 969.31, d.f. = 90, p= < 2.2e-16) in three seasons. Trees contributed the major percentage of diet in all three seasons. Shrubs were consumed relatively in higher proportion in winter (29.00 %), than in summer (19.89 %) and monsoon (17.83 %). The preference order of forbs followed from summer (20.56 %) to monsoon (17.83 %) and winter (11.50 %). Grasses in monsoon were consumed distinctly in higher percentage (16.83 %) than in summer (10.22 %) and winter (5.00 %). Climbers contributed in small proportion in all three seasons. Browse to grass ratio was maximum in winter (6.08) while it declined to 3.82 in summer and to 1.97 in monsoon. The niche breadth (B_s) of the food plants was 0.050 showing that the FHAs are highly selective of specific forage plants. Niche breadth was broader in summer season (0.045) but narrowed to 0.039 in monsoon and to 0.028 in winter. FHAs in BNP are concentrate feeders and browsers with a high degree of food plant selectivity. Similar studies are to be conducted in other landscapes also and with sympatric and potential competitor species to understand its niche overlaps and degree of competition.

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LIST OF ABBRIVIATIONS

BCP	Bardia Conservation Programme
BNP	Bardia National Park
BPP	Biodiversity Profile Project
CDB	Central Department of Botany
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora.
Cm	Centimeter
CMOS	Complimentary metaloxide semiconductor
DCM	Digital Camera Module
DHM	Department of Hydrology and Meteorology
DNPWC	Department of National Parks and Wildlife conservation
g	gram
GoVN	Government of Nepal
GPS	Global Positioning System
IAAS	Institute of Agriculture and Animal Science
IUCN	International Union for Conservation of Nature and Natural Resources
Kg	kilogram
Km	kilometer
m	meter
Msl	Measurement at sea level
NTNC	National Trust for Nature Conservation
USB	Universal Serial Bus
w/v	weight/volume

1. INTRODUCTION

Quantifying diet is the first important aspect of studying animals, without full understanding of what they eat, why they eat, where they eat, how it changes over time, species specific management is nearly impossible. Feeding habits of mammals are in the center of interests of population biology and ecology (Green 1987). Efficient management of ungulate herds requires extensive knowledge of herbivore diets and food habits (Holechek et al. 1982, Mofareh et al.1997, Sandoval et al. 2005). Knowing the diet composition of herbivores is important for understanding their foraging ecology and for mediating their effects on vegetation and ecosystems (Barcia et al. 2007). Knowledge of diet selection is fundamental in understanding several aspects of ungulate ecology (Hobbs et al. 1983) and management of ungulate populations often requires diet to be estimated (Bookhout 1996). Food plays an important role in species reproduction, growth and survival (Pekins et al. 1998) so have an impact on species population dynamics. It is more important for patchily distributed (Sharma et al. 2013), vulnerable (IUCN 2013) and low density species (Sharma et al. 2009) like four horned antelope *Tetracerus quadricornis* (de Blainville 1816), the feeding ecology of which is very little studied in India (Berwick, 1974, Krishna et al. 2009, Baskaran et al. 2011) and not in Nepal till date. The most widely used indirect technique for determining diet composition of herbivores is fecal analysis through the microhistological identification of epidermis fragments in the stomach content or fecal pellet (Baumgartner 1939, Dusi 1949). It is often the only practical method available, particularly with some rare, endangered and evasive wild herbivores on which collecting ruminal samples are not possible (Gonzalez and Duarate 2007). It also does not require contact with individuals and is therefore considered non-invasive. Sampling also requires little equipment and can be used to compare different species or individuals of the same species simultaneously (Holechek et al. 1982). The microhistological technique involves mounting a sample of rumen contents on microscope slides so that species can be identified by their unique cell and structural properties (Sparks and Malechek 1968). While adopting this technique, it requires a library be constructed of all forage species within the study area which is used as a reference to the species of forage found within pellets collected in order to determine the diet composition.

1.1 Species introduction

Four Horned antelope *Tetracerous quadricornis* (de Blainville 1816) is a small tropical antelope endemic to the Indian sub-continent (Corbet and Hill 1992) and occurs only in India and Nepal (Prater 1980, Rice 1991, Rahmani 2001, Singh and Swain 2003, Sharma et al. 2005, Leslie and Sharma 2009). It is also called *Chouka* or *Chousinga*. Four horned Antelope, hereafter as 'FHA', is taxonomically classified under the boselaphini tribe, sub family bovinae and family bovidae. The IUCN Red list has listed this animal as vulnerable species with decreasing population trend (IUCN 2013) and is included in Appendix III of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). It lives in undulating or hilly terrain (Prater 1980, Rahmani 2001) and has a distribution, occurring in scattered populations throughout most of India, from the Himalayan foothills to peninsular India (Rahmani 2001). About 95 percent of its global population occurs in India while rest 5 percent in Nepal (Rahmani 2001). In Nepal, they are reported from four protected areas; Bardia National Park (Steinheim et al.2005), Chitwan National Park (Gurung and Singh 1996), Parsa wildlife Reserve (Shrestha 2001) and Banke National Park (DNPWC 2010). Some small numbers may be found outside reserves in the forested areas of Banke and Bara Districts (Heinin and Yonzon 1994). These reports from Nepal suggest that the species is present in the Terai, but a recent ungulate distribution survey in the Indian Terai Arc region did not find any evidence on the occurrence of this species in Terai (Johnsingh et al. 2004). This low-density species was formerly distributed widely in deciduous forests throughout its range, but the current distributional patterns are largely unknown and conservation efforts are hindered by the lack of information on species-habitat relationships (Krishna et al. 2008). FHAs are unique, being the only bovid with four horns in males and are the last survivors of a form very similar to that of the ancestors of the entire sub family. Its nearest relatives among antelopes are Nilgai *Boselaphus tragocamelus*, the African Bushbuck *Tragelaphus species*, Kudu *Tragelaphus species* and Eland *Taurotragus species* (Pokharel 2010). The tribe Boselaphini is believed to have emerged around 6.54-9.64 million years ago in India and are considered to be very primitive, having hardly changed since Miocene period, around 15 million years ago (Bibi 2007).

1.1.1 Morphology

Generally adult FHA weighs 17-21 kg and stand 55-64 cm at the shoulder height (Sharma and Rahmani 2004) and there is no diagnostic size dimorphism between the sexes (Sharma 2006). The Four Horned Antelope has a golden brown coat that darkens after the monsoon season and fades after winter. There is a dark stripe running down the front of each leg and conspicuous white ring just above the hooves. The male has peculiar two pairs of horns. The rear pair of horns starts developing when it is a few months of age while the development of the second pair starts at an age of about 14-15 months (Sharma and Rahmani 2004). The antlers are nearly straight, conical in shape and pointed upwards. The anterior pair of antlers measure approximately 1-2.5 cm which are always shorter than the posterior ones (8-12 cm). The front pair of antlers may fall off in older animals, or may merely be represented by nodules of black, hairless skin (Prater 1971). The female is similar to the male in all aspects but has no horns. Relative to their masses, stature, coloration and habitat preferences, FHA may be confused with Barking Deer (*Muntiacus vaginalis*) and hog deer (*Axis porcinus*) (Nowak 1991).

1.1.2 Ecology

1.1.2.1 Population characteristics

Densities of *Tetracerus quadricornis* are generally low and vary depending on habitat conditions, competition with domestic livestock, predation, and degree of protection (Leslie and Sharma 2009). No density estimates of *T. quadricornis* are available from Nepal (Heinen and Yonzon 1994). Specific population densities reported from India vary in different Parks and Reserves from 0.22–0.75 individuals/km^2 in Gir Lion Sanctuary (Berwick 1974, Berwick and Jordan 1971, Khan 1997, Khan et al. 1996, Rice 1991) to 2.05 individuals/ km^2 in Kanha National Park (Schaller 1967). Maximum life span of *T. quadricornis* is generally ≤10 years (Grzimek 1990, Jones 1982). Group size data (Karanth and Sunquist 1992) suggest that FHA tend to be solitary, with a maximum size being three and occur at very low densities (usually less than 1/sq km).

1.1.2.2 Habitat use

FHA is a habitat generalist (Berwick 1974, Sharma 2006) and is mostly observed in dry deciduous mixed forest with thickets and clusters of trees even within open dry patches, hilly terrain and limited human disturbances (Prater 1980, Sharma 2006, Sharma et al. 2005, Singh 2001). It is non-migratory, and although little is known about its space use, it is likely sedentary (Krishnan, 1972) with individuals possibly occupying exclusive home ranges (Sharma and Rahmani, 2004). They have habit of defecating in a particular site that indicates that they are the home range animals. *T. quadricornis* avoids disturbed areas and distribution is constrained by their daily need for free water (Blanford 1888, Krishnan 1972, Prater 1980).

1.1.2.3 Food Habits

FHA is a herbivore with a ruminal digestive system. It is a browser and concentrate feeder (Karanth and Sunquist 1992, Sharma and Rahmani 2004). It forages selectively and prefers nutritious plant parts such as fruits, flowers and fresh leaves (Berwick 1974, Sharma et al. 2005). About 8 percent of the FHA diet comprises of fruits and flowers (Bhaskaran 2011). The FHA prefers, in ascending order, legumes, other herbaceous species, woody species and grasses- generally reflecting selection of most nutritious forage available (Solanki and Naik 1998). Some important food species are *Bauhinia racemosa, Terminalia crenulata, lannea coromandelica, Embilica officinalis, Acacia leucocephloea, Diospyros spp., Ziziphyus spp., Soymida spp. and Bombax ceiba* flowers (Krishna et al. 2009). The antelope have been reported to be dependent on water (Prater 1971 and Krishna et al. 2009), but Berwick (1974) found that the food intake of the four horned antelope in captivity did not change in response to water deprivation. This indicates that this ungulate has an intermediate water needs (Krishna et al. 2009).

1.1.3 Behaviour

The four horned antelope is a shy, non-herding ungulate and occurs solitary or in groups of less than 4 individuals throughout the year (Leslie and Sharma 2009). Breeding likely peaks

in June-July when the chance of seeing pairs of females and males is highest (Sharma et al. 2005). Very little is known about the courting behavior. Pairs can be seen moving together for a few months. Breeding males tolerate fawns, but they are wary of presence of any other males (Sharma and Rahmani 2004). Parturition can occur throughout the year but newborns are noted most often in October- November (Sharma et al. 2005). The alarming call is like that of *Muntjac'*s, but emitted at lower pitch (Sharma et al. 2009). Natural history observations of four horned antelope by Sharma et al. (2009) suggest that during foraging, the animal remains alert and cautious frequently raises its head before getting back to foraging. The majority of time for foraging is spent during the mornings and rests and sleeps during noon and evening. The FHA prefers closed canopy thickets with dense undergrowth or grass cover for resting. It has peculiar anti-predatory behavior where it prefers to hide than run, making it obscure (Sharma et al. 2009). The FHA has tendency to defecate on middens which is shared not only by one or more individuals, but also by Nilgai (*B. tragocamelus*), Chinkara (*Gazella bennettii*) like ungulates (Sharma et al. 2005). This habit coupled with that of marking with their pre-orbital glands is a means of maintaining territories (Sharma and Rahmani 2004, Krishna et al. 2009).

1.2. Rationale of the Study

Studying feeding ecology is the first step in studying an animal's ecology because it provides information on resource use, habitat utilization and competitive interactions. Food also plays an important role in species reproduction, growth and survival, so have an impact on species population dynamics. Knowledge of diet composition is essential to take management decisions for viable population maintenance in the wild. Furthermore, this species is one of the least known mammalian species in Nepal and no efforts are made to investigate its feeding ecology till today. Hence, the conservation efforts are haltered due to lack of basic information on this low density species. One of the first steps towards the conservation of this species is to identify the food habits. Realizing these facts, this study is focused on the food habits of FHA to increase the biological knowledge of the species and aid in making management decisions.

1.3 Objectives

The aim of the study was to document ecological information on food habit of four horned Antelope in Bardia National Park. The specific objectives were to:

- Determine the diet of the FHA in BNP.
- Assess the seasonal variation in diet of FHA in BNP.
- Evaluate niche breadth of the food plants of FHA in BNP.

1.4 Limitations

The actual sample size required for accurate estimation of FHA diet was unknown. During monsoon season, the heavy rain caused sweeping away of the FHA pellets in the field. Furthermore, during monsoon and winter seasons, pellets could not be immediately dried up to avoid fungal growth, hence many pellet samples decayed. So the sample size remained below required in monsoon and winter season. Hence the results could not be extrapolated for whole of the seasons. Furthermore, the year-round load shedding extended the lab work and compelled to change the method. All the reference plant species could not be classified to their scientific names from National Herbarium and Plants Laboratories, Lalitpur.

2. LITERATURE REVIEW

The Four Horned Antelope is patchily distributed in India and in some pockets of Nepal but enough detailed studies has not been conducted on it. A community study on wild ruminants in the Gir forest ecosystem by Berwick (1974) was the first study that furnished information on population density, age structure, and food consumption of this species. He observed the population density of 0.22 individuals/ km^2, ratio of male: female: fawn to be 7:5:1 with group size 1.5 and the food selected were woody plants that were highly palatable but rare in abundance. Rice (1990) reported the status of four-horned antelope based on information collected through a questionnaire survey from all states of India and reported that the four-horned antelopes were distributed in all of the Indian States south from Uttar Pradesh except Kerala. Baskaran and Desai (1999) assessed distribution of four-horned antelope in relation to major habitats, its time activity, and feeding, breeding and social organization in Mudumalai Wildlife Sanctuary, India. Krishna et al. (2008) investigated habitat factors influencing the four-horned antelope occurrence in Bandipur Tiger Reserve, India and found the tree-savanna deciduous habitat sub-type, characterized by relatively open habitats with a lower tree density and a high degree of deciduousness as the most preferred habitat by the species. Baskaran et al. (2009) evaluated population distribution and conservation of four-horned antelope in the tropical forest of Southern India. Authors observed population density of 0.22 individuals/ $km^2$and the antelopes were restricted to dry deciduous and dry thorn forests. Overgrazing by cattle and weed invasion were the threats. Similarly, Natural history observations of four-horned antelope in Panna National Park, India by Sharma et al. (2009) showed that this species had a preference for browsing over grazing, used closed canopy thickets for resting had a peculiar anti-predatory behavior and their randomly placed middens were used as points of communication. More recently, there have been a few review documentations on its taxonomic nomenclature, distribution, ecology and behavior (Leslie and Sharma 2009, Krishna et al. 2009). Baskaran et al. (2011) studied the habitat preference, activity budget, diet, social behaviour and breeding in Mudumalai Wildlife Sanctuary, India and indicated that this species prefers dry deciduous forests, is a mixed feeder and non-herding. The gestation period last for 8 months and newborns are sighted from February to

May with mean litter size 1.6. The patchy distribution of four-horned antelope in a tropical dry deciduous forest in Panna Tiger Reserve in Central India was explained by Sharma et al. (2013). They observed that distribution probability of the species was highest for habitats with tree species richness within habitat patches.

2.1 Diet of Four Horned Antelope

During a dry season free-choice feeding trials conducted in pens for wild ruminants in Gir forest ecosystem, India, Berwick (1974) observed FHAs consuming *Ziziphus mauritiana* most frequently (24.40 %). Other plants with maximum bites were *Bauhinia racemosa* (16.4 %), *Terminalia tomentosa* (9.10 %), *Soymida febrifula* (8.60 %), and *Acacia leucophloea* (6.3 %). Grasses were consumed occasionally contributing 0.2 percent. The Cafeteria experiments conducted to investigate food preferences on a captive FHA in Van Vihar National Park cum Zoo in Bhopal, India, Sharma et al. (2009) observed that 6 plant species out of 10 plants served were consumed by the animal in varying proportions. None of the grasses were consumed, whereas *Zizyphus mauritiana* (43 %), *Acacia nilotica* (31 %), *Acacia leucophloea* (11 %) and *Acacia catechu* (9 %) were foraged in decreasing order of preference. Aonla and bamboo were consumed in small and insignificant proportions (less than 3 %). Baskaran et al. (2011) studied the dry season diet of the FHA in the tropical forests of southern India and identified a total of 24 plants included in its diet. The plant species included 14 grasses, 5 herbs, 4 trees and 1 shrub. In the 24 species of food plant identified, *G. hirsuta* (a shrub) was the most frequently used food plant, which contributed nearly 5.6 % to the overall diet. In general, grasses constituted major part of the diet contributing to 28.6 %, followed by trees (8.2 %), herbs (6.7 %) and shrub (5.6 %). Notably, only 52 % of the plant remains from the pellet were identified and the rest (48 %) were unidentified either due to over digestion of cells or due to lack of reference slides.

Nevertheless, the vital data are still lacking for almost all prospects of FHAs, and more specifically for Nepal.

2.2. Microhistological Analysis

Dietary information of large free-roaming herbivores has become an increasingly important tool in resource management. In the past seven decades, the microhistological technique introduced by Baumgarter and Martin (1939) has been widely used to determine the botanical composition of herbivore diet.Various analytical procedures exist for determining the diet composition of herbivores. Havstad and Donart (1978) have generalized them as visual appraisal, manual separation, microhistological technique and microscope point technique. Of these procedures, the microhistological technique has become the preferred method for determining plant composition of animal diets from fecal sample (Havstad and Donart 1978). The accuracy of this technique was tested by Sparks and Malechek (1968) and they reported a nearly 1:1 correspondence between relative density of species fragments and the actual percentage composition by weight of hand compounded diets. However, other researchers (Holechek and Valdez 1985a, 1985b) reported this relationship does not occur for all forages.

The microhistological technique is based on three assumptions (Havstad and Donart 1978, Sparks and Malechek 1968, Fracker and Brischle 1944): (i). the fragments of plants are randomly distributed on microscope slides, (ii) percentage frequency can accurately estimate particle density and this measurement directly predicts dry weight percent composition of the sample, and (iii) ratios of identifiable to non-identifiable particles within a species are equal to one i.e. every species is as identifiable as another. The microhistological technique involves collection of diet samples, which can be from oesophageal or rumen of fistulated animals, intestinal digesta of dead animals, or fecal samples. Fresh pellets provide the most accurate results; however fossilized fecal samples dated at over 10,000 years old have also been used to determine animal diets (Hansen 1978). Vegetative fragments in samples are identified by comparison with reference slides, micro-photographs, or hand-drawn figures (Johnson et al.1983).

Microhistological analysis for determining food habits of large herbivores can be biased by differential digestibility of ingested plant species (Holechek et al. 1982). Its accuracy of fecal analysis can be affected by the extent of digestion of plant epidermis as it passes through the alimentary tract of a ruminant (Slater and Jones 1971, McInnis et al. 1983). Results from

fecal analyses can be improved by species-specific correction factors that compensate for differential digestibility of ingested forages (Voth and Black 1973, Dearden et al. 1975, Fitzgerald and Waddington 1979). Biases can also occur from poor training of technicians (Holechek and Gross 1982), sample preparation (Vavra and Holechek 1980), small sample size (Anthony and Smith 1974) and level of magnification of microscope (Holechek and Valdez 1985). Sometime correction factors are used to eliminate biases in sample (Anthony and Smith 1974).

Microhistological analysis has been utilized to determine botanical composition of diets of many families of mammals, including Cervids like deer, elk and moose (O'Bryan 1983; Kirchoff and Lorensen 1998), Leproids like rabbits and hares (Adams et al. 1962; Sparks 1968) and Equids like wild horses (Hansen et al. 1977). In Nepal, this method has been applied in diet analysis of Rhino (Jnawali 1995, Pradhan et al. 2008), Swamp Deer (Pokharel 1996), Asian Elephant (Steinheim et al. 2005, Pradhan et al. 2008), Gaur (Chhetri 2006), Barking Deer (Nagarkoti and Thapa 2007), Wild Sheep (Shrestha and Wegge 2008), mountain domestic and wild ungulates (Shrestha et al. 2005) and Red Panda (Thapa 2010, Panthi et al. 2012).

