# Nutritional Ecology of Asian elephant (*Elephas maximus*) and Human-Wildlife Interactions

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***Extinction is forever, endangered means we still have time.***

***Alesander***

# Abstract

Reducing human-wildlife conflict has recently been recognised as an important aspect of wildlife management and represents one of the most complex challenges currently facing conservationists worldwide. Conflicts between humans and wild animals arise as a result of the loss, degradation and fragmentation of wildlife habitats through anthropogenic activities such as logging, animal husbandry, agricultural expansion and infrastructure development. Habitat fragmentation results in reduced areas of habitat and increased probability of contact between people and wild animals as the animals move in order to meet their nutritional and other ecological and behavioural requirements. Habitat degradation has led to food-related problems in populations of many species of wildlife, and the Asian elephant (*Elephas maximus)* is particularly vulnerable because it requires such a large amount of food per day. Large herbivores, such as elephants, are especially likely to suffer during periodic food shortages when they cannot meet their nutritional targets. Understanding the dietary and nutritional needs of elephants is crucial for managing habitats in ways that will ensure their survival, in particular by minimising conflict with humans. However, obtaining information about the dietary requirements of wild animals is difficult.

This thesis investigates the diets and nutritional priorities of captive, domestic and wild elephants through the application of nutritional geometry. Initially, I examined the food intake, food composition and the resultant dietary macronutrient and fibre intake in a captive female Asian elephant. My results showed that the proportions of the elephant's daily macronutrient and neutral detergent fibre (NDF) intake were different than the

proportions in the daily mixture of provisioned foods and were consistent across days, suggesting that she was selectively feeding on available foods. Results indicated that she prioritised the ratio of protein: non-protein energy in her diet, with the ratio of non-protein macronutrients (fats and non-structural carbohydrates) to digestible fibre (NDF) being varied so as to maintain a more constant proportion of dietary protein. Similar results in which the proportion of dietary energy contributed by protein was prioritised. This was revealed in my study on domesticated elephants, with most elephants maintaining constant proportional protein energy in their diet, but different individuals achieving this by consuming different ratios of non-protein energy (NPE) to neutral detergent fibre (NDF) energy. I also carried out a food preference survey for the wild elephants. I found that 57 species of fodder plants in 28 families were consumed by wild Asian elephants, including 13 species of grasses, five shrubs, two climbers, one herb and 36 trees. The feeding preference index further showed that browse species are preferred during the dry season, while a browse and grass combination is favoured during the rainy season. These findings were used to test the hypothesis that the elephants are selectively feeding against a null hypothesis that feeding is proportional to availability. The difference in the availability and the utilisation supports the alternative hypothesis of selective feeding to obtain the required macronutrient intake. An investigation of human–elephant conflict through a questionnaire survey showed that the depletion of natural forage inside and outside protected areas leads to an increase in elephants raiding crops because the grain-laden cultivated food plants are more palatable and more nutritious than wild browse plants. This study concluded that among the many factors, dietary requirements and selective browsing habits are believed to be the root causes in precipitating destructive behaviour in wild elephants, leading to fatal human-elephant conflict. This study also found that locally in central Nepal, crop raiding was the main cause of conflict with humans. Respondents believed that human-elephant conflict could be minimised by re-vegetating internal parklands and park boundaries with native elephant food plants. The study also showed that regional conflict intensity as measured per elephant damage was high in western Nepal; however, conflict regarding human and elephant casualties was higher in central and eastern regions.

In summary, this study substantially advances our knowledge of the nutritional ecology of elephants and makes a significant contribution towards understanding the dietary and nutritional aspects of three different groups of elephants (captive, non-captive domestic and wild), as well as the nutritional drive of human-elephant conflicts. My findings have implications for the management of habitats for the conservation of Asian elephants and the mitigation of human–elephant conflict.

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Firstly, I would like to express my sincere gratitude to my principal supervisor Dr Weihong Ji for the continuous support that I have received during my PhD study. I would like to thank you for encouraging me in my research and for allowing me to progress as a research scientist. These five years have been a roller coaster; there have been stressful times, but there have been some astounding moments that I will never forget. Thank you for always believing in me and constantly guiding me for my betterment. I have thoroughly enjoyed working with you, and I could not imagine having a better advisor and mentor for my PhD study.