3. MATERIALS AND METHODS

3.1 Materials

The scientific instruments and chemicals used during the field study and laboratory were:

1. GPS (Garmin eTrex 7)
2. Compass (Silva)
3. Compound Microscope (Proway)
4. Digital camera for microscope (DCM510; USB2.0; 5M pixel, CMOS chip)
5. Sodium Hydroxide (10 % and 15%)
6. Sodium Hypochlorite (4%)
7. Staining substances: Methylene blue (5 g/100 ml water) and gentian violet solution (1g/100 ml water)

3.2 Study Area

3.2.1 Location and boundaries

The study was conducted in the Babai Valley of Bardia National Park, Nepal (Fig.3.1). The Bardia National Park (BNP), located between 28°15'-28°40' N and 81°15' -81°40' E in the western Terai and Churia of Nepal, is the largest National Park in the lowland Terai covering an area of 968 km^2 (Steinheim et al. 2005). The park was established to protect representative ecosystems and to conserve tigers and their prey species. Initially, a small area was gazetted as the Karnali Wildlife Reserve in 1976. In 1982, it was renamed as Bardia Wildlife Reserve, and was extended to its current size in 1984. The reserve was given the status of National Park in 1988 and is listed under category II by IUCN. The Babai valley, extending from Parewa Odar to Chepang, was included in the park in 1984 after resettling the 1500 households from the valley to outside the park boundaries. In 1997, an area of 327 km^2 surrounding the park comprising forest and private lands was declared as buffer zone (*http://www.dnpwc.gov.np)*. The eastern boundary of the park is Surkhet- Kohalpur road; the

western boundary is the Geruwa River. The northern boundary lies at the crest of churia and most of the southern boundary is human settlements and cultivation.

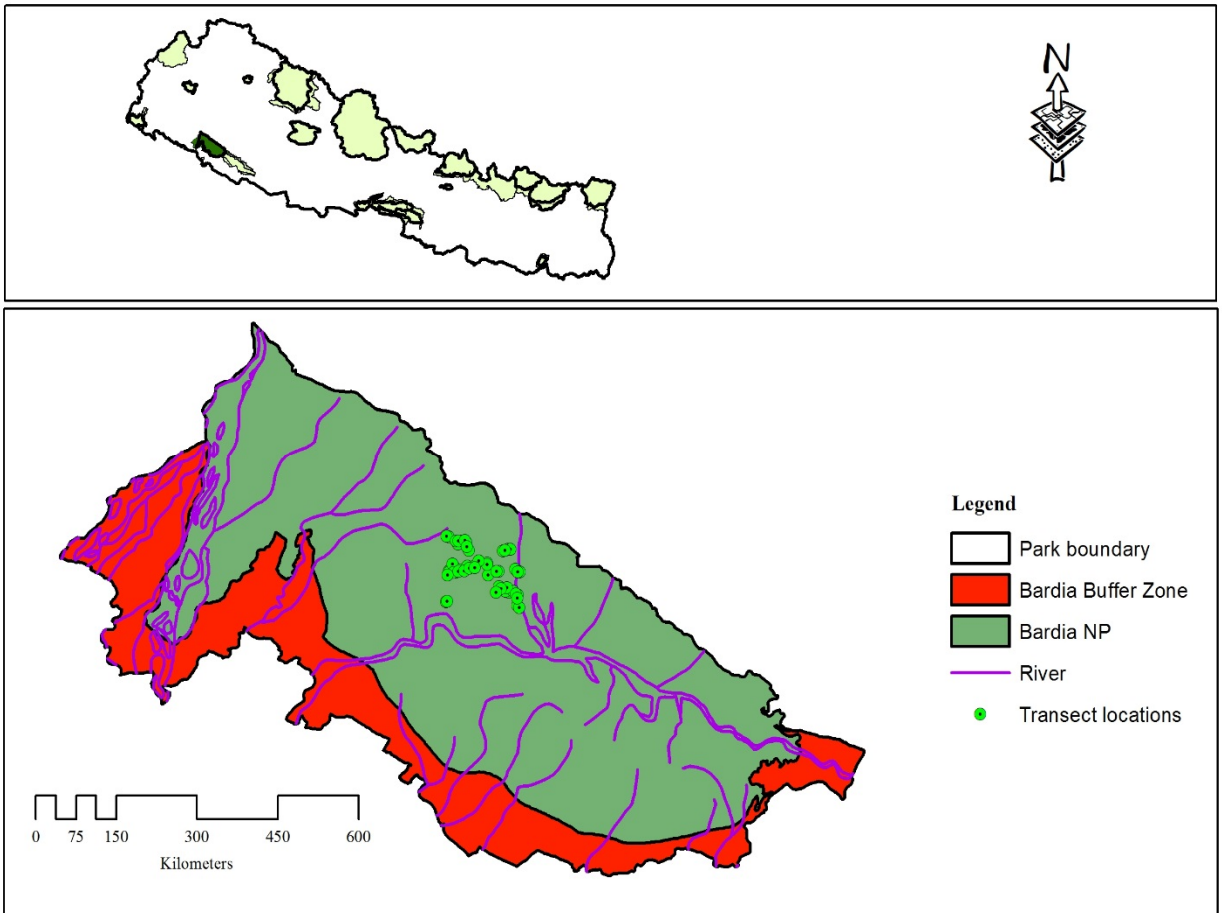

Figure3.1. Map of Bardia National Park, Nepal showing transects locations.

3.2.2 Topography

The Bardia National Park covers the areas of Siwalik and flat flood plains. Large part of the park is composed of southern slopes of the Churia hills and the gravelly foothills of Bhabar belt. The park can be categorized into five distinct land types namely the Churia (Siwaliks), the Bhabar foothills, the alluvial flat lands, the riverine floodplains and the Babai valley. The altitudinal gradient ranges from 152m (msl) at the south-western corner of the reserve to the elevation of 1441m (msl) at Sukurmala to the crest of Churia ridge (Dinerstein 1979b).

3.2.3 Climate

The climatic data of Chisapani (28˚3" N, 81˚1" E, and elevation 225 m) has been used for the analysis. The park has a subtropical monsoonal climate with three distinct seasons; monsoon (June to September), winter (October until mid-February) and dry (mid-Februarys to June). The mean annual rainfall between 2002 and 2012 was 2069.61 mm with about 90 % of the total rainfall occurring from May to September (Figure 3.2).

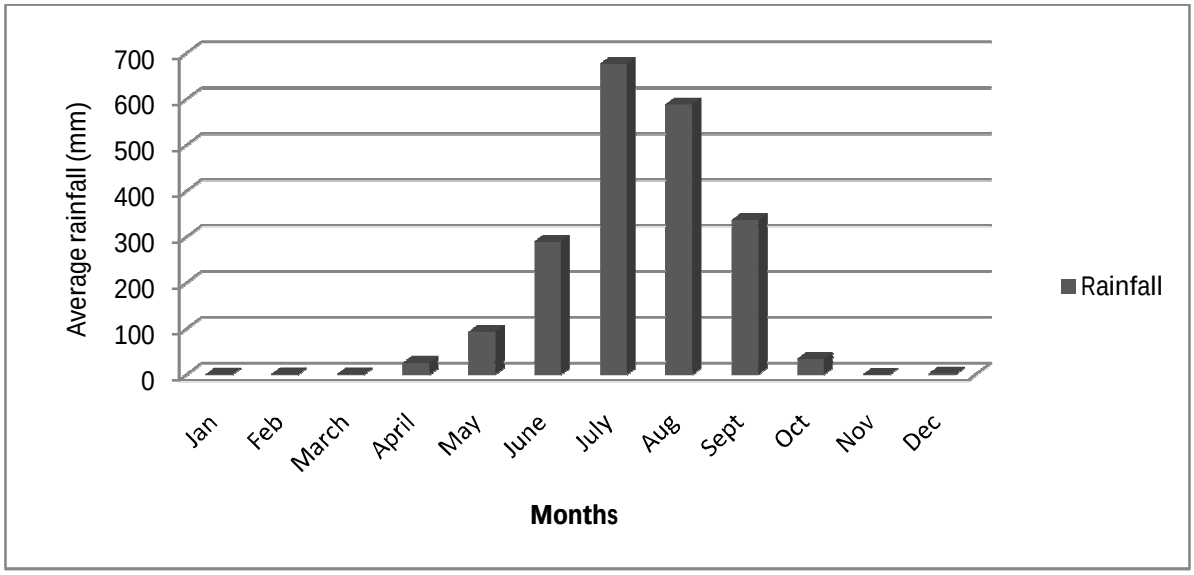

Figure 3.2: Average monthly rainfall (2002-2012) at Chisapani, Karnali, Nepal.

(Source: DHM/GoVN)

The average monthly minimum temperature of periods between 2002 and 2012 was recorded to be 10.45 ºC; likewise the average monthly maximum temperature was 36.7 ºC (Figure 3.3). Winter temperature falls almost to freezing point whereas from March to June temperature can reach as high as 43 ºC.

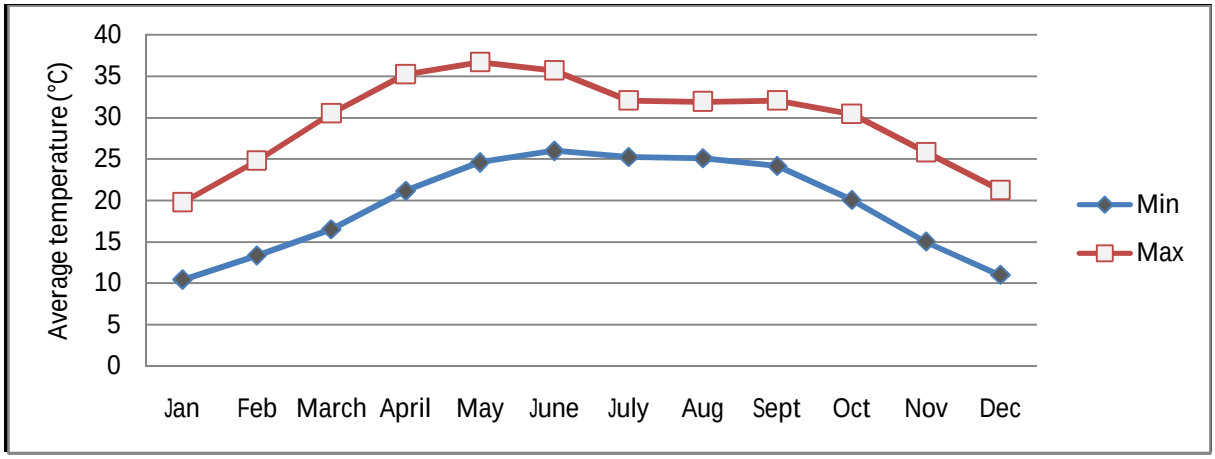

Figure 3.3: Average monthly maximum and minimum temperature (2002-2012) at Chisapani, Karnali, Nepal. (Source: DHM/GoVN)

The average relative humidity drops down to below 50% and the average temperatures warm up peaking up to 36.7˚C. The average monthly relative humidity was recorded maximum 87.23% in the month of August and minimum 47.82% in the month of April between 2002-2012 (Figure 3.4). Pre-monsoon rain during May onsets the increase of relative humidity and makes the vegetation bloom.

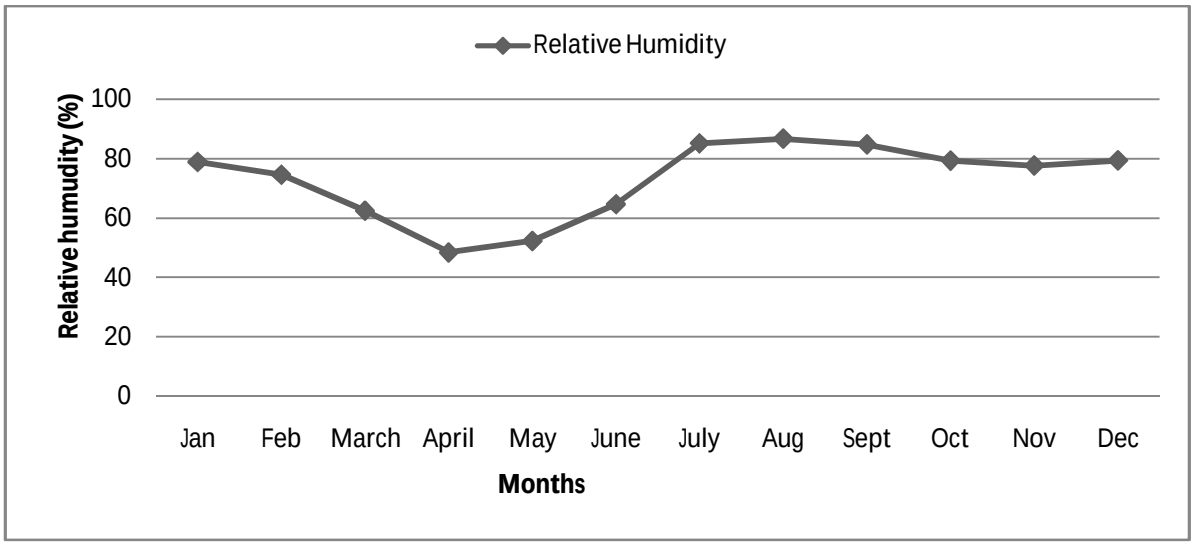

Figure 3.4: Average monthly relative humidity (2002-2012) at Chisapani, Karnali, Nepal. (Source: DHM/GoVN)

3.2.4 Vegetation

The vegetation is sub-tropical, consisting of a mosaic of early successional floodplain communities along the Babai River and its tributaries, and with large areas of climax Sal *Shorea robusta* forest on the upper drier land. The park holds two major eco-regions, namely the Terai-duar Savannas and grasslands, and the Himalayan Subtropical broadleaved forests (Malla 2009). Around 76 percent of the total park area is covered by forest, of which 52 percent of the total plant species are trees, 20 % are shrubs while remaining 8 % are herbs (Bhuju et al. 2006). Dinerstein (1979b) classified the vegetation of the park into six major types which was later modified by Jnawali and Wegge (1993) into seven types. The major vegetation types are Sal forest, Riverine forest, mixed hardwood forest, wooded grasslands, Phantas and Tall alluvial Flood plain grassland. Important flora in the park includes *Shorea robusta, Terminalia tomentosa, Mallotus phillippensis, Acacia catechu, Dalbergia sissoo, Bombax ceiba, Pinus roxburghii, Buchanania latifolia, Dillenia pentagyna, Murraya koenigii, Colebrookea oppositifolia, Pogostemon benghalensis, Imperata cylindrica, Saccharum spp* (Shrestha et al. 1997).

Based on the variables such as dominant and associated tree species, canopy cover, and with the help of information from Shrestha et al. (1997) and Steinheim et al. (2005), Pokharel (2010) classified seven different vegetation associations in Babai valley.

***Terai Sal forest*:** This is a mixed forest where the Sal (*Shorea robusta*) forms about 50 % or more of the total coverage. This type of forest is similar to the Terai Pure *S. robusta* Forest (TPSRF) of Shrestha, 1997 and the *S. robusta – Buchanania latifolia* forest of Dinerstein (1979a). The upper canopy trees can reach heights of between 20 to 40 m and is mainly dominated by *S. robusta* and *Terminalia tomentosa*. These two species form the main upper canopy layer. *Mallotus phillipensis, Buchanania latifolia, Adina cordifolia, Bauhinia variegata* and *Desmodium oojeinense* are the other associated species. *Flemingia strobilifera*, a shrub species, locally called "*bansapti*" is the indicator of this habitat type and other associated shrub includes *Osbeckia stellata*. *Flemingia strobilifera*, a climber, is common in this forest type. Because of the dense canopy, there is low diversity of grass species which is sparsely distributed on the ground. Common grass species found here are *Eulaliopsis binata, Desmostachya bipinnata* and *Imperata cylindrica*.

Moist mixed riverine forest: This type of forest forms large stands along stream sides and riverbanks. It is a mixed forest of tall and medium height trees with a thick understory of tangled shrubs and grasses. Moist mixed riverine forest is the same habitat classified by Shrestha et al. 1997 and is similar to the *Ficus glomerate – Mallotus philippensis – Eugenia jambolana* forest of Dinerstein 1979a. This type of forest extends from flat area to the area with gentle slope. The forest is mainly dominated by *Syzygium cumini, Mallotus phillipensis* and *Schleichera oleosa.* Other associated species include *Bombax ceiba, Ficus glomerata, Acacia catechu, Mitragyna parvifolia, Cleistocalyx operculatus, Mangifera indica* and *Adina cardifolia*. Some common shrubs found in this forest type include *Osbeckia stellata, Achyranthes bidentata,* and *Asparagus racemosus*. *Bauhinia vahlii* is common climbers. Grass distribution varies from sparse to the dense depending on the extent of disturbance from flood and bare rocks. Common grass species include *Brachiaria racemosa, Imperata cylindrica* and *Desmostachya bipinnata*.

***Hill sal forest*:** It is mostly found in hilly area. This type of forest is similar to the hill *Shorea robusta* forest (HSRF) of Shrestha et al. 1997. Average height of upper canopy trees is less than 15m. Hill sal forest is mainly dominated by *Shorea robusta, Terminalia tomentosa and Buchanania latifolia*. Other associated species includes *Desmodium oojeinense* and *Picrasma javanica. Phoenix humilis*, a shrub species, locally called "*Thakal*", is considered as an indicator of this forest. *Bauhinia vahlii* is common climber while *Eulaliopsis binata* and *Imperata cylindrica* are common grass species. Grass density is relatively higher in this habitat than in Terai sal forest and Moist Mixed Riverine forest.

Mixed deciduous hill forest: On dry areas in Siwalik hill especially on southern slopes, the hill Sal forest is replaced by this type of forest. This forest occurs on exposed dry slopes where soil is thin (Shrestha et al. 1997) and is mainly dominated by *Anogeissus latifolia*. Other associated species include *Terminalia tomentosa, Picrasma javanica, Nyctanthes arbourtristis,* and *Mallotus phillipensis*. The average canopy height of trees is generally less than 15 m. *Phoenix humilis* and *Asparagus racemosus* are the dominating shrubs while *Eulaliopsis binata, Imperata cylindrica,* and *Saccharum sps* are the major grass species.

***Wooded grassland and savanna*:** This vegetation association is similar to the wooded grassland or savanna of Shrestha et al. 1997. This includes grass dominated areas on the flat

region mostly in low elevation and some areas at higher elevations but the slope with less than 5 degrees. There are thinly scattered trees with irregular and open crowns. Commonly found tree species are *Bombax ceiba, Adina cordifolia, Terminalia tomentosa, Acacia catechu* and *Mitragyna parvifolia*. In the case of higher elevation, *B. ceiba* is absent. The vegetation is dominated by *Imperata cylindrica* and *Saccharum spontaneum*. *Zizyphus sps* forms the understory shrub layer and is considered as an indicator of this vegetation association.

***Floodplain grassland and streambed*:** Floodplain grassland is typically characterized by tall grass species such as *Saccharum spontaneum, Saccharum benghalensis* and *Phragmites karka*. This type of grassland is found only along the stream banks especially along the Babai river bank. This area is highly affected by the seasonal flood.

3.2.5 Fauna

Habitat mosaics of Bardia National Park support a diverse range of ungulates and other faunal groups (Dinerstein 1979b). It harbors 59 species of mammals, 407 species of birds, 42 species of reptiles and amphibians and 124 species of fishes (BPP 1995 and DNPWC 2001). Around 70-80 Asian Elephants (*Elephas maximus*) have now become resident to the park (Steinheim et. al. 2005). Eighty three Rhinos were translocated in seven translocation events over a period of 17 years (1986–2003) in BNP but subsequent surveys in 2007 and 2008 have confirmed their complete disappearance from the park (Thapa et al. 2009). The globally endangered fauna in BNP include Tiger (*Panthera tigris*), Hispid Hare (*Aprophagus hispidus*), Gangetic Dolphin (*Platanista gangetica*) and Bengal Florican (*Houbaropsis bengalensis* (Baral et al. 2002). Sambar (*Rusa unicolor*), Goral (*Naemorhedus goral*), Spotted Deer (*Axis axis*), Four-horned Antelope (*Tetracerus quadricornis*), Wild Pig (*Sus scrofa*), Swamp Deer (*Rucercus duvauceli*), Barking Deer (*Muntiacus vaginalis*) and Hog Deer (*Axis porcinus*) are the co-existing ungulate community. The predators in BNP are Tiger (*Panthera tigris*), Leopard (*Panthera pardus*), Leopard Cat (*Prionailurus bengalensis*), Fishing Cat (*Felis viverrina*), Jungle Cat (*Felis chaus*), Jackal (*Canis aureus*), Hyena (*Hyaena hyaena*), Large Palm Civet (*Vierra zibetha*), Common Palm Civet (*Paradoxurus hermaphroditus*) and Ratel (*Mellivora capensis*). The park also supports Sloth Bear (*Melurus*

ursinus), Yellow Throated Marten (*Martes flavigula*) and Pangolin (*Manis pentadactyla*) and reptile species like Mugger Crocodile (*Crocodylus palustris*) and endangered Gharial (*Gavialus gangeticus*).

3.3 Methods

3.3.1 Sampling design

Systematic belt transect method (Buckland et al. 2004) was used to collect reference plants and pellets. First transect was selected randomly and an interval of 200 m was maintained between next consecutive transects. The length of transects ranged from 400 meters to 4000 meters depending upon the topography and site accessibility. Transects were traversed in north-south direction except to east of Guthi post, where transects were laid in east-west direction. The north-south transects were selected to include different vegetation types varying with altitude and east-west transects due to plain topography towards east of Guthi.

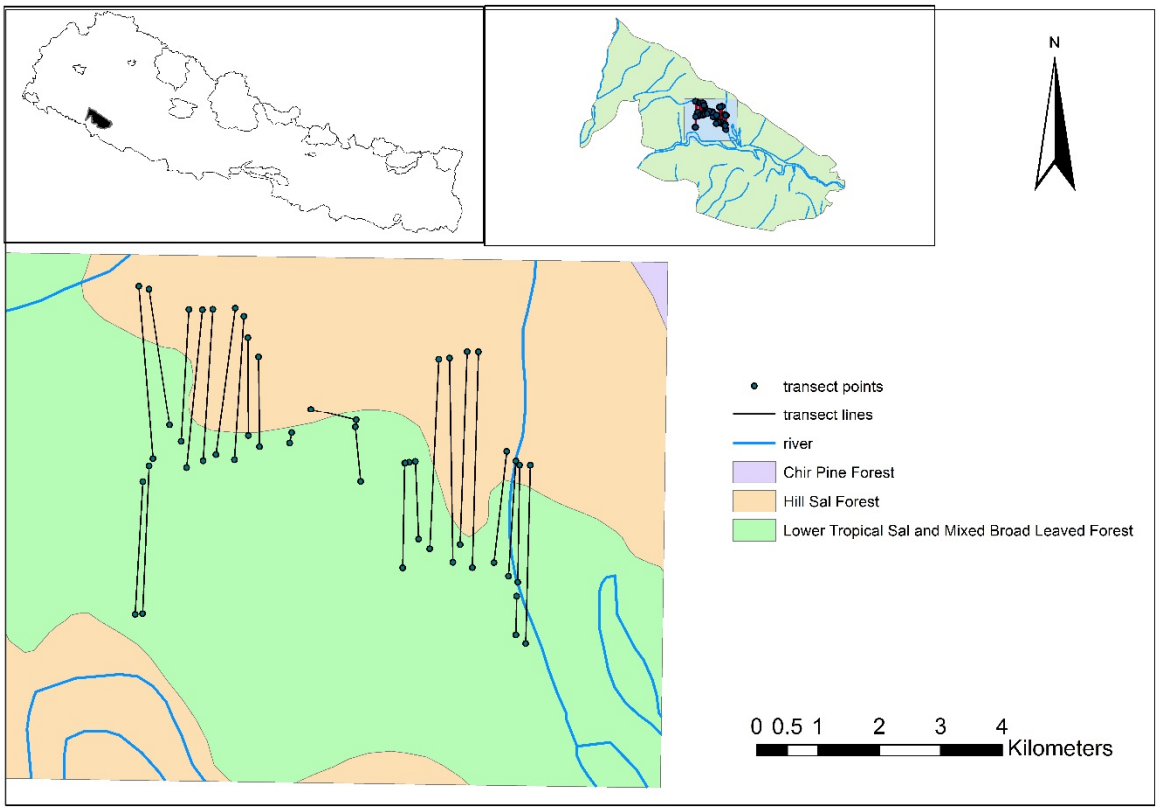

Fig. 3.5: Map showing area surveyed inside BNP and line transects.

3.3.1.1 Field Survey

Field surveys were conducted in three different seasons during summer (March-April, 2012), monsoon (September, 2012) and winter (January, 2013). Same transects were surveyed in all three seasons. Four persons walked parallel in each of transect. A 20 m strip width was maintained by spacing 2.5 m on either side of each individual to enhance the possibility of discovering more FHA pellets as well as because of the topography and available field assistants. The same transects were used in all three seasons and the plants and pellets available within the strips were collected.

3.3.1.2 Reference plant collection

Parts of potential food plants, that could be reached by the FHA for feeding and encountered during transect survey were collected for the preparation of reference slides. These parts included the leaves, twigs, fruits, flowers and bark. The plant species were labeled with either Nepali or Tharu name or both. All the collected plant materials were preserved in herbarium press and brought to National Herbarium and Plant Laboratories, Lalitpur for further identification and confirmation.

3.3.1.3 Pellet Identification and collection

Pokharel (2010) confirmed the shape, size and texture of FHA pellets in BNP by installing camera traps in the suspected middens of FHA. Joint field surveys with him helped in identification and confirmation of the FHA pellets. The pellets from the midden were taken as reference to avoid the misidentification during further field survey. There was considerable variation exhibited in the shapes of FHA pellets. Unlike the typical comma-shaped pellets of Barking Deer (*Muntiacus muntjak*) (Dinerstein, 1980), FHA pellets is elongated. In some cases the shape of pellet is cylindrical with pointed shape at one end. In such case, the pellet size is generally bigger than the pellet of Barking Deer. Besides this, the pellet size from soil eaten FHA is much bigger than that from FHA with normal diet. In some middens, there was a mixture of pellets with different shapes and sizes and in some, very small pellets, possibly of young ones

antelope, were also observed. The colour of pellets also varied from light grey to black. White pellets were due to the presence of higher soil content in the animals' diet.

Fresh pellets, less than two days old, identified on the basis of texture and moisture content were collected in polythene zip lock bags and labeled with GPS location, date and status of the sample. About one-fourth proportion of each samples found within the transects were collected. These samples were air dried in the field to remove moisture and prevent fungal growth. All the collected materials were brought to the laboratory of Central Department of Zoology, Tribhuvan University for further analysis.

3.3.2 Microhistological Analysis

The microhistologcal technique introduced by Baumgarter and Martin (1939) was used in determining plant composition of FHA fecal matter. This method involves microscopic recognitions of indigestible plant fragments mainly epidermal features, which are the characteristics of plant groups (Metealf 1960). This method involves preparation of reference and faecal slides and their interpretation.

3.3.2.1 Slide Preparation

Samples of plant parts were dried in the oven at 60 °C in the laboratory of Central Department of Zoology, Tribhuvan University. Then the dried samples were separately grounded into powder through electric blender and the powder was sieved in mesh size 1mm to 0.3 mm. The powder retained on the 0.3 mm sieve was chosen as final reference sample for slide preparation. Similar procedure was followed for faecal samples.

The microhistological slides of reference plants were prepared following the methods given by Anthony and Smith (1974), modified by Holechek, Vavra and Pieper (1982) and Jnawali (1995). This method was adapted by Wegge et al. (2006), Nagarkoti and Thapa (2007) and Panthi et al. (2012), in Nepal. In this method, three spatulas of reference plant powder was put in test tubes and treated with 100 ml of 15% (W/V) Sodium hydroxide (NaOH), and boiled giving water bath until the solution became transparent. The sample was cooled and

washed with hot water to remove NaOH. The residue was then treated with few drops of staining chemical- methylene blue (1 g/100 ml water) for 1 minute and then thoroughly rinsed. The stained fragments were mounted on standard microscope slides in a glycerin medium and covered with a cover slip.

Two different methods were used for preparing fecal sample slides. Above mentioned method was adopted for 17 samples of summer season and Norbury (1988) for rest 83 samples. This method was found less tedious, less time consuming and the slides were clearer and easier to differentiate than those of the first mentioned method. In this method- fecal samples were placed in Petri dishes and bleached with 50 ml of 4% Sodium hypochlorite for 6-24 hours at room temperature to remove mesophyll tissue and to render the epidermis identifiable. The bleached contents were then rinsed well in a sieve and then the rinsed fragments were treated with few drops of staining substance-gentian violet solution (1 g/100 ml water) for 10 seconds and again well rinsed. The stained fragments were mounted on standard microscope slides in a glycerin medium and covered with a cover slip.

Both reference slides and faecal pellet slides were observed immediately after preparation at different magnifications; 100X, 200X and 400X with a compound microscope and each fragments were photographed using digital camera for microscope (DCM510; USB2.0; 5M pixel, CMOS chip) in a laptop using software- ScopeTek Scope Photo; Version: x64, 3.1.615 (*http://www.scopetek.com*).

3.3.2.2 Slide interpretation

For each fecal sample, non-overlapping and distinguishable 30 fragments, observed while moving the slides from left to right in the microscope, were identified considering the specific histological feature of the epidermis i.e., cell wall structure, shape and size of cells, trichomes; and shape and size of stomata as key features to match the features of fecal plant fragments.

3.3.3. Determination of optimum sample size

To determine optimum sample-size required for accurate estimation of the FHA diet, all pellet samples were randomized and incidence of each food plant species in the pellet samples were plotted cumulatively until all the samples were included and the asymptote of the curve was obtained. Numbers of samples analyzed to obtain asymptote of the curve were considered to be the optimum sample size for quantifying diet.

3.4 Data analysis

To analyze the diet data, four levels of classifications were constructed into which plant fragments were assigned: (1) Functional group (F.G.): (i) grasses, (ii) forbs, (iii) shrubs, (iv) climbers and (v) trees; (2) Broad taxonomic group (B.T.): (i) monocots and (ii) dicots; (3) family; and (4) species.

a. Diet composition

Diet composition was expressed into percentage of occurrence (O %) (Cavalini and Lovari, 1991).

$$\text{Percentage of Occurrence (O \%)} = \frac{numberoffragmentsofeachfood}{Totalnumberofplantfragmentsread} \text{X } 100$$

b. Seasonal variation in diet composition

Pearson's Chi-square test (χ^2) was used to determine the significance of any differences found in preferences among functional categories and among plant species in three different seasons using program R (R Console version 2.15.2).

c. Niche Breadth

To evaluate degree of selectivity of plant species included in the diet, Levin's measure of Niche Breadth (Levins 1968) described by Krebs (1999), which measures how uniformly resources are being utilized, was used.

The equation is

$$B = \frac{1}{\sum_{i=1}^{n} pi2}$$

Where, B= Levin's Measure of Niche Breadth

pi= Percentage of total samples belonging to species i (i= 1, 2……, n)

n= total number of plant species in all samples.

Diversity was standardized to a scale of 0.0 to 1.0 by using Hurlbert's method (Krebs 1999).

$$B_s = \frac{B-1}{n-1}$$

Where, Bs= Levins's standardized niche breadth, and *n* is the number of possible resource states.

A low value of B_s indicates that the animal is selective of specific forage.

d. Browse to grass ratio

To evaluate whether the FHA is a browser or grazer, the monocots and dicots were further assigned as grass and browse respectively (Jerman 1974, Shipley 1999) and their ratio was calculated.

Browse to grass ratio $(B/G) = \frac{\sum(Bp)}{\sum(Gp)}$

Where; B_p=Percent occurrence of all browse plant species in the diet

G_p=Percent occurrence of all grass plant species in the diet.

4. RESULTS

Different vegetative parts of 104 plant species (10 grasses, 16 forbs, 36 shrubs, 6 climbers and 36 trees) were collected for reference library preparation (Annex I). Out of these, 92 plant species could be nomenclature to their species level while 12 plants could be categorized only to their functional categories (grass, forbs, shrub, climber and tree). Those plants, which could not be identified to species or genera, were grouped into "Unknown grass", "Unknown forbs", "Unknown shrub", “Unknown climber" and "Unknown tree". A total of 1889 microhistological photographs of different features of 94 plant species were prepared for reference library, and for 10 species existing microhistological photographs prepared by Dr. Narendra M.B. Pradhan were used. Key diagnostic characteristics of the microhistological features of the reference plants were classified for the ease of identification of the plants in the diet (Annex-II). These were prepared enumerating some of the important features that are useful for microscopic analysis. These key features include; epidermal cell shape, size and arrangement; vascular vessels type; stomata type and arrangement; venation characteristics; shape and arrangements of hairs and trichome, crystal types.

4.1 Diet Composition

A total of 3000 plant fragments of 100 pellet samples from three different seasons; summer (n=60), monsoon (n=20) and winter (n=20) were analyzed through microhistological technique and 45 species belonging to 20 different families were identified in the FHA fecal pellets.

FHA was found to be mixed feeder feeding on grasses, forbs, shrubs, climbers and trees. The animal fed on 15 tree species, 15 shrubs, 8 forbs, 5 grasses and 2 climbers (Figure 4.1.1, Table 4.1).

Table 4.1: Percentage composition of various plant categories (F.B. = Functional category; B.C. = Broad category, family and species) identified in pellets of four horned antelope in summer, monsoonand winter seasons in BNP, Nepal.

F.C.	B.C.	Family	Species	Summer	Monsoon	Winter	Overall
Grasses	Monocots	Graminae	*Eulaliopsis binata*	3.28	11.33	2.50	4.73
			Imperata cylindrica	4.67	5.33	2.50	4.37
			Digitaria sps	0.11	--	--	0.07
			Themeda triandra	1.78	--	--	1.07
			Paspalam distichum	0.39	0.17	--	0.27
Forbs	Monocots	Graminae	*Cynodon dactylon*	3.28	0.50	0.33	2.13
			Hemarthria compressa	1.06	--	--	0.63
	Dicots	Asteraceae	*Blumeopsis flava*	1.83	1.00	1.50	1.60
			Ageratum cristata	6.94	4.00	--	4.97
		Leguminoseae	*Desmodium sps*	--	2.17	--	0.43
		Compositae	*Blumea virens*	2.78	7.00	4.33	3.93
		Acanthaceae	*Justicia sps*	3.33	2.00	1.00	2.60
		Unknow Forb	---	1.33	1.17	4.33	1.90
Shrubs	Monocot	Graminae	*Thysanolaena maxima*	1.56	--	--	0.93
		Liliaceae	*Asparagus phillipensis*	0.17	--	--	0.10
	Dicots	Acanthaceae	*Justicia simplex*	0.22	--	--	0.13
			Barleria cristata	4.39	8.67	4.83	5.33
			Phlogacanthus sps	1.72	--	0.18	1.07
		Verbenaceae	*Clerodendrum viscosum*	--	2.33	7.50	1.97
			Clerodendrum sps	1.28	--	--	0.77
		Amaranthaceae	*Achyranthus sps*	3.22	2.50	1.00	2.63
		Rubiaceae	*Anthocephalus chinensis*	0.22	--	--	0.13
		Euphorbiaceae	*Phyllanthus emblica*	0.06	0.33	--	0.10
		Oleaceae	*Nyctanthes arbortristis*	2.33	1.00	0.33	1.67
		Labiatae	*Pogostemon benghalensis*	1.89	--	9.17	2.97
		Compositae	*Artemisia indica*	0.33	--	0.67	0.33
		Unknown shrub 1	---	1.33	0.50	3.83	1.67
		Unknown shrub 2	---	1.17	2.50	1.5	1.50
Climbers	Dicots	Apocynaceae	*Trachelospermum lucidum*	1.28	3.50	2.17	1.90
		Unknown climber	---	3.72	1.17	--	2.47
Trees	Monocot	Graminae	*Bambusa vulgare*	0.39	10.50	5.50	3.43
	Dicots	Euphorbiaceae	*Mallotus philippensis*	2.67	0.50	0.83	1.87
			Bridelia retusa	5.17	2.83	4.00	4.47
		Rubiaceae	*Hymenodictyon arixenese*	1.61	2.33	7.67	2.97
			Mitragyna parviflora	6.61	1.67	2.00	4.70
		Anacardiaceae	*Rhus wallichii*	0.5	--	--	0.30
			Buchanania lanzans	0.72	0.83	2.83	1.17
		Leguminoseae	*Acacia catechu*	1.06	--	--	0.63
			Bauhinia sps	0.06	--	--	0.03
		Myrsinaceae	*Myrsine semiserrata*	1.44	--	2.17	1.30
		Rutaceae	*Aegle marmelos*	0.11	0.50	--	0.17
		Rhamnaceae	*Zizyphus mauritiana*	1.94	3.00	0.83	1.93
		Dipteriocarpaceae	*Shorea robusta*	1.44	1.67	0.17	1.23
		Sapindaceae	*Schleichera oleosa*	0.72	1.17	0.83	0.83
		Myrtaceae	*Eugenia sps*	0.50	0.50	2.17	0.83
Unidentified				19.39	17.33	23.33	19.77

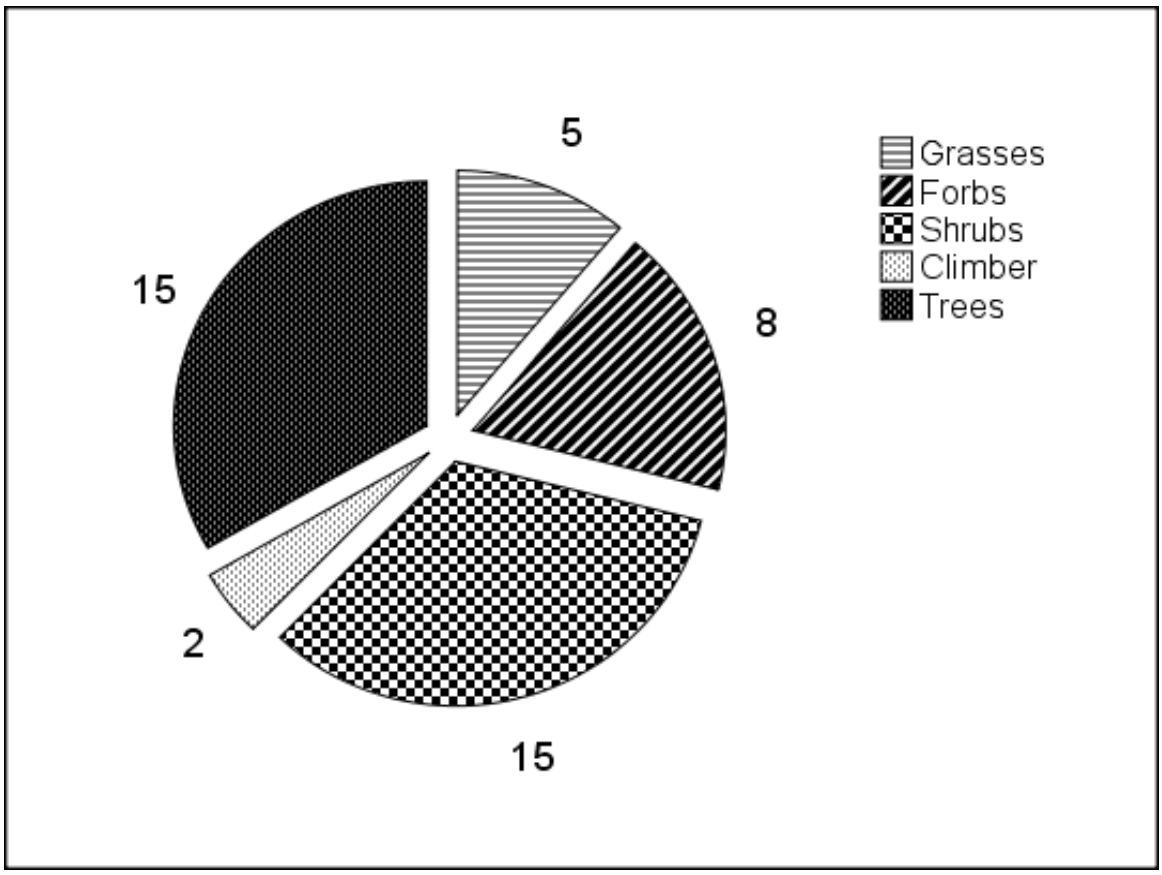

Figure 4.1.1: Number of species in different functional categories consumed by four horned antelope in BNP, Nepal.

Trees contributed the higher proportion (25.87 %) of diets of FHA, followed by shrubs (21.3 %), forbs (18.2 %), and grasses (10.5 %) in terms of percentage occurrence. Climbers contributed lowest percentage of occurrence (4.36%) in the diets (Figure 4.1.2).

The FHA was found to consume 10 species of monocots (grass) and 35 species of dicots (browse). The ratio of browse to grass was found to be 3.52, showing strong affinity towards browse plant species.