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I wish to express my sincere thanks to the Dean and the Campus Chief at the Pokhara Campus, Institute of Forestry, Tribhuvan University, Nepal, for granting me the study leave and all the necessary facilities for this project, including laboratory access. I hope to bring my increased knowledge back home to strengthen the Department of Park Recreation and Wildlife Management at the Institute of Forestry, Tribhuvan University, Nepal.

Thanks to the Ministry of Forests and Soil Conservation/Department of National Parks and Wildlife Conservation, Government of Nepal for granting permission to conduct this research and the National Trust for Nature Conservation and Chitwan National Park office, Sauraha, for the necessary support during my study period.

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# List of abbreviations

| Item | Term |
|---|---|
| ADIN | acid detergent insoluble nitrogen |
| AOAC | association of official analytical chemists |
| AP | available protein |
| ADF | acid-detergent fibre |
| ADL | acid-detergent lignin |
| BW | body weight |
| CF | crude fat |
| CINE | classical insect nutritional ecology |
| CI | conflict intensity |
| CP | crude protein |
| CV | coefficient of variation |
| DE | digestible energy |
| DM | dry matter |
| DMD | dry matter digestibility |
| DMI | dry matter intake |

# List of abbreviations

| Item | Term |
|---|---|
| EE | ether extract |
| ES | ecological stoichiometry |
| GF | geometric framework |
| IVI | important value index |
| ME | metabolised energy |
| N | nitrogen |
| NDF | neutral detergent fibre |
| NG | nutritional geometry |
| NSC | non-structural carbohydrates |
| OFT | optimal foraging theory |
| PI | preference index |
| r | correlation coefficient |
| RMT | right- angled mixture triangle |
| TB | tuberculosis |
| VDC | village development committee |

# Preface

Human-wildlife conflict has recently become a fundamental aspect of wildlife management. It represents the most complex challenge currently faced by conservationists worldwide. Conflict arises mainly because of the loss, degradation and fragmentation of habitats through human activities such as logging, animal husbandry, agricultural expansion and infrastructure development projects (Fernando et al. 2005). When habitat becomes fragmented, smaller wilderness areas allow greater contact and therefore conflict with humans as wild animals seek to fulfil their nutritional, ecological and behavioural needs (Sukumar 1990).

Destruction of human assets brought about by the wild elephant is the most inescapable conflict because of this megaherbivore's wide-ranging behaviour, fidelity to its home range, large appetite and propensity and ability to destroy human property. Among the many factors precipitating wild elephants' destructive behaviour, dietary needs are believed to be the root cause. Indeed, crop raiding sometimes leads to fatal human-elephant conflicts. The wild elephant is a selective herbivore which is attracted to crops, purportedly because cultivated plant foods are palatable and nutritious and have lower secondary defences than wild browse plants (Sukumar 1990).

In Nepal, remote village communities with inadequate resources frequently fall victim to conflicts with wildlife (WWF Nepal 2007). Habitat degradation due to the increasing human population in Nepal has given rise to food-related problems in wildlife populations, and the Asian elephant is particularly vulnerable because it requires an average of 150 kg per day to survive (WWF 2016). Large herbivores like elephants are therefore more likely to fall victim to periodic food shortages. This food deficit triggers the dispersal of elephants, and they raid crops and create havoc around outlying human settlements when they cannot meet their nutritional targets (Parker et al. 2007).

Understanding wild elephants' dietary needs are crucial for mapping the conservation ecology of elephants and for managing habitats in ways that will ensure their survival by minimising conflicts with humans. However, obtaining information about the dietary needs of wild animals is difficult. Thus, I started my study of wild elephants by investigating the diets of captive and domestic elephants. My captive/domestic elephant studies provided an opportunity—in a controlled situation—to validate key research methods before using lower-resolution measures to study wild populations. In addition, my initial studies of captive and non-captive domestic elephants allowed us to gather important information on the management of elephants' dietary needs and husbandry practices under captive conditions.