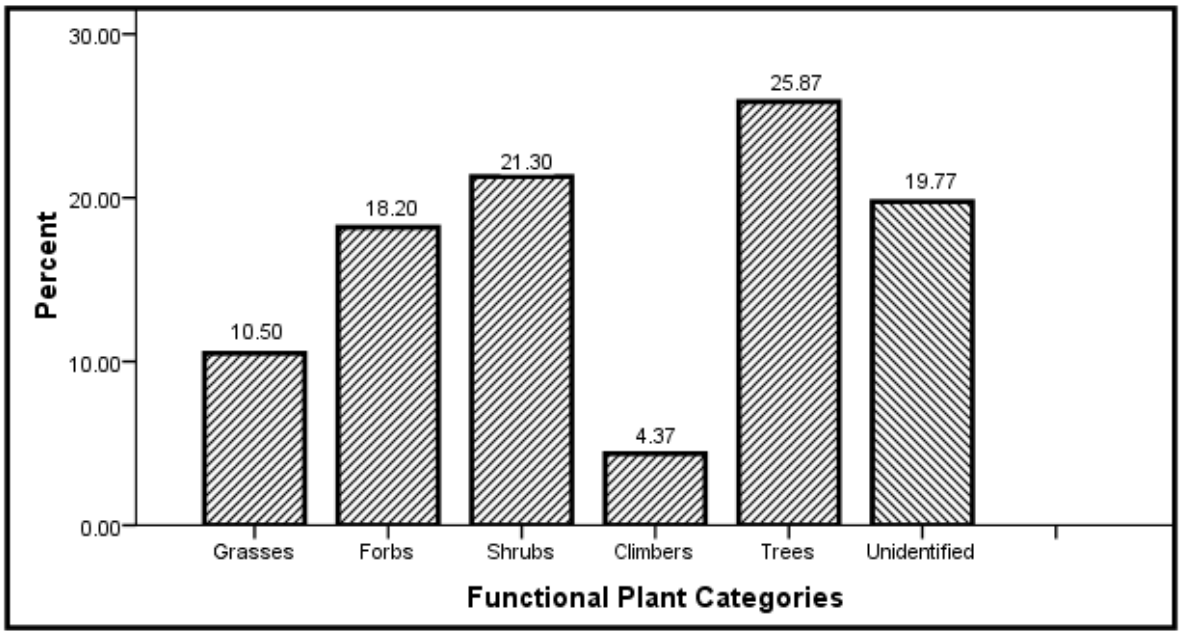

Figure 4.1.2: Percentage Occurrence of functional plant categories identified in the pellets of four horned antelope in BNP, Nepal.

Twenty different plant families were consumed by FHA in Babai valley (Table 4.1). The Gramineae family (five species) was consumed in highest proportion (17.64 %) followed by Acanthaceae (9.13 %) and Rubiaceae (7.8 %). Other remarkable plant families eaten were Asteraceae (6.56 %), Euphorbiaceae (6.4 %), Compositae (4.26 %), Labiatae (2.96 %), Verbenaceae (2.73 %) and Amaranthaceae (2.63 %). Leguminoseae, Liliaceae, Apocynaceae, Myrsinaceae, Rutaceae, Rhamnaceae, Dipteriocarpaceae,Sapindaceae and Myrtaceae were present in relatively small proportions in the diet. One forbs, two shrubs and a climber which could not be identified to their family level constituted 7.50 percent of overall diet (Figure: 4.1.3).

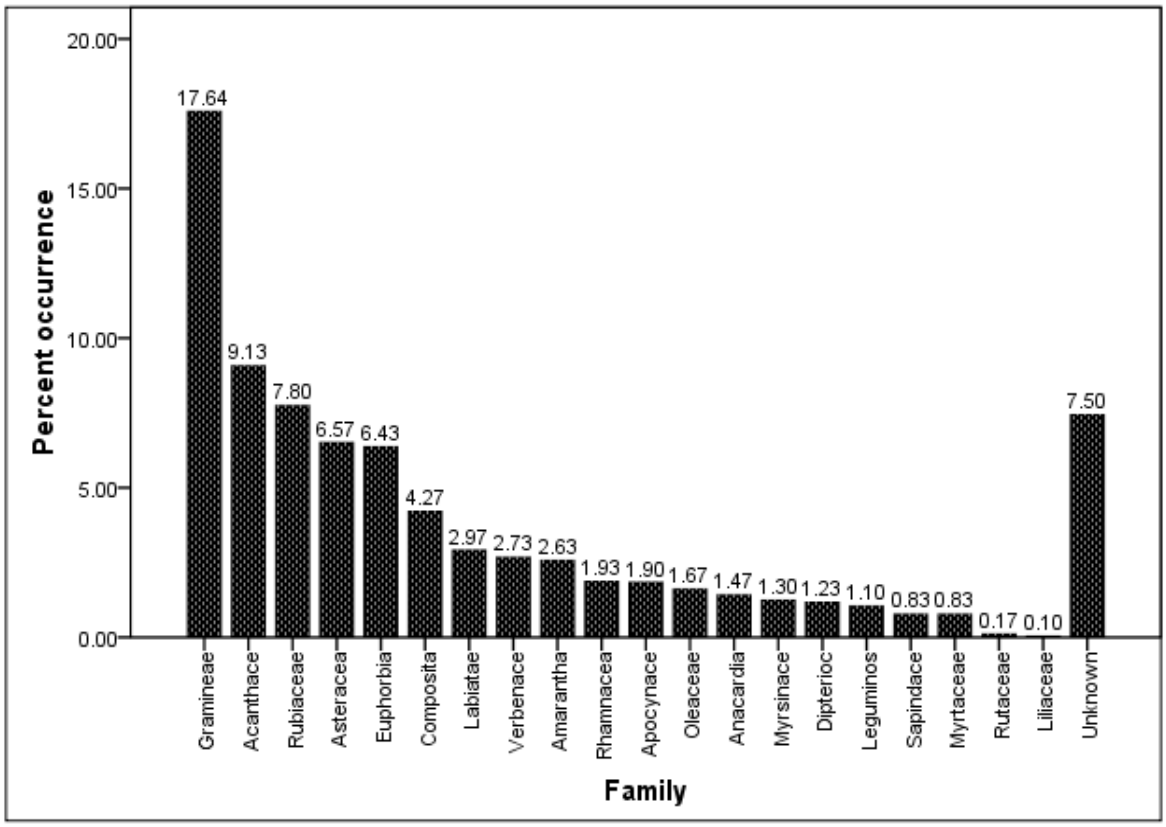

Figure 4.1.3: Percentage of occurrence of different plant families in the diet of four horned antelope in BNP, Nepal.

The percent occurrence of different plant species shows that *Metragyna parviflora* (4.7 %), *Bridelia retusa* (4.47 %), *Bambusa vulgare* (3.43 %), *Hymenodictylon arixenese* (2.97 %), *Zizyphus mauritiana* (1.93 %), *Mallotus philippensis* (1.86 %), *Buchanania lanzans* (1.67 %), *Myrsine semiserrata* (1.30 %) and *Shorea robusta* (1.23 %) were the major tree species consumed while *Aegle marmelos, Schleichera oleosa, Acacia catechu, Rhus wallichi, Bauhinea* sps *and Eugenia* sps had their occurrence below one percent.

Likewise, *Berlaria cristata* was the dominating food item among the shrubs showing its percentage occurrence of 5.33 percent, followed by *Pogostemon benghalensis* (2.96 %), *Achyranthus* (2.63 %), *Clerodendrum viscosum* (1.96 %), *Nyctanthes arbortristis* (1.66 %) and by *Phlogacanthus* sps (1.067 %). Other shrubs; *Thysanolaena maxima, Asparagus phillipensis, Anthocephalus chinensis, Phyllanthus emblica, Artemisia indica, Justicia*

simplex and *Clerodendrum* sps were present in small amounts. Forbs were also present in remarkable proportions in the diet. They contributed 18.2 % of the overall diet. *Ageratum cristata* (4.97 %) and *Blumea virens* (3.93 %) were the main forbs preferred by the animal. *Cynodon dactylon* (2.13 %), *Justicia* sps (2.6 %), *Blumeopsis flava* (1.6 %), *Hemartheria compressa* (0.63 %) and *Desmodium sps* (0.43 %) were other forbs fed. *Eulaliopsis binata* and *Imperata cylindrica* were the principal food among grass species. They contributed 4.73 percent and 4.36 percent respectively. Rest, *Themeda triandra* (1.0 %), *Paspalam distichum* (0.26 %) and *Digitaria* sps (0.06 %) were also present in minority. In addition, two climbers; *Trachetospermum lucidum* and one unknown climber were used up in 1.9 percent and 2.46 percent respectively as food.

4.2 Sample Optimization for the study of FHA diet

A harmonious consistency in food items occurrence was observed after analyzing 1230 fragments from 41 pellet samples collected during summer season. A sample size of 1230 epidermis fragments from 41 independent pellet groups each containing 30 epidermis fragments is optimum for obtaining unbiased estimates of diet composition of FHA in the Babai valley. This optimum sample size could not be determined due to inadequate sample size during winter and monsoon seasons (Fig. 4.2).

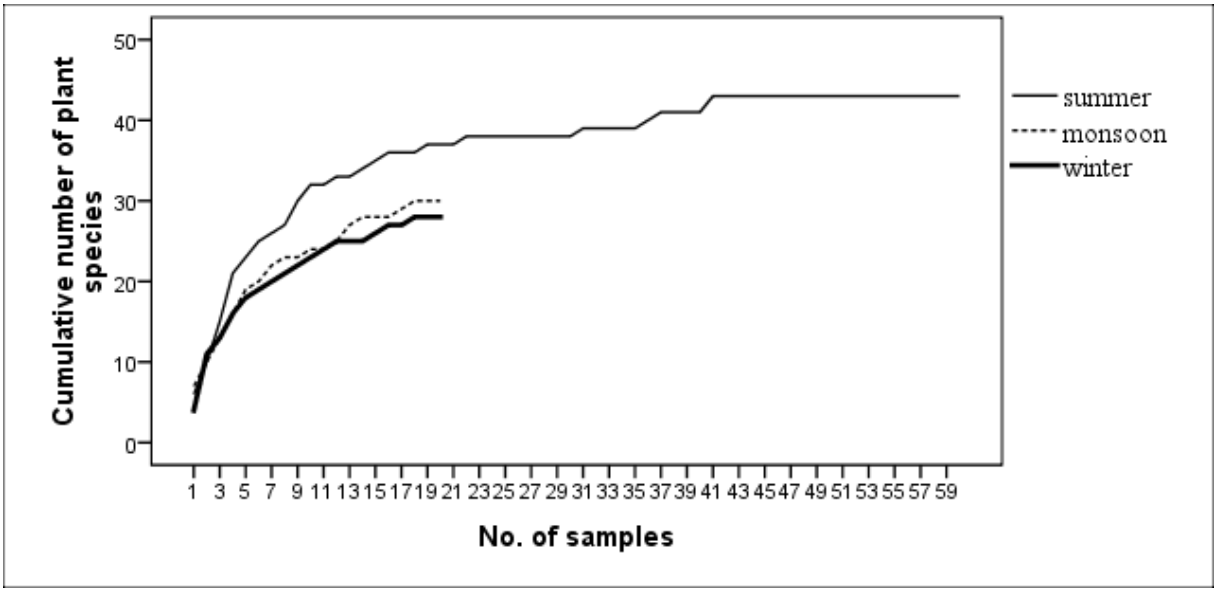

Figure 4.2: Relationship between numbers of new plants occurrence in FHA diet with increased number of pellet samples analyzed in summer, monsoon and winter seasons.

4.3 Seasonal Variation in Diet Composition

Tree species contributed relatively higher proportion of diet in all the three seasons. They contributed 29.00, 25.50 and 24.94 percent respectively during summer, monsoon and winter seasons. Shrubs were consumed relatively in higher proportion during winter (29.00 %), than in summer (19.89 %) and monsoon (17.83 %). The consumption patterns of forbs were higher during summer (20.56 %) followed by monsoon (17.83 %) and winter (11.50 %). Grasses in monsoon were consumed distinctly in higher percentage (16.83 %) than in summer (10.22 %) and winter (5.00 %). Climbers contributed in small proportion in all three seasons. It was 5 percent in summer, 4.67 percent in monsoon and only 2.17 percent in winter.

The consumption of broad categories of plants show that the browse to grass ratio was higher in winter season (6.08) while it declined to 3.82 in summer and to 1.97 in monsoon.

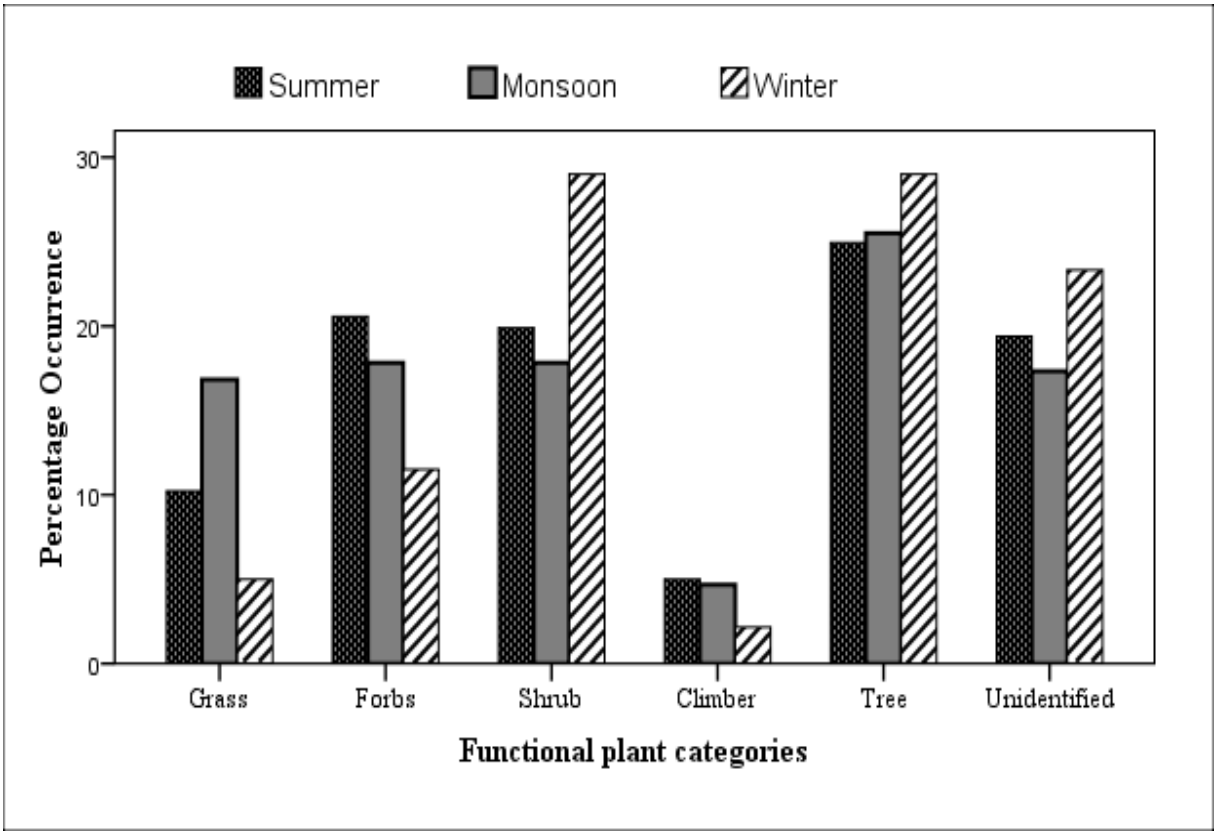

Figure 4.3: Percentage Occurrence of different functional plant types identified in the pellets of four-horned antelope in BNP, Nepal during summer, monsoon and winter seasons.

4.3.1. Seasonal variation in consumption of plant types and species

The Chi-square test (χ^2) revealed that there was significant difference in the frequency of consumption of plant types (grasses, forbs, shrubs, climbers and trees) in different seasons (χ^2= 112.20, d.f. = 10, p-value <0.001). Similarly, the frequency of consumption of specific plant species was significantly differ in different seasons (χ^2= 969.31, d.f. = 90, p-value <0.001).

4.3.2 Summer season diet

During summer season, FHA consumed 43 different species of plants belonging to 20 different families (Table 4.1). Trees were the major diets consumed (24.95 %). Altogether 15 tree species, belonging to 11 families were present in the summer diet. Forbs with 7 species were second important category contributing 20.56 percent of the diets. Furthermore, 19.88 percentage of occurrence was lent by shrubs, 10.22 percent by grass and 5.00 percent by climbers. FHA ate 14 shrubs, five grasses and two climbers during summer (Figure 4.3.2, Table 4.1). In this season, FHA fed on 32 browse species of plants and 10 grasses (Table 4.1) and the browse to grass ratio was obtained as 3.82.

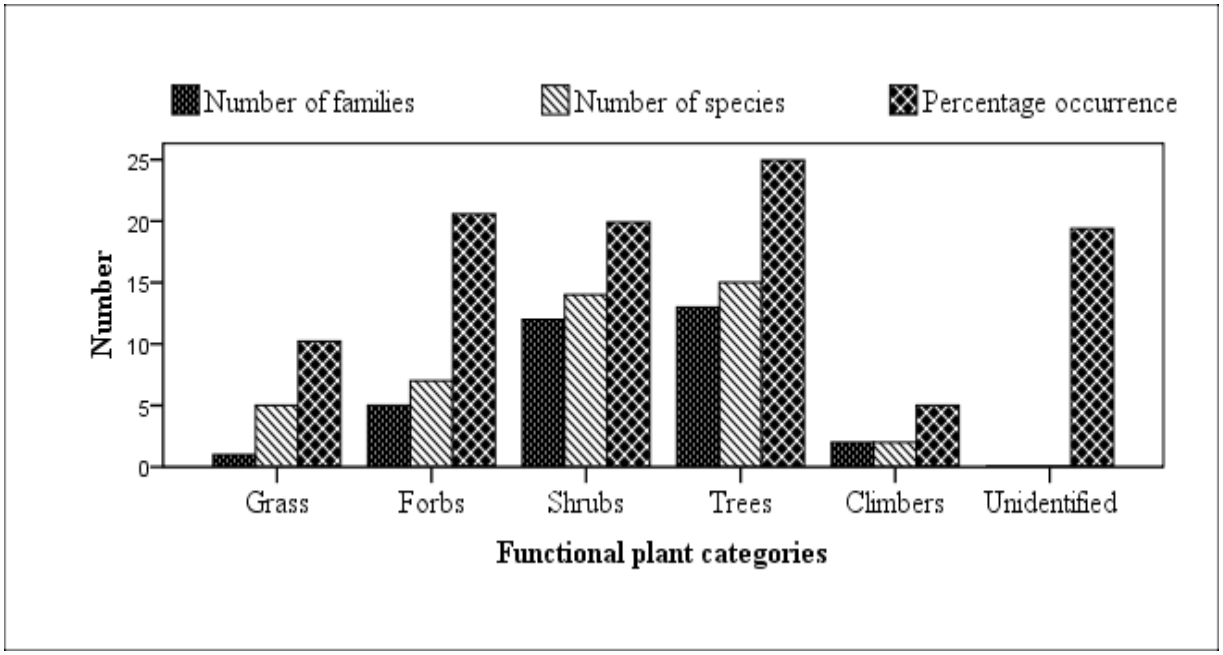

Figure 4.3.2: Number of families, number of species and percentage occurrence of different plant types identified in the pellets of four horned antelope in summer season.

4.3.3 Monsoon season diet

In Monsoon season, FHA consumed 30 species belonging to 17 families and comprised of 3 grasses, 7 forbs, 7 shrubs, 2 climbers and 11 trees (Table 4.1). Trees were consumed in highest proportion (25.50 %) while shrubs and forbs were consumed in equal proportion

(17.83 %) in this season. Three species of grass (Graminae) contributed 16.83 percent of occurrence in the diet. Two climbers were also available in the diet and added 4.67 percent of occurrence to the total diet (Figure 4.2.3). In this season, FHA fed on 25 dicots (browse) plants and 5 monocots (grasses) (Table 4.1) and the browse to grass ratio was found to be 1.97.

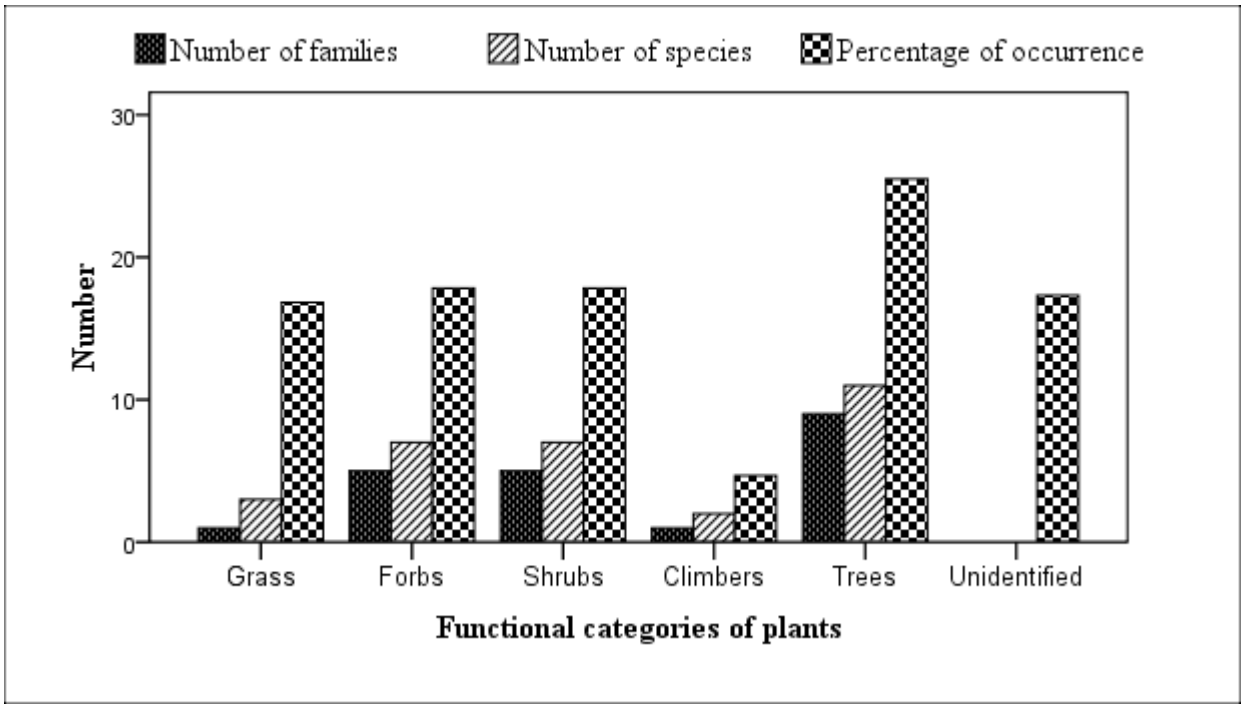

Figure 4.3.3: Number of families, number of species and percentage occurrence of different plant types identified in the pellets of four horned antelope in monsoon season.

4.3.4 Winter season diet

The FHA ate 28 species of plants during winter season belonging to 20 families (Table 4.3). FHA showed equal affinity towards the consumption of trees and shrubs; each contributed 29.00 percent of winter diet. Five species of forbs shared their proportion of the diet by 11.5 percent. Only two grasses and a climber were consumed in winter. They contributed 5.0 percent and 2.17 percent respectively (Figure 4.3.4).In this season, FHA fed on 24 dicot (browse) species of plants and 4 monocots (grasses) (Table 4.1) and the browse to grass ratio was obtained as 6.08.

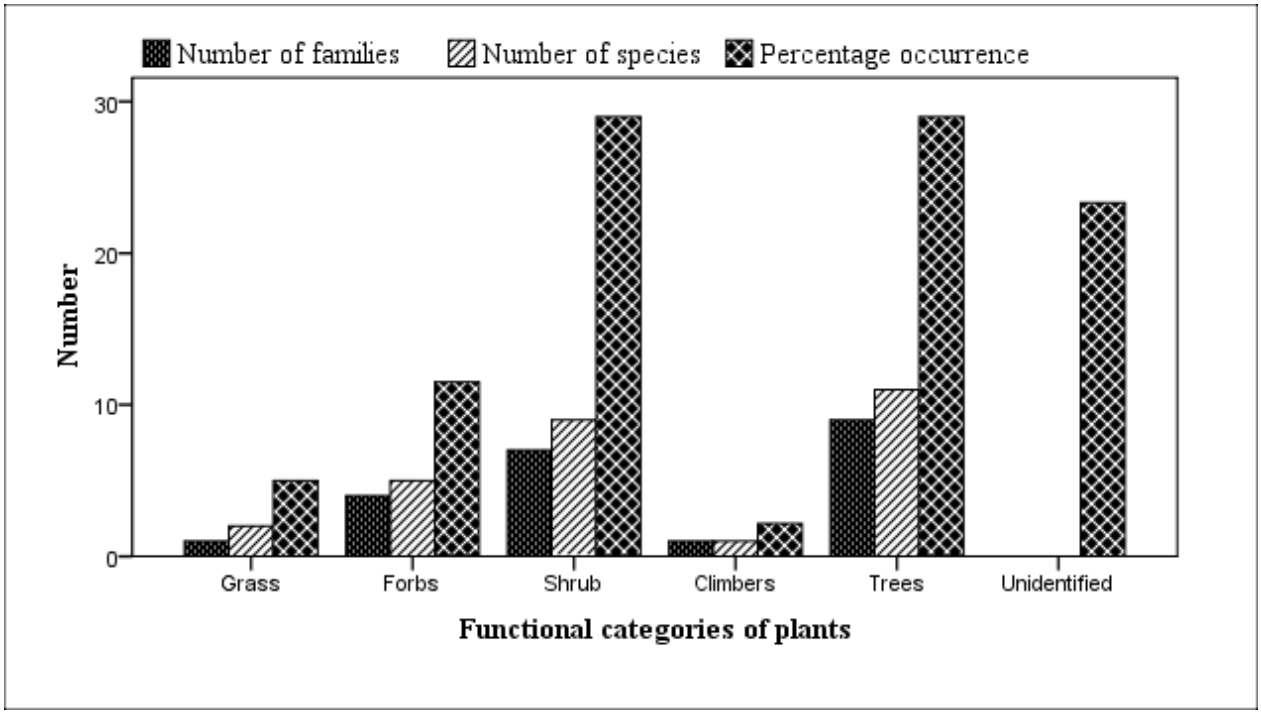

Figure 4.3.4: Number of families, number of species and percentage occurrence of different functional categories of plant identified in the pellets of four horned antelope in winter season.

4.4 Niche Breadth

The niche breadth (B_s) of the food plants included in the diet was found to be 0.050 showing that the FHAs are highly selective of specific forage plants. Niche breadth was comparatively broader in summer season (B_s=0.045) but in other two other seasons, the niche breadth decreased to 0.039 in monsoon and to 0.028 in winter (Table 4.2).

Table 4.2. Incidence in number of samples (IN), Incidence percentage (I %) and Niche Breadth (B_s) of plant species identified in pellets of FHA in summer, monsoon and winter seasons in BNP, Nepal.

Food plants	Summer (n=60)		Monsoon (n=20)		Winter (n=20)		Overall (n=100)	
	IN	(I %)	IN	(I %)	IN	(I %)	IN	(I %)
Barleria cristata	20	33.33	8	40.00	8	40.00	36	36.00
Bridelia retusa	24	40.00	4	20.00	4	20.00	32	32.00
Ageratum cristata	25	41.67	5	25.00	--	--	30	30.00
Blumea virens	14	23.33	6	30.00	8	40.00	28	28.00
Mitragyna parviflora	19	31.67	3	15.00	3	15.00	25	25.00
Bambusa vulgare	4	6.67	10	50.00	9	45.00	23	23.00
Pogostemon benghalensis	13	21.67	--	-	10	50.00	23	23.00
Justicia sps	16	26.67	4	20.00	3	15.00	23	23.00
Achyranthus sps	16	26.67	3	15.00	3	15.00	22	22.00
Hymenodictyon arixenese	8	13.33	2	10.00	11	55.00	21	21.00
Unknown climber	17	28.33	4	20.00	--	--	21	21.00
Eulaliopsis binata	10	16.67	6	30.00	4	20.00	20	20.00
Zizyphus mauritiana	11	18.33	6	30.00	1	5.00	18	18.00
Imperata cylindrica	9	15.00	5	25.00	3	15.00	17	17.00
Unknown forb	6	10.00	2	10.00	9	45.00	17	17.00
Unknown shrub s2	8	13.33	5	20.00	3	15.00	16	16.00
Mallotus philippensis	13	21.67	1	5.00	1	5.00	15	15.00
Unknown shrub s1	5	8.33	1	5.00	8	40.00	14	14.00
Clerodendrum viscosum	--	--	4	20.00	10	50.00	14	14.00
Cynodon dactylon	12	20.00	1	5.00	1	5.00	14	14.00
Myrsine semiserrata	7	11.67	--	--	6	30.00	13	13.00
Eugenia sps	6	10	1	5.00	6	30.00	13	13.00
Buchanania lanzana	7	11.67	2	10.00	3	15.00	12	12.00
Nyctanthes arbortristis	9	15.00	2	10.00	1	5.00	12	12.00
Trachetospermum lucidum	7	11.67	2	10.00	1	5.00	11	11.00
Blumeopsis flava	8	13.33	1	5.00	2	10.00	11	11.00
Shorea robusta	6	10.00	3	15.00	1	5.00	10	10.00
Hemarthria compressa	9	28.33	--	--	--	--	9	9.00
Schleichera oleosa	3	5.00	1	5.00	3	15.00	7	7.00
Phlogacanthus sps	6	10.00	--	--	1	5.00	7	7.00
Thysanolaena maxima	6	10.00	--	--	--	--	6	6.00
Themeda triandra	6	10.00	--	--	--	--	6	6.00
Clerodendrun sps	6	10.00	--	--	--	--	6	6.00
Rhus wallichii	5	8.33	--	--	--	--	5	5.00
Acacia catechu	5	8.33	--	--	--	--	5	5.00
Artemisia indica	3	5.00	--	--	1	5.00	4	4.00
Asparagus racemosus	3	5.00	--	--	--	--	3	3.00
Paspalam distichum	2	3.33	1	5.00	--	--	3	3.00
Anthocephalus chinensis	2	3.33	--	--	--	--	2	2.00
Aegle marmelos	1	1.67	1	5.00	--	--	2	2.00
Phyllanthus emblica	1	1.67	1	5.00	--	--	2	2.00
Desmodium species	--	--	2	10.00	--	--	2	2.00
Bauhinia sps	1	1.67	--	--	--	--	1	1.00
Digitaria sps	1	1.67	--	--	--	--	1	1.00
Justicia simplex	1	1.67	--	--	--	--	1	1.00
Niche Breadth (B_s)		0.045		0.039		0.028		0.050

5. DISCUSSION

In total, 45 plant species belonging to 20 different plant families were identified through microhistological study of the pellet samples (n=100) of FHA (Table 4.1). The result revealed that browse species are the most important foods for FHAs, constituting 66.95 percent of the overall diet proportion while grass species constituted only 13.67 percent. Rest 19.77 percent of the plant fragments remained unidentified. This contradicts to the findings of Baskaran et al. (2011), who reported equal proportion of grass and browse. The browse domination in the diet, in this study, supports the results of the feeding observations made on free ranging (Berwick, 1974) and tamed antelopes (Solanki and Naik 1998, Sharma 2006) from the central and western India. According to Hofmann (1989), concentrate feeders choose a mixed diet with grasses less than 25 percent and show a remarkable degree of forage selectivity. The FHAs in Bardia National Park are concentrate feeders, consuming different proportions of various plant species and forage categories (grasses, forbs, shrubs, climbers and trees). Plant species differ in protein and fibre contents which influences animals' food choice (Klaus-Hugii et al. 1999) and digestibility (Harborne 1991). The food selectivity in FHAs may be result from nutritional requirements, the need to decrease fiber intake, and maximization of protein intake in order to increase digestibility.

On the whole, trees constituted the major part of the diet contributing to 25.86 percent, followed by shrubs (21.30 %), forbs (18.20 %), grasses (10.50 %) and climbers (4.37 %). The study made by Baskaran et al. (2011) in tropical forests of southern India during dry season revealed grasses as the major constituent of FHA diet (28.6 %) followed by trees (8.0 %), shrubs (5.6 %) and herbs (6.7 %). He argues that during dry seasons grass become too coarse and less nutritive hence this antelope depends on both browse and grass, and appears to adapt its feeding according to availability. The shrub *Berlaria cristata* of the family Acanthaceae is the most preferred plant by this species in BNP. The other plants, in decreasing order of preferences, are *Ageratum cristata* (Asteraceae), *Euloliopsis binata* (Graminae), *Matragyna parviflora* (Rubiaceae), *Berdelia retusa* (Euphorbiaceae), *Imperata cylindrica* (Graminae), *Blumea virens* (Compositae), *Bambusa vulgare* (Graminae),

Hymenodictyon arixenese (Rubiaceae), *Pogostemon benghalensis* (Labiatae), *Achyranthus* sps (Amaranthaceae), *Cynodon dactylon* (Graminae), etc. (Table 4.1). The cafeteria experiments of Berwick (1974) in Gir forest ecosystem, India, and Sharma et al. (2009) in Van Vihar National Park cum Zoo in Bhopal, India, showed that *Zizyphus mauritiana* was the most preferred plant for the tamed FHAs (> 24 %). This study reveals a contrasting result showing minimum affinity (1.93 %) towards the consumption of *Z. mauritiana* in the wild. Although highly palatable, the thorns of *Z. mauritiana* inhibit its consumption in the natural habitats (Berwick, 1974). The FHA in BNP does not show much preference towards climber plants. Only two climbers (*Trachetospermum lucidum* and one unknown) were consumed in small percentage.

Microhistological analysis method includes multiple successive sampling from the individuals, pellets and epidermis fragments. Sampling size, therefore, could affect the estimate in all consecutive sampling steps (Katona and Altbacker 2002). The greater the diet diversity of a species and the smaller the similarity of individuals, the larger the required minimum sample size is (Kovacs and Torok 1997). For determining FHA diet, reading 30 randomly distributed plant fragments per slide per pellet from 41 independent pellet groups provide a reasonable optimum sample size. This result presented is only valid for the conditions of the study area (BNP) but can provide first guidance for similar studies in other habitats and situations.

There was marked differences in the frequency of consumption of different plant types by FHA in different seasons. Seasonal fluctuations in diets occur and their aggregation gives an assessment of resource utilization (Baltolome et al. 1998). Although inadequate sample sizes in monsoon and winter seasons make it inappropriate to extrapolate this result as the diet of entire seasons, but still, it is rather fair to say that the FHAs in BNP prefer browse species. The other closely related species of this antelopes are also found to be browsers; such as African Bushbuck (*Tragelaphus scriptus*) (Odendaal 1983), Kudu (*Tragelaphus species*) (Owen-Smith 1993) and Eland (*Taurotragus oryx)* (Buys 1990). FHA preferred to eat tree species in all three seasons but in different proportions (Table 4.1). The FHA consumed tree species more in winter season but decreased its consumption during summer and monsoon. Forbs were consumed more in summer than in monsoon and winter. The consumption of

grasses was more in monsoon than in summer and winter. The consumption of grass was in higher proportion during monsoon season, as the FHAs are known to consume grasses more in monsoon season while have specialized foraging preferences in other seasons (Rodger and Panwar 1988). The grasses in monsoon are rich in nutrient content compared to other seasons (Sukumar 1989) while in other seasons they become too coarse and poor in nutrient contents (Baskaran 1998).

Consumption patterns of different food plants vary with seasons (Table 4.1). The five most frequently consumed plants in summer were (in descending order of preference); *Ageratum cristata*, *Mitragyna parviflora*, *Bridelia retusa*, *Imperata cylindrica* and *Berlaria cristata* while in monsoon, this order followed; *Euloliopsis binata*, *Bambusa vulgare*, *Berlaria cristata*, *Blumea virens* and *Imperata cylindrica*. In winter, *Pogostomum benghalensis* was followed by *Hymenodactylon arixensis*, *Berlaria cristata*, *Blumea virens* and an unknown shrub. In environments with prominent seasonal changes, food resources are commonly limited and dietary quality and quantity are highly varied during dormant seasons. Consequently, highest intakes of digestible nutrients by herbivores occur in summer or rainy seasons (Parker et al. 2009). In BNP too, the plant resource heterogeneity, duration of the dormant season, and rate of decline in forage quality all must have affected the seasonal cycle of food intake by FHA.

Nearly one fifth (19.77 %) of the total plant fragments remained unidentified in this study. This percentage was 48 percent in the study made by Baskaran et al. (2011). In-vitro digestibility greatly influences the results of microhistological analysis particularly in the estimation of grass and forbs content (Vavra and Holechek 1980). The digestive efficiency of deer is very high so the ingested plant parts are almost degraded (Korschgen 1971). FHA prefers fruits, flowers and fresh leaves (Berwick, 1974; Sharma et. al, 2005, Baskaran et al. 2011) which are highly degradable. Thus, this heavy percentage of unidentified plants in the diet could be due to high mastication and efficient digestion by the animal. Also, the biasness subjected to microhistological analysis, like sample preparation (Vavra and Holechek 1980), poor training of technician (Holechek and Gross 1982) and differential digestibility of diet components (Holechek et al. 1985) may have influenced in resulting the large percentage of fecal plant fragments unclassified.

The FHAs in BNP tend to feed selectively (Standardized Levin's Measure of Niche Breadth = 0.0104). The statistically re-established hypothesis of Jerman (1974) by Brashares et al. (2000) suggests that feeding selectivity of ruminants is negatively correlated with its body size and group size. Hence, smaller species require more energy per unit weight. Smaller antelopes have smaller stomachs compared to larger ruminants but have high metabolic requirements. This prohibits them from feeding large quantities of coarse forages that are high in fiber content and low in protein contents. Plant species differ in protein and fibre contents which influences animals' food choice (Klaus-Hugii et al. 1999) and digestibility (Harborne 1991). Since highly nutritious and protein rich food is scarce, FHA do not attain high abundances (Sharma et al. 2009). The selective feeding strategy of FHA in BNP fits the Jarman's hypothesis. Berwick (1974) and Sharma et al. (2009) also concluded that this species as a selective feeder. The food selectivity in FHAs may be result from nutritional requirements, the need to decrease fiber intake, and maximization of protein intake in order to increase digestibility.

The FHAs preferred browse species in all seasons. During winter the browse to grass ratio was higher (6.80) than in summer (3.8) and winter (1.97). This shows that during winter FHAs feed strongly on browse plants while during monsoon these plants are substituted by grass species. The possible reason for this may be that during winter season the cold and low moisture retards the growth of grass species and most grasses dry up becoming coarse and less nutritive. FHAs, in turn, feed mostly on browse plant species to meet their nutritional requirements. But during monsoon, the first rain in the pre-monsoon season stimulates new grass growth, and the intercalary meristem growth of monocots is more nutritious than apical growth in browse plants (Jarman 1974). So the browse plants are substituted by grass species for food during monsoon.

Accounting the potential dietary competition of FHA with other sympatric ungulates in Babai valley, it is observed that there is some degree of sharing of food plant species with Swamp Deer, Hog Deer, Rhino and Elephant. Six of the plant species (*Themeda* sps, *Cynodon dactylon, Imperata cylindrca, Hemarthria compressa* (Ghode dubo), *Mallotus phillippenensis* and *Ziziphus mauritiana*) consumed by Swamp Deer, Hog Deer and Rhino (Wegge et al. 2006) are also consumed by the FHAs. *Aegle marmelos*, *Bauhinia* sps,

Desmodium sps, *Mallotus phillippenensis*, *Zizyphus mauritiana*, *Cynodon dactylon*, *Imperata cylindrica* and *Themeda* sps observed in the diets of Rhino and Elephant (Pradhan et al. 2008) are also observed in FHA diet. Interestingly, FHA was found consuming only one plant in common (*Imperata cylindrica*) with Barking Deer - a potential competitor of FHA. But the diet of Barking Deer was studied in Shivapuri National Park, Nepal (Nagarkoti and Thapa 2007), so generalization from the studies conducted in different landscapes and different vegetation availability may be misleading. Hence, more research in sympatric ungulates sharing the same landscape and same resources is required.

6. CONCLUSION AND RECOMMENDATIONS

For Four-horned Antelopes of Bardia National Park, Nepal, 45 plant species belonging to 20 different plant families are the sources of nutritional supplements. They are concentrate feeders and choose a mixed type of functional plant categories in different proportions. Altogether, 5 grasses, 8 forbs, 15 shrubs, 2 climbers and 15 tree species were the contributing food items to the FHA diets. FHA prefers nutrition rich browse plant types rather than grasses providing evidence towards its browsing behavior in feeding. Trees, followed by shrubs and forbs are the plants of preferences for the animal in the wild. The narrow niche breadth of the food items in the diet justifies that FHAs are selective of food plants and choose plants as per to meet their nutritional requirements. The most frequently consumed *Berlaria cristata, Ageratum cristata*, *Euloliopsis binata*, *Matragyna parviflora*, *Berdelia retusa*, *Imperata cylindrica*, *Blumea virens*, *Bambusa vulgare*, *Hymenodictyon arixenese*, *Pogostemon benghalensis*, *Achyranthus* sps, *Cynodon dactylon,* etc. are some of the major food items for this animal. Although the lower quantity of sample sizes in monsoon and winter seasons may decrease the robustness of the findings, it can be concluded that grass species support significantly in monsoon diets while browse species are vital in all seasons. The most frequently consumed plants in summer are *Ageratum cristata*, *Mitragyna parviflora, Bridelia retusa*, *Imperata cylindrica, Euloliopsis binata* and *Berlaria cristata* while in monsoon, *Euloliopsis binata*, *Bambusa vulgare*, *Berlaria cristata*, *Blumea virens* and *Imperata cylindrica* are fed. In winter *Pogostomum benghalensis*, *Hymenodactylon*, *Berlaria cristata, Blumea virens, Buchanania lanzans and Euloliopsis binata* are the plants of concern.

Based on this study, following recommendations are put forward.

- Detailed food habit studies of this species with adequate sample sizes of whole year should be conducted in Bardia National Park and other landscapes too.
- Knowledge on feeding ecology and feeding niche overlap is a prerequisite for management, hence similar studies to be conducted with sympatric and potential

competitor species to understand its niche overlaps, degree of competition and know how it manages to adjust with other similar ungulates.

- The ongoing phatas (grassland) management to increase grassland area should be assessed in relation to its impact on feeding ecologies of browser herbivores like FHAs.

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ANNEXURES

Annex. I. Plants collected from Bardia National Park for reference library preparation.

S.N.	Plant Code	Functional category	Local Name	Family	Scientific Name
1	1	Grass	Babiyo	Graminae	*Eulaliopsis binata*
2	3	Grass	Siru	Graminae	*Imperata cylindrica*
3	4	Grass	Ureli	Graminae	*Themeda caudata*
4	5	Shrub	Forsa	Tilaceae	*Grewia sps*
5	7	Tree	Bhalayo	Anacardiaceae	*Rhus wallichii*
6	8	Tree	Kalikath	Myrsinaceae	*Myrsine semiserrata*
7	9	Tree	Paadan	Leguminoseae	*Desmodium oojeinense*
8	11	Tree	Dhairo	Lythraceae	*Woodforbia*
9	12	Shrub	Asare	Lythraceae	*Lagerstroemia parviflora*
10	13	Shrub	Dattiwan	Amaranthaceae	*Achyranthus*
11	14	Climber	Bhorla	Leguminoseae	*Bauhinia vahlii*
12	15	Shrub	Bansapti	Leguminoseae	*Flemingia*
13	16	Shrub	Amriso	Graminae	*Thysanolaena maxima*
14	17	Tree	Jamun	Myrtaceae	*Syzygium cumini*
15	18	Tree	Dudh khirra	Apocynaceae	*Holarrhena pubescens*
16	19	Tree	Rohini	Euphorbiaceae	*Mallotus philippensis*
17	20	Shrub	Kurilo	Liliaceae	*Asparagus phillipensis*
18	21	Shrub	Vede kuro	Acanthaceae	*Barleria cristata*
19	22	Shrub	Unknown shrub	--	--
20	23	Shrub	Baauri	Rubiaceae	*Anthocephalus chinensis*
21	24	Shrub	Dhurseli	Labiatae	*Colebrookea oppositifolia*
22	25	Tree	Bel	Rutaceae	*Aegle marmelos*
23	26	Tree	Bayar	Rhamnaceae	*Zizyphus mauritiana*
24	27	Tree	Sal	Dipteriocarpaceae	*Shorea robusta*
25	28	Tree	Kusum	Sapindaceae	*Schleichera oleosa*
26	29	Tree	Tendu	Moraceae	*Ficus hispida*
27	30	Shrub	Thakal	Papaveraceae	*Argemone maxicana*
28	31	Tree	Ber	Rubiaceae	*Hymenodictyon arixenese*
29	32	Tree	Khair	Leguminoseae	*Acacia catechu*
30	33	Tree	Bamboo	Graminae	*Bambusa vulgare*
31	34	Shrub	Amala	Euphorbiaceae	*Phyllanthus emblica*

32	35	Shrub	Chitena		
33	36	Tree	Rukh gaayo	Euphorbiaceae	*Bridelia retusa*
34	37	Tree	Seto siris	Leguminoseae	*Albizia procera*
35	38	Shrub	Dahi Kamala	Verbenaceae	*Callicarpa macrophylla*
36	39	Tree	Taaki	Leguminoseae	*Bauhinia*
37	40	Grass	Banso	Graminae	*Digitaria*
38	41	Shrub	Dhairo	Lythraceae	*Woobfordia fruticosa*
39	42	Shrub	Parijaat	Oleaceae	*Nyctanthes arbortristis*
40	43	Tree	Dhurseli	Labiatae	*Colebrookea oppositifolia*
41	44	Tree	Piyari	Anacardiaceae	*Buchanania lanzans*
42	45	Shrub	Parijaat	Oleaceae	*Nyctanthes arbortristis*
43	46	Shrub	Asare	Rutaceae	*Murraya koenigii*
44	47	Grass	Dhaddi	Graminae	*Themeda triandra*
45	48	Grass	Sano Narkat	Graminae	*Phragmites karka*
46	49	Tree	Unknown Tree	--	--
47	50	Tree	Main kaandaa	Rubiaceae	*Xeromphis spinosa*
48	51	Shrub	Bhati	Verbenaceae	*Clerodendrum*
49	52	Shrub	Rudilo	Labiatae	*Pogostemon benghalensis*
50	53	Tree	Tikul	Rubiaceae	*Mitragyna parviflora*
51	54	Shrub	Jhadu	Solanaceae	*Solanium pseudocapsicum*
52	55	Shrub	Mohani ghas	Elaeagnaceae	*Elaeagnus infundabularis*
53	56	Climber	Dudhe lahara	Rubiaceae	*Hedyotis scandens*
54	57	Climber	Batulpaate	Apocynaceae	*Trachetospermum lucidum*
55	58	Shrub	Banmaaraa	Oleaceae	*Nyctanthes* sps
56	59	Tree	Pankath	Boraginaceae	*Ehretia laevis*
57	60	Forb	Vede kuro	Asteraceae	*Xanthium strumarium*
58	61	Shrub	Unknown Shrub	--	--
59	62	Grass	Kans	Graminae	*Saccharum spontaneum*
60	63	Forb	Tori Gandhe	Asteraceae	*Blumeopsis flava*
61	65	Grass	Unknown grass	--	--
62	66	Shrub	Rukh bayar	Tilaceae	*Grewia sps*
63	68	Shrub	Titepati	Compositae	*Artemisia indica*
64	70	Forb	Ganne jhar	Asteraceae	*Ageratum cristata*
65	72	Tree	Sadan	Myrtaceae	*Eugenia* sps
66	73	Shrub	Tite bhaat	Verbenaceae	*Clerodendrum sps*
67	74	Forb	Bish-kavre	Malvaceae	*Sida sps*
68	76	Forb	Dubo	Graminae	*Cynodon dactylon*
69	77	Forb	Ghode-ghas	Graminae	*Hemarthria compressa*
70	79	Climber	Dudhe ahara	Apocynaceae	*Vallaris solanacea*

71	80	Shrub	Unknown Shrub	--	--
72	81	Forb		Leguminoseae	*Desmodium sps*
73	82	Forb	Unknown Forb	--	--
74	83	Forb	Boke jhaar	Compositae	*Vernonia cineria*
75	84	Forb	Mulapate	Compositae	*Blumea virens*
76	85	Forb		Acanthaceae	*Justicia*
77	86	Forb	Dudhe jhar	Euphorbiaceae	*Euphorbia*
78	87	Forb	chari amili	Oxalidaceae	*Oxalis acetosella*
79	88	Climber	Unknownclimber	--	--
80	89	Tree	Kumbi	Lecythidaceae	*Careya arborea*
81	91	Shrub		Euphorbiaceae	*Phyllanthus*
82	93	Shrub	Karaudaa	Apocynaceae	*Carissa spinarum*
83	94	Tree	Pipiri	Solanaceae	*Soanium erionthum*
84	95	Grass	Arthyunge	Gramineae	*Heteropogon contortus*
85	96	Shrub		Tilaceae	*Grewia*
86	97	Forb		Acanthaceae	*Justicia*
87	98	Grass	Banso	Graminae	*Paspalam*
88	99	Forb		Acanthaceae	*Berleria cristata*
89	100	Shrub		Tilaceae	*Grewia*
90	101	Shrub		Acanthaceae	*Justicia simplex*
91	102	Tree	Sadhan	Myrtaceae	*Eugenia*
92	103	Tree	Tuni	Meliaceae	*Toona ciliata*
93	104	Tree	Koiralo	Anacardiaceae	*Bauhinia purpuria*
94	105	Tree	Taaki	Anacardiaceae	*Bauhinia variegata*
95	106	Tree	Sisoo	Leguminoseae	*Dalbergia sissoo*
96	107	Climber		Schizaeaceae	*Lygodium flexuosum*
97	108	Tree	Aank	Asclepiadaceae	*Calotropis gigantea*
98	109	Shrub		Acanthaceae	*Phlogacanthus*
99	111	Shrub		Leguminoseae	*Crotolaria alata*
100	112	Forb		Symplocaceae	*Symplocos sumantia*
101	113	Shrub	Unknown Shrub	--	--
102	201	Tree	Unknown Tree	--	--
103	203	Tree		Malpighianaceae	*Hiptage bengalensis*
104	204	Tree	Unknown Tree	--	--

Annex. II. Key histological characters of various plant particles identified from reference plant specimens.

Features: Crystals

Plant code	Plant species	Characteristic features
9	*Desmodium oojeinense*	Polygonal shaped, enclosed in a rectangular enclosure, arranged compactly in lines.
19	*Mallotus philippensis*	Cube shaped; some ovular, enclosed on square enclosure, arranged in lines.
26	*Zizyphus mauritiana*	Polygonal shaped, densely distributed; few ovular and arranged in lines
32	*Acacia catechu*	Round and/or rectangular, densely arranged in rows of lines, sometimes pentagonal enclosed in polygonal enclosure.
42	*Nyctanthes arbortristis*	Rectangular, present in pairs or single, freely arranged in lines.
46	*Murraya koenigii*	Quadrilateral shaped, distributed in straight lines in several columns, sometimes dispelled.
72	*Eugenia* sps	Pentagonal or hexagonal, arranged in columns.
51	*Clerodendrum sps*	Square shaped, unequal sized, densely dispersed.
105	*Bauhinia variegate*	Polygonal shaped, densely arranged in lines
18	*Holarrhena pubescens*	Styloid crystals densely distributed, pointed tips, and appears like broken glass.

Feature: Hairs and Trichomes

Plant code	Plant species	Characteristic features
14	*Bauhinia vahlii*	S-shaped with round base and pointed tip, smooth outline.
5	*Grewia sps*	Eight-sixteen warty hairs emerged from a common base, pointed tips, and densely dispersed forming a mesh like structure.
7	*Rhus wallichii*	Single, or if two lying opposite to one another, smooth and straight with pointed tips.
8	*Myrsine semiserrata*	Single, straight and smooth with pointed tip, coated with transparent coating.

12	*Lagerstroemia parviflora*	Singly arranged, mostly curved; sometimes straight, emerging with an oval shaped base and pointed tip.
19	*Mallotus philippensis*	Straight projection with curving at the tips, densely dispersed and look like a mesh.
24	*Colebrookea oppositifolia*	Sectioned into three-five segments, cylindrical base, segments towards tip decrease in diameter, look like an arthropod appendage.
36	*Barleria cristata*	Segmented, rectangular segments connected by nodes, look like an arthropod appendage.
51	*Clerodendrum Viscosum*	Slightly curved, segmented, smooth, pointed tip, bounded by a dark membrane.
52	*Pogostemon benghalensis*	Single or segmented into two, oval based with sharp pointed tip, projected to common direction, warty particles inside covered by smooth outer layer.
53	*Mitragyna parviflora*	Needle shaped with oval base, warty substances inside forming a line, smooth surface, singly arranged, random distribution.
55	*Elaeagnus infundabularis*	Short hairs emerged from stomata shaped oval base, straight projection, pointed tips, smooth surface, thinly distributed.
70	*Ageratum cristata*	Emerged from a single base and projected in all directions, smooth surfaced with small bubble like structures inside, densely distributed forming mesh like structure.
73	*Clerodendrum sps*	Single, long, curved, with pointed tip, segmented into two with three intersegments in each segment.
79	*Vallaris solanacea*	Long flagella like, singly originated from oval base, smooth surface, projected to a common direction, sharp pointed tip.
86	*Euphorbia sps*	Curved to a comma shape, segmented into 5 segments, look like arthropod appendage, single origin, rough surface, and random distribution.
87	*Oxalis acetosella*	More than 15 in number, originated from a single base, serrated surface, look like an octopus.
94	*Soanium erionthum*	Long thread like, originated from a circular base having dark substances inside, inner dark lining running towards pointed tip, smooth, random projection and dense (> 30) distribution.
96	*Grewia sps*	Three-eight, originating from single and large oval dark base, smooth surface, projected at opposite directions.
204	Unknown tree	Alternately arranged, smooth surface, long with pointed tip, projected at random direction.

Feature: Stomata

Plant code	Plant species	Characteristic features
3	*Imperata cylindrical*	Stomata are arranged in a straight line in several columns, surrounded by subsidiary cells, columns are separated by long cells.
26	*Zizyphus mauritiana*	Cross celled: two subsidiary cells enclose the stomata, their common wall arranged parallel to the axis of stomata arranged randomly,
14	*Bauhinia vahlii*	Dispersed stomata are surrounded by one or more subsidiary cells, axis of stomata faces different direction.
24	*Colebrookea oppositifolia*	Arranged far from one another, surrounded by subsidiary cells.
76	*Cynodon dactylon*	Dog-bone shaped stomata, arranged in line, surrounded by subsidiary cells.
1	*Eulaliopsis binata*	Arranged in straight line, separated by long sinus cells, sinus cells are separated by silica cells.
12	*Lagerstroemia parviflora*	Dispersed stomata, axis facing different directions, guarded by two guard cells.
13	*Achyranthus sps*	Feebly dispersed stomata, axis facing different directions, guarded by several subsidiary cells
16	*Thysanolaena maxima*	Arranged in straight line, separated by long sinus cells, sinus cells are separated by silica cells.
17	*Syzygium cumini*	Densely distributed stomata, guarded by four-six subsidiary cells
20	*Asparagus phillipensis*	Arranged in straight line, separated by two-three rows of long sinus cells.
25	*Aegle marmelos*	Dispersed stomata, axis facing different directions, guarded by two-three guard cells.
30	*Argemone maxicana*	Arranged in a common axis line, surrounded 4 guard cells by unequal sized six-eight subsidiary cells,
39	*Bauhinia sps*	Randomly distributed, four subsidiary cells; two equal sized lie at right angle to the axis of stomata and rest two unequal sized lie along the axis.
40	*Digitaria sps*	Arranged in straight line, separated by long sinus cells, sinus cells are separated by silica cells.
44	*Buchanania lanzans*	Randomly distributed, four-six unequal sized polygonal subsidiary cells surround the stomata.
46	*Murraya koenigii*	Randomly distributed, four-six unequal sized polygonal

		subsidiary cells surround the guard cells.
47	*Themeda triandra*	Arranged in straight line, separated by long sinus cells, sinus cells are separated by silica cells.
68	*Artemisia indica*	Arranged in a common axis, surrounded by eight-ten subsidiary cells, oval shape appearance with guard cells.
74	*Sida sps*	Randomly distributed, guard cells are surrounded by four comma shaped subsidiary cells.
77	*Hemarthria compressa*	Arranged in straight line, separated by long sinus cells, sinus cells are separated by silica cells.
82	Unknown	Randomly distributed, the guard cells are surrounded by four subsidiary cells
94	*Soanium erionthum*	Randomly distributed, the guard cells are surrounded by six unequal sized subsidiary cells.
112	*Symplocos sumantia*	Randomly distributed, the guard cells are surrounded by four-six unequal sized subsidiary cells.

Features: Epidermal cells and vascular characteristics

Plant code	Plant species	Characteristic features
1	*Eulaliopsis binata*	Sinus/serrated cells separated by ring like silica bodies, arranged parallel, long with narrow breadth. Some quadrilateral or rectangular and unequal sized, embedded compactly, sizes increase towards outer sides.
3	*Imperata cylindrica*	Rectangular or sinus cells, unequal sized, embedded compactly, parallel veins, length variable.
4	*Themeda caudata*	Rectangular cells, arranged parallel, every two rows separated by serrated veins.
5	*Grewia sps*	Rectangular cells, unequal sized; some appear to be round while others elongated, decrease in size towards outside.
7	*Rhus wallichii*	Quadrilateral or rectangular; sharp cut edges, appear like bands.
8	*Myrsine semiserrata*	Polygonal or rectangular, unsystematic arrangement in polygonal cells while arranged in rows in rectangular, unequal sized, separated by narrow depressions.
9	*Desmodium oojeinense*	Rectangular long cells, brick-wall like appearance and arrangement.
11	*Woodforbia*	Mostly Square shaped or quadrilateral with brick-wall like arrangements, sometimes polygonal with random arrangements, separated by narrow depressions.

12	*Lagerstroemia parviflora*	Polygonal with dark spots inside, arranged compactly, unequal sized. Peculiar large dark spots in some fragments.
14	*Bauhinia vahlii*	Weakly anticlinal separated from one another or if rectangular attached compactly, distinct broad veins.
13	*Achyranthus sps*	In between the veins mass of circular bubbles like appearance. Most are weakly anticlinal, while some are rectangular with brick-wall like arrangements.
15	*Flemingia*	Long and rectangular, embedded like brick-walls, unequal sized.
16	*Thysanolaena maxima*	Four-six rows of unequal sized pentagonal cells are separated by bands of rectangular cells, or sometimes sinus cells appear in place of these pentagonal cells.
17	*Syzygium cumini*	Thin elongated rectangular; or anticlinal cells, rectangular cells appear like narrow tubes
18	*Holarrhena pubescens*	Rectangular cells arranged in rows, spiral xylem vessels,
19	*Mallotus philippensis*	Rectangular or square cells with overlapping edges along the axis, some appear as bands of sequentially arranged rectangular figures, Annular xylem vessels, Mass of round bubbled structure appear on either side of veins.
20	*Asparagus phillipensis*	Long strips of rectangular or sinus cells, filled with lobed materials throughout.
21	*Barleria cristata*	Filamentous and/or rectangular cells, sometimes weakly sinus, elongated, varying width, distinct joints along the side of breadth.
22	Unknown Shrub	Irregularly shaped and lobed or Filamentous long cells, some rectangular appear in sets of four-six forming bands.
23	*Anthocephalus chinensis*	Mostly rectangular, some polygonal, appear as if cell is transected by a thin partition in the middle. Some appear in long strips.
24	*Colebrookea oppositifolia*	Rectangular cells running parallel along the veins. Some appear with bubble like heavy mass along with hairs.
25	*Aegle marmelos*	It is unique showing a large round dark mass around which small bodies prevail on either sides of veins. Xylem vessels are annular.
26	*Zizyphus mauritiana*	Rectangular cells with dense crystals. Xylem vessels are pitted type.
27	*Shorea robusta*	Polygonal cells with dark nucleus like body inside, forming a mesh like structure, veins have dark elongated dotted lines.
28	*Schleichera oleosa*	Irregularly lobed or round cells, sometimes rectangular with

		crystals running in lines. Spiral xylem vessels.
29	*Ficus hispida*	Long linings with rectangular or polygonal cells, cells are rough in outline and bear nucleus at one-third part of the cell.
30	*Argemone maxicana*	Rectangular or square shaped, rough surfaced cells, three-five rows of cells lying between long linings of vein, silica bodies' lye along the veins.
31	*Hymenodictyon arixenese*	Irregularly lobed or rectangular cells, peculiar sieve tubes, some transparent thread like bodies are seen dispersed.
32	*Acacia catechu*	Irregularly lobed cells, or rectangular with polygonal crystals
33	*Bambusa vulgare*	Rectangular cells along the veins, brick-wall like arrangement, peculiar sieve tubes
34	*Phyllanthus emblica*	Large round dark bodies prevail around which small bodies lie on either sides of veins. Xylem vessels in veins are annular.
35		Irregularly lobed or rectangular cells, some bright spots with rings are densely distributed.
36	*Bridelia retusa*	Rectangular cells, brick-wall like arrangement; sometime separated by stripped lining along the longitudinal section of the cell. In some, along the veins, dark round cells are densely distributed. Vascular vessels are spiral.
37	*Albizia procera*	Rectangular cells, while moving towards inner side get decompressed into polygonal shape, rough epidermal surface; Sometimes bubbled round dense mass is observed.
39	*Bauhinia*	Various shaped (rectangular, square, lobed, polygonal) cells surround guard cells, veins contain rectangular cells.
40	*Digitaria*	Sinus cells arranged like brick-walls, veins contain three rows of nodular silica bodies at certain interval.
41	*Woobfordia fruticosa*	Unequal sized lobed cells, annular vascular vessels.
42	*Nyctanthes arbortristis*	Round, lobed or hexagonal cells, compactly arranged, Long thread like segmented bodies are densely distributed in some.
43	*Colebrookea oppositifolia*	Pentagonal or polygonal cells, unequal sized.
44	*Buchanania lanzans*	Every six polygonal cells surround one stomata. There lies a big round body enclosed by 12-14 cells. Sometimes mixed arrangement of rectangular and polygonal cells is seen. Annular xylem vessels.
45	*Nyctanthes arbortristis*	Round, lobed or hexagonal cells, compactly arranged, sometimes bubbled round dense mass is observed.
46	*Murraya koenigii*	Polygonal cells separated by narrow depressions, concentrated towards stomata, some appear like a mass of round cells.

		Annular vascular vessels.
47	*Themeda triandra*	Rectangular or sinus cells, unequal sized, embedded compactly, parallel veins, length variable, veins with serrated outgrowing.
49	Unknown tree	Irregularly lobed or rectangular cells. Sometimes hairs protrude from rectangular cells. Annular xylem vessels.
50	*Xeromphis spinosa*	Polygonal (some hexagonal) cells are embedded compactly while rectangular cells are arranged in brick-wall like arrangements, unique conical body with inner linings originated from oval base run towards pointed tip.
51	*Clerodendrum*	Rectangular cells in brick-wall arrangements and polygonal cells separated from one another by narrow depressions are found. Annular xylem vessels are present.
52	*Pogostemon benghalensis*	Mix-up of rectangular and elongated pentagonal cells, two pentagonal cells share a common base while tilting tips face opposite directions. In addition, sinus anticlinal cells are also present Xylem vessels are spiral type.
53	*Mitragyna parviflora*	Cells are rectangular with hairs emerging from them, some are bubble round forming dense accumulation around veins. Xylem vessels are spiral.
54	*Solanium pseudocapsicum*	Large oval dark mass around which small round bodies prevail on either sides of veins are seen.
55	*Elaeagnus infundabularis*	Hairs growing from sinus anticlinal cells, while rectangular cells are filamentous. Xylem vessels are spiral.
56	*Hedyotis scandens*	Rectangular or polygonal cells; sometimes present in mass of round bodies. Vascular vessels are spiral.
57	*Trachetospermum lucidum*	Long, elongated and filamentous cells have distinct outer transparent layer, silica bodies present. Vascular vessels are annular.
58	*Nyctanthes*	Rectangular cells form brick-wall appearance while sinus anticlinal and round cells are found around veins. Vascular vessels are annular.
59	*Ehretia laevis*	Most of the rectangular cells along with polygonal cells accumulate around stomata with their longitudinal axis facing towards guard cells.
61	Unknown shrub	Long, elongated and filamentous cells, sometimes round. Vascular vessels are spiral.
63	*Blumeopsis flava*	Rectangular cells form brick-wall appearance while some show plate of linings forming flaps like structure.
65	Unknown grass	Weakly sinus cells with strips of veins consisting equal sized rectangular cells.

68	*Artemisia indica*	Rectangular or polygonal cells are arranged in unidirectional rows. Uniquely, this plant shows a mass of long fibers.
70	*Ageratum cristata*	Hexagonal cells with oval structure are uniquely arranged, rectangular cells are small sized and compactly attached.
72	*Eugenia* sps	Polygonal cells with dark nucleus like body inside, forming a mesh like structure, veins have dark elongated dotted lines.
73	*Clerodendrum sps*	Polygonal cells surround a mass of 10-12 celled ring from where hair emerges, rectangular cells are equal sized and arranged in brick-wall arrangements. Xylem vessels are spiral.
74	*Sida*	Rectangular or quadrilateral cells with arched edges are separated by narrow depressions and irregularly lobed cells contain hairs. Xylem vessels are spiral.
76	*Cynodon dactylon*	Sinus cells are followed by rectangular cells. Rectangular cells have arched edges. Polygonal cells when present are arranged in 3-5 rows separated by veins.
77	*Hemarthria compressa*	Sinus cells and hexagonal cells are present. Hexagonal cells are arranged in a bee-hive pattern. Six-eight rows of sinus cells are separated by veins.
79	*Vallaris solanacea*	Rectangular cells form brick-wall structure, while irregularly lobed cells are distributed along veins. Serrated long linings are also present. Sometimes bubbled round bright cells with dark spots are also seen.
80	Unknown Shrub	Rectangular and filamentous cells have narrow depressions between their joints. Xylem vessels are spiral.
81	*Desmodium species*	Peculiar thin and long thread like structures form a mesh like appearance, while unequal sized filamentous rectangular cells are also present.
82	Unknown Forb	Filamentous long cells with sharp cut ends, unequal sized round cells have dark spots inside, Xylem vessels are spiral.
83	*Vernonia cineria*	Cells appear as if cylindrical and are overlapping, thin and long thread like structures form a mesh like appearance.
84	*Blumea virens*	Two cells join to form parallelogram; the common base lies perpendicular to the longitudinal axis, other cells are rectangular with arched edges and arranged in brick-wall form,
85	*Justicia*	These are unique broom like structures formed by several long threads. Threads have rough surface, some filamentous dark bodies are seen,
86	*Euphorbia*	Round cells give rise to hairs while polygonal cells bear darkish stuffs inside, the curved veins possess rectangular bodies attached compactly along the veins.

87	*Oxalis acetosella*	Long filamentous rectangular cells arranged in same row, some parallelogram like are arranged in brick-wall pattern.
88	Unknown climber	Equally sized nearly square cells are arranged in brick-wall structure while rectangular cells are arranged in rows forming bands/strips of cells.
89	*Careya arborea*	Unequal sized lobed cells and polygonal cells. Polygonal cells are interconnected by narrow depression, Vascular vessels are spiral.
91	*Phyllanthus*	Elongated unequally sized hexagonal cells, sometimes filamentous bodies forming a bunch.
93	*Carissa spinarum*	Rectangular or quadrilateral shaped cells with rough surface, some appear like tubular in shape.
94	*Soanium erionthum*	Irregularly lobed cells with hairs emerging from them, Rectangular or quadrilateral shaped cells intercellular depressions. Annular xylem vessels.
95	*Heteropogon contortus*	Filamentous and rectangular cells, variable sizes, sinus cells between the veins.
96	*Grewia sps*	Uniquely arranges cells; two pairs of cells lie attached to the veins while others lie facing perpendicular to the paired cells. Lobed cells possess dark spots.
97	*Justicia sps*	Unequal sized and elongated hexagonal cells, filamentous cells form broom like structure.
98	*Paspalam sps*	Unique arrangement of rectangular cells towards veins and hexagonal cells next to them. In some, rectangular cells are variable sized and filamentous while in others equally sized rectangular cells are arranged in 4-6 rows between the veins. Sometimes sinus cells are also found.
99	*Berleria cristata*	Two types of cells; square shaped and irregularly lobed.
100	*Grewia*	Rectangular cells, some filamentous cells. Xylem vessels are spiral.
101	*Justicia simplex*	Mostly square shaped, some rectangular arranged in brick-wall arrangement. Spiral xylem vessels.
102	*Eugenia*	Rectangular cells mixed with conical cells, veins bear crystals.
103	*Toona ciliata*	Rectangular cells arranged in rows and sinus anticlinal cells arranged between the veins. Spiral xylem vessels.
104	*Bauhinia purpuria*	Most cells are quadrilateral, few are polygonal arranged compactly.
105	*Bauhinia variegate*	Mixed rows of rectangular and polygonal cells, bear hairs and crystals,
106	*Dalbergia sissoo*	Random arrangements of lobed, pentagonal and polygonal cells

		between the veins. Unequally sized rectangular cells bear crystals.
107	*Lygodium flexuosum*	Long filamentous rectangular cells have arched edges and appear like broom, Xylem vessels are spiral.
108	*Calotropis gigantean*	Variable sized polygonal shaped cells with narrow intercellular depressions surround around stomata. Xylem vessels are annular.
109	*Phlogacanthus*	Fine equal sized rectangular cells are arranged like brick-wall while several rows of elongated hexagonal cells follow next to them. Xylem vessel are spiral.
111	*Crotolaria alata*	Round cells are distributed between veins and rectangular cells are in brick-wall arrangement, sometimes oval dark bodies arrange in lines around rectangular cells.
112	*Symplocos sumantia*	Irregularly lobed cells with dark spots prevail between the veins. Rectangular and polygonal cells are unequal in size and randomly arranged.
113	Unknown shrub	In some, filamentous and rectangular cells are compactly arranged in rows, in some rows of equally sized rectangular cells are arranged parallel forming banded structure while in others, unequal sized rectangular cells are arranged in brick-wall form
201	Unknown tree	Dark rectangular, quadrilateral and polygonal cells with clear intercellular spacing are seen, Xylem vessels are spiral
203	*Hiptage bengalensis*	Polygonal and irregularly lobed cells are compactly distributed around stomata and veins.
204	Unknown tree	Quadrilateral and dog-bone shaped cells are arranged in rows, while lobed cells with dark spots are found between veins. Veins give rise to hairs.

Annex III. Average monthly temperature (2003-2012) at Chisapani meteorological station, Karnali.

Month	Temp	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Jan	Max	16.2	19.1	*	22.5	21	19.8	22.5	17.3	*	19.9
	Min	9.7	10.6	*	10.8	9.7	10.3	12.5	9.7	*	10.3
Feb	Max	23.7	25	*	28.5	24.7	23	*	24	*	24.6
	Min	13	13.7	*	16.2	13.9	12	*	12.5	*	12.3
March	Max	28.1	30.4	30.5	30.7	28.3	30.8	31.3	32.2	30.5	31.4
	Min	16.4	11.4	17.3	17.2	16.3	17.5	17.1	18.8	16.9	16.3
April	Max	35.7	36.1	36.3	35.8	25.1	35.6	37	38.5	35	37
	Min	21.8	17.4	21.2	21.2	21.9	21.4	22.6	23.5	20.6	20.03
May	Max	37.3	35.9	37.3	36	36.5	36.2	36.8	*	35.7	39.1
	Min	24.3	23.2	23.9	24.3	24.2	24	27.1	*	24.5	26.1
June	Max	34.6	33.9	38.9	34.1	35.5	32.8	38	37.2	33.3	38.6
	Min	24.9	24.3	26.9	25.6	26.2	25.4	28.7	24.4	25.3	28.2
July	Max	32.1	34	31.8	32.2	31.7	30.5	33.6	32	31.4	31.7
	Min	25	25.4	25.2	25.7	24.7	24.9	25	25.6	25.2	25.8
Aug	Max	31.9	34	31.5	32.2	31	31.2	32.2	*	31.4	32.1
	Min	25.5	25.4	25	25.2	25.1	24.7	24.6	*	25.2	25.2
Sept	Max	30.6	34.6	32.2	32.2	31.4	32.3	31.3	*	32.2	32.1
	Min	24.2	23.3	24.9	23.9	24.1	24.1	23.8	*	25	24.3
Oct	Max	31.1	33.3	30.6	31.2	30.3	*	23.9	30.9	31.8	31.2
	Min	20.4	20	21.1	21.1	21.1	*	14.3	21	21.7	19.8
Nov	Max	26.3	26.1	25.9	26.4	25.7	*	23.9	26.1	26.1	25.6
	Min	15.9	10.6	14.9	16.2	15.4	*	14.3	17.1	16.9	13.9
Dec	Max	20.9	22.9	21.4	22	21.5	*	19.7	20.8	21.3	20.8
	Min	12.2	8.4	10.7	12.3	11.9	*	12.4	10.3	11.6	10.9

Annex IV.Average monthly rainfall (2002-2012) at Chisapani metereological station, Karnali

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	99.1	53.3	6.2	54.9	194.5	218.6	529.4	707.6	268.5	38.4	6.6	1
2003	99	104.1	5.1	20.9	45.4	404	652.1	416.6	519.4	3.9	0	1
2004	1	15.3	0	86.2	91.7	76.5	749.4	501.8	407.4	167	0	0
2005	*	*	20.5	*	*	223.7	637.7	682.1	261.7	38.7	0	4
2006	0	1	70.4	18.6	139	325.6	426.8	624.5	412.6	36.5	0	20
2007	0	74.8	0	0	60.7	315.9	1560	957.5	317.4	4.7	0	2.2
2008	14.9	11	0	61	98.9	598.7	864.6	653.9	371.5	61.2	0	0
2009	0	*	9	0	73	195.7	653.5	855.2	427.8	12.8	1.5	0
2010	25.1	41.3	0.2	0	*	191.5	627.9	*	*	16.2	0	0
2011	0	0	0	9.1	142.2	594.7	762.1	0	225.4	0	0	0
2012	22.5	16	13	12	0	47	624.8	492	156	0	0	0

(Source: DHM/GOVN).

Annex V. Average monthly Humidity % at 8:45 and 17:45 (2001- 2010) at Chisapani metereological station, Karnali.

Month	Time	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Jan	8:45	81.1	85.8	79.8	*	74.1	66.3	73.0	82.0	79.5	*	83.3
	17:45	87.3	90.7	84.4	*	73.6	62.0	67.3	80.5	86.4	*	82.9
Feb	8:45	80.2	86.2	83.7	*	72.9	79.1	94.8	*	80.1	*	75.4
	17:45	83.9	84.7	70.1	*	68.4	82.2	*	*	82.0	*	69.5
Mar	8:45	73.3	71.1	58.2	64.0	59.6	67.6	*	53.6	63.8	68.3	59.9
	17:45	70.2	68.4	56.3	59.4	61.4	55.2	*	57.9	54.6	61.2	66.2
Apr	8:45	64.7	45.2	51.4	47.9	55.9	57.4	*	42.8	41.9	46.2	39.0
	17:45	59.8	40.5	48.1	46.7	57.5	52.1	*	43.2	29.8	48.4	52.1
May	8:45	72.9	39.1	51.6	44.2	66.2	54.0	56.1	51.2	*	57.1	40.0
	17:45	74.4	36.6	46.0	42.3	63.7	53.9	53.1	53.5	*	57.8	33.7
Jun	8:45	81.3	72.5	66.	51.6	71.2	68.9	80.4	52.8	61.4	72.8	55.3
	17:45	82.8	65.0	61.9	44.2	68.3	67.4	77.9	48.7	53.2	77.4	42.5
Jul	8:45	87.1	82.3	85.7	86.2	84.1	82.4	88.1	80.6	86.2	89.9	87.4
	17:45	88.5	86.7	83	84.2	85.3	80.3	87.0	81.5	84.6	88.6	83.1
Aug	8:45	89.0	84.0	84.1	85.6	82.5	84.4	86.3	87.1	*	89.8	88.6
	17:45	87.0	89.8	87.9	86.7	84.2	86.5	86.7	88.1	*	88.3	87.1
Sep	8:45	86.2	85.0	86.3	80.6	80.1	79.9	77.7	80.4	*	86.8	88.0
	17:45	92.5	89.4	88.1	84.1	84.1	81.8	81.9	86.1	*	89.7	85.6
Oct	8:45	77.6	73.5	78.7	77.3	73.0	74.8	*	77.8	73.0	79.5	77.6
	17:45	89.4	80.1	82.8	82.9	80.8	81.2	*	74.8	84.8	88.3	78.5
Nov	8:45	80.8	76.4	77.4	69.7	76.9	71.8	*	77.8	78.0	84.9	78.8
	17:45	83.5	79.4	72.9	78.4	73.9	66.0	*	74.8	81.5	92.9	78.2
Dec	8:45	83.5	81.2	*	77.7	76.5	67.9	*	79.2	76.1	79.9	82.7
	17:45	87.1	80.2	*	76.1	72.9	75.1	*	84.4	80.6	86.5	81.3

PHOTOPLATES

I. Photographs form study area

a) Habitat of Four-horned antelope in BNP.

b)Transect walk

c) Hump of FHA pellets

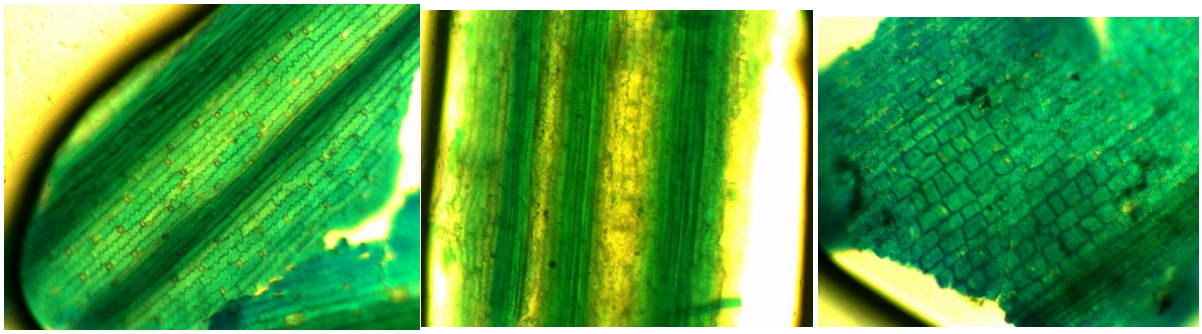
d) Pellets of FHA fed on mud

e) Collection of FHA faecal pellets

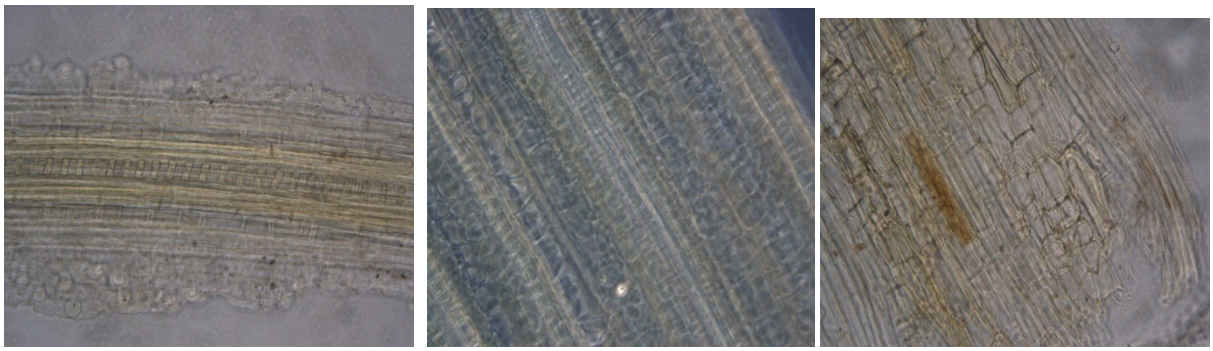
f) Cut down trees to increase grassland

II. Selected histological photographs of principal food plants of FHA in BNP, Nepal.

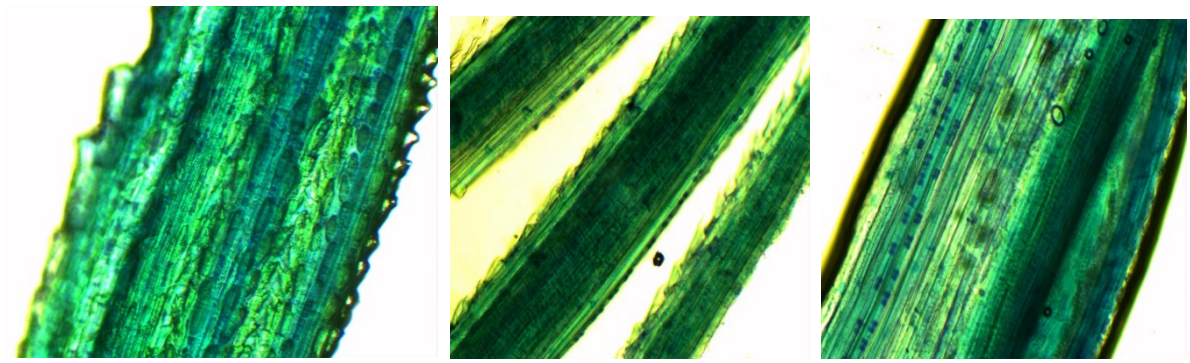
a) *Eulaliopsis binata* (Babiyo)



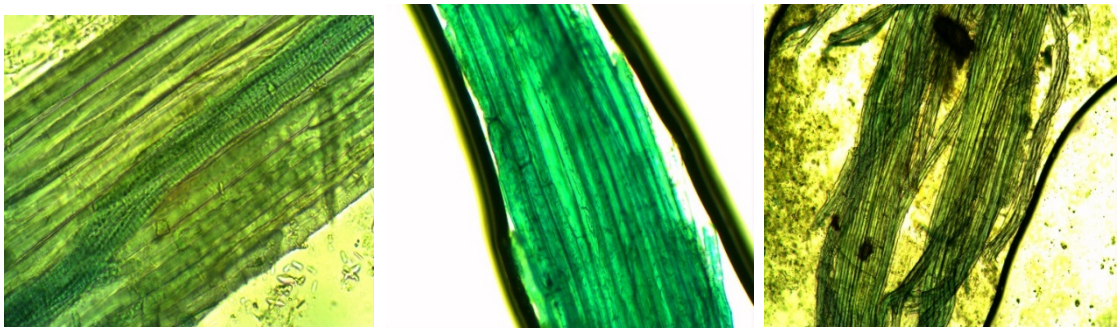
b) *Imperata cylindrica* (Siru)



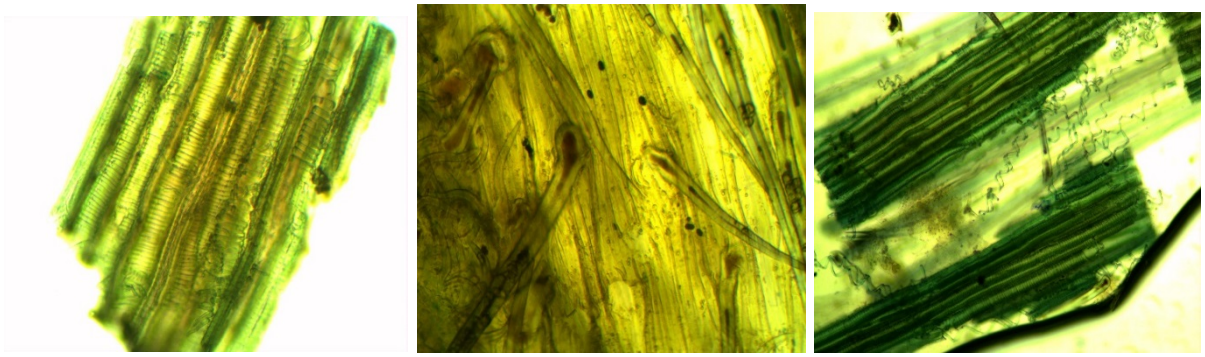
c) *Themeda triandra* (Dhaddi)



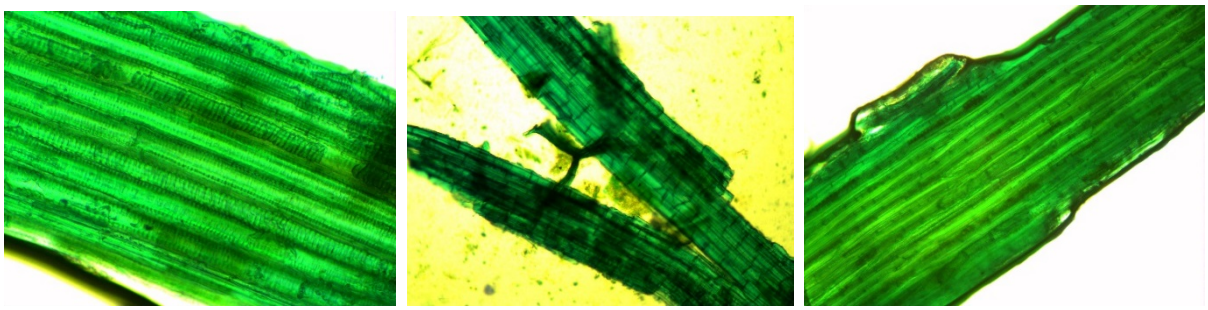
d)*Trachetospermum lucidum* (Batulpate)



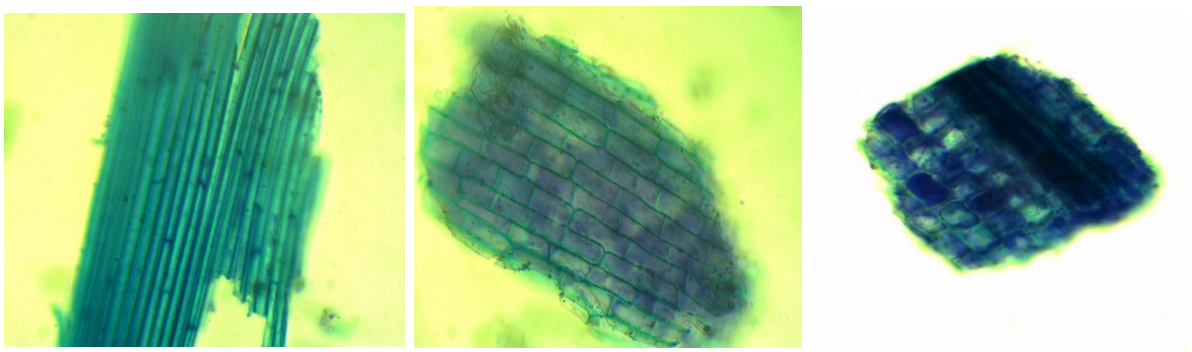
e) *Matragyna parviflora* (Tikul)



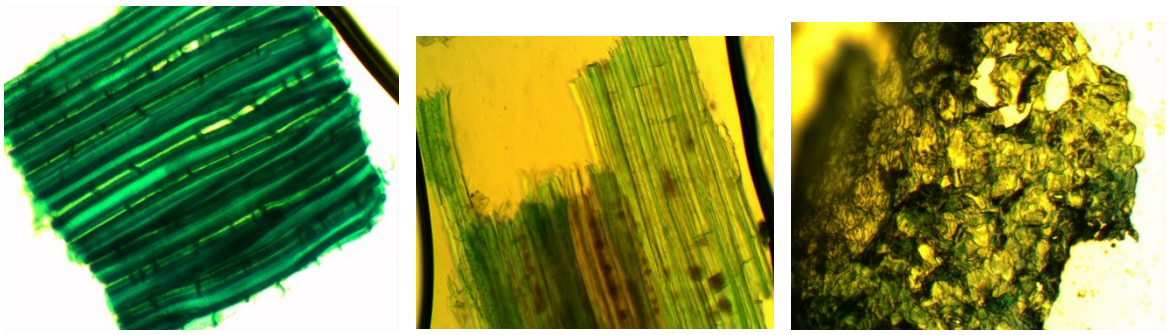
f) *Bridelia retusa* (Rukh gaayo)



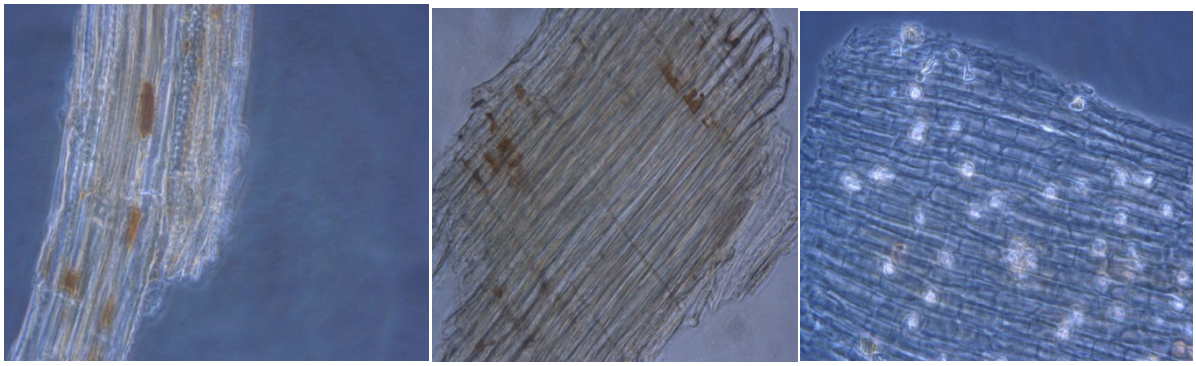
g) *Bambusa vulgare* (Bans)



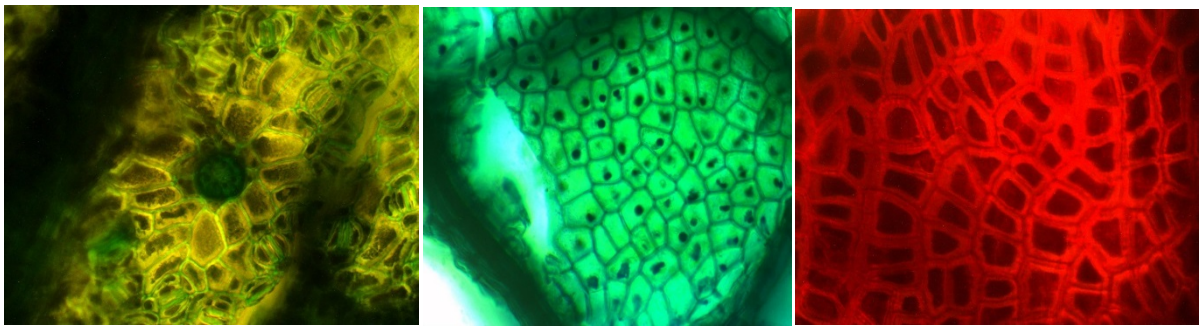
h) *Hymenodictyon arixenese* (Ber)



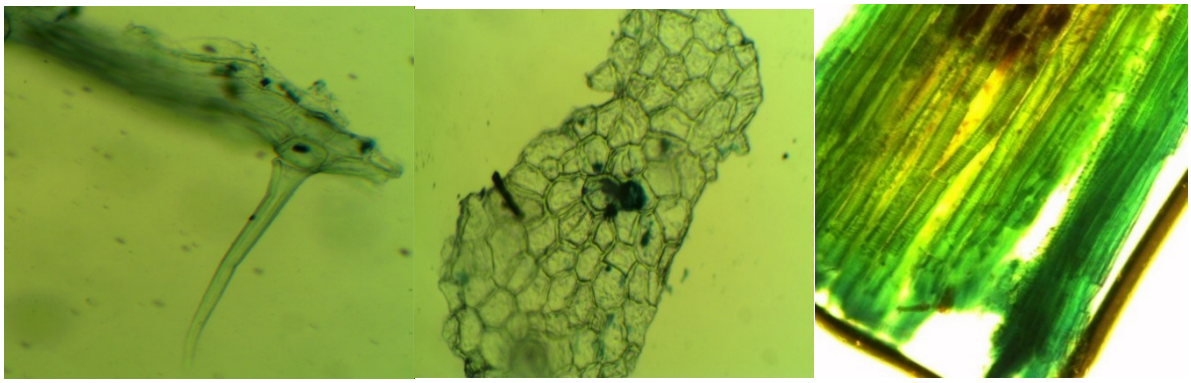
i) *Zizyphus mauritiana* (Bayar)



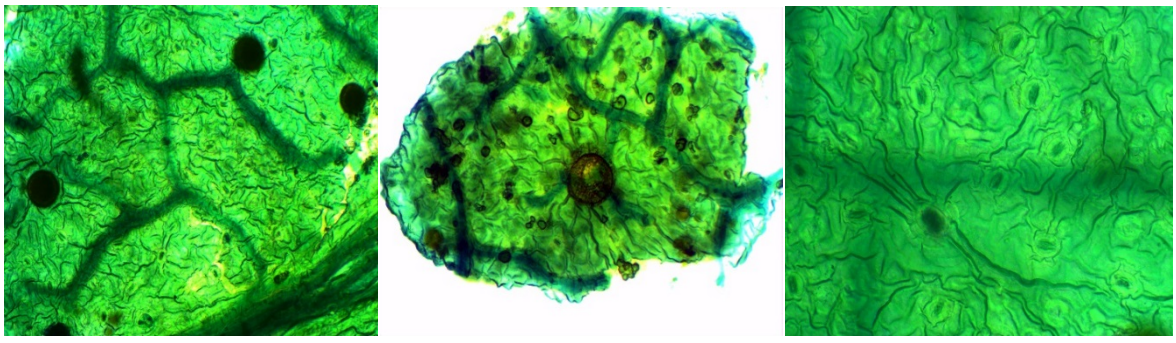
j) *Sorea robusta* (Saal)



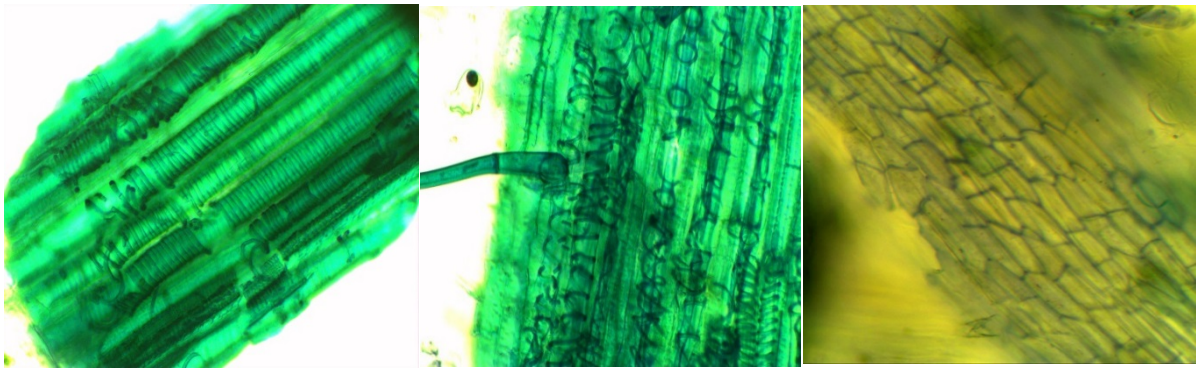
k) *Myrsine semiserrata* (Kalikath)



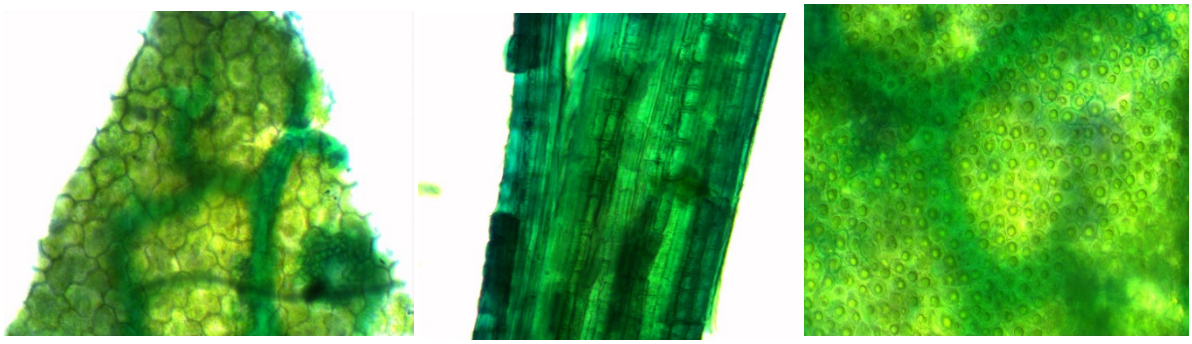
l) *Aegle marmelos* (Bel)



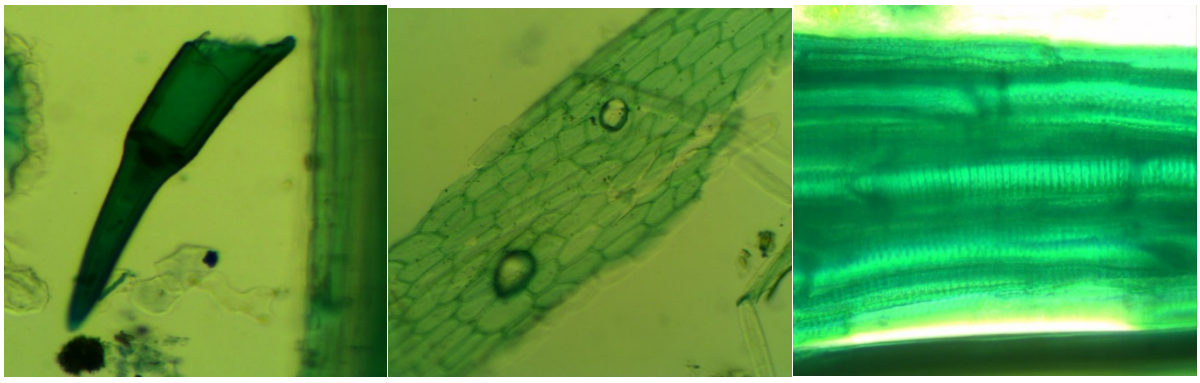
m) *Pogostemon benghalensis* (Rudilo)



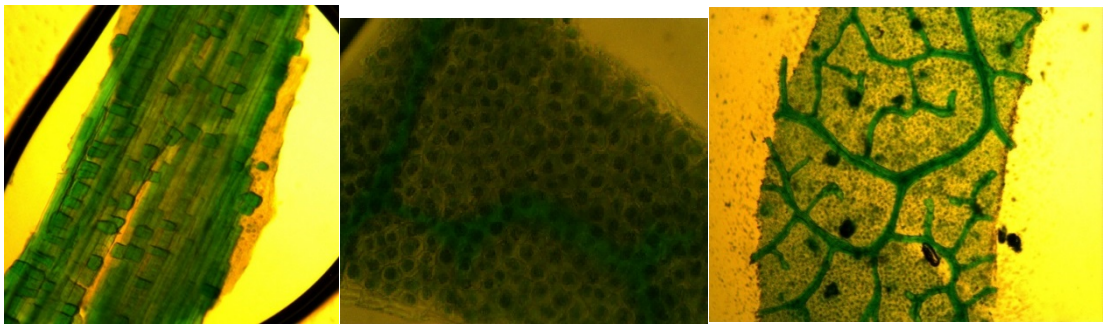
n) *Achyranthus* sps (Dattiwan)



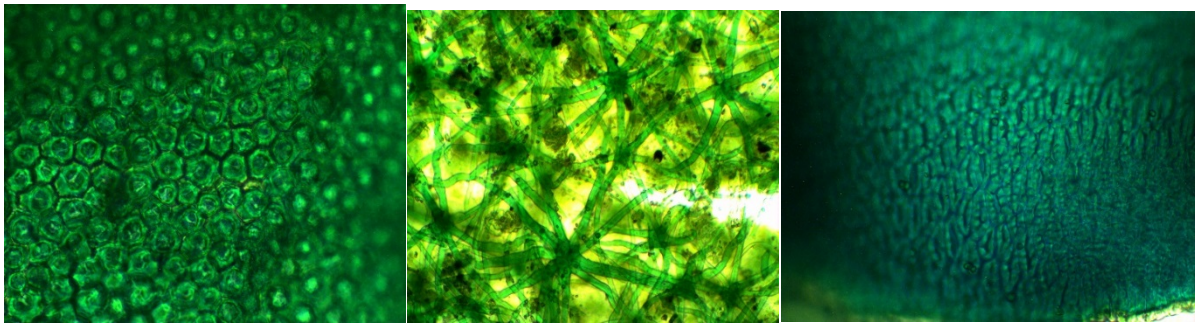
o) *Clerodendrum viscosum* (Bhaati)



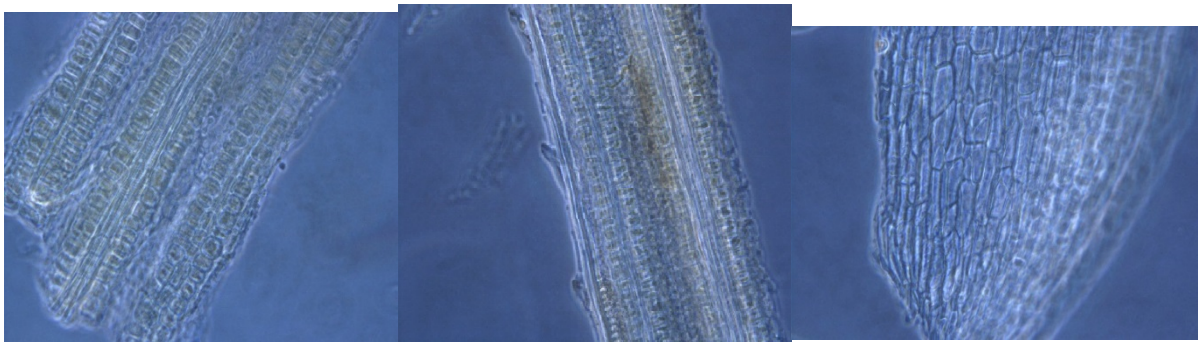
p) *Nyctanthes arbortristis* (Parijaat)



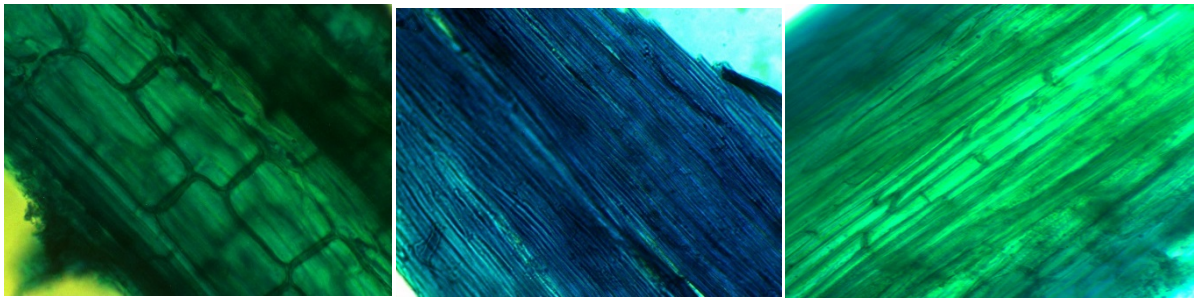
q) *Ageratum cristata* (Ganne ghar)



r) *Cynodon dactylon* (Dubo)



s) *Blumea virens*



t) *Justicia* sps