This thesis investigates the dietary and nutritional aspects of three different groups of elephants (captive, non-captive domestic and wild), ranging patterns of the Asian elephants and the human factors in the human-elephant conflicts and elephant conservation. It provides important baseline information for addressing further questions around the role of nutrition in human-elephant conflict, developing predictive models for managing human-wildlife conflict and to help formulate strategies for balancing the elephant's needs and human survival.

This dissertation is original and consists published and unpublished chapters, independent work by the author, Koirala RK. The data collection for chapter 2 was permitted by the Auckland Zoo's animal ethics committee (AEC) on 7th August 2012. The fieldwork for Chapters 3, 4 and 6 was permitted by DNPWC (Department of the national park and wildlife conservation) government of Nepal (ref numbers 3300, Chitwan national park; and 873, Parsa wildlife reserve, whose status is recently upgraded to the national park) respectively. The permission covers both biological and social data collection as well as animal and human ethics.

I was the lead investigator for the projects covered by Chapters 1, 2, 3 6 and 7 where I was responsible for forming research questions, data collection and analysis, as well as the majority of the manuscript composition.

A version of Chapter 4 has been published [Koirala RK, Ji W, Aryal A, Pathak ML, Raubenheimer D. 2016]. Feeding preferences of the Asian elephant (*Elephas maximus*) in Nepal. BMC Ecology. 16:54. I was the lead investigator, responsible for all forming research questions, data collection and analysis, as well as manuscript composition. Aryal A and Pathak ML were involved in the early stages of data collection and contributed to manuscript edits. Ji W and Raubenheimer D were the supervisory authors on this project and was involved throughout the project in all aspects.

A version of Chapter 5 has been published [Koirala RK, Ji W, Aryal A, Rothman J, Raubenheimer D. 2015]. Dispersal and ranging patterns of the Asian Elephant (*Elephas maximus*) in relation to their interactions with humans in Nepal, Ethology Ecology & Evolution 28:221-31. I have conceptualised the project, reviewed literature and drafted the manuscript. Raubenheimer D, Ji W, Rothman J, was the supervisory authors on this project and was involved throughout the project in manuscript edits. Aryal A contributed in manuscript edits including figures and map preparation.

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# Thesis outline

The primary aim of this thesis is to understand whether the human-wildlife conflict is driven by food preferences and nutritional needs. Such knowledge is important for conservation management of elephant populations, their habitat and mitigation of human-elephant conflict.

This thesis includes two themes: 1) Diet and nutritional ecology of Asian elephants, and 2) human-wildlife interaction. Exploration of these themes leads to recommendations for developing strategies to balance wildlife conservation and human needs.

Theme one of this thesis documents the pattern of diet preference of the wild Asian elephant (*Elephas maximus*) in the Terai region of Nepal and evaluation of nutritional values of food plants selected by captive and domestic Asian elephants. Such information is vital for understanding elephant–habitat interactions, especially in the wild. **Chapters 1-4** are included under the first theme.

Theme two covers aspects on the distribution and movement patterns of the Asian elephant (*Elephas maximus*) and the nature and status of human-elephant interactions in the Terai region of Nepal and documents the causes and extent of damage by wild elephants in central Nepal.

The aim is to understand general human-elephant conflict issues in order to more effectively manage elephant habitats and reduce human-elephant conflicts. Theme two contains **Chapters 5–7**.

Each chapter was written as a stand-alone paper for publication in a scientific journal. Chapter 4 has been published in BMC Ecology and Chapter 5 in Ethology, Ecology and

Evolution. Chapter 2 and 6 are submitted to the journals. The published chapters follow respective journal format.

Below are details of each chapters.

## Theme 1: Wildlife nutritional ecology and conservation strategies

**Chapter 1** Understanding the aspects of elephant diet and nutrition relevant to minimising human-Asian elephant conflict.

This chapter provides an overview of relevant literature on the diet and nutritional aspects of the Asian elephant and introduces the different frameworks to explain nutritional ecology concepts. The chapter highlights the nutrient balance hypothesis that may influence food selection and the "nutritional geometry" analytical framework and its application to the foraging ecologies of elephants. I further review human-elephant conflict and its potential link to habitat loss and consequent effects on elephants' foraging abilities.

**Chapter 2** Diet composition and macronutrient prioritisation in a captive Asian elephant.

This chapter investigates the relationship between macronutrient composition of food provisioned to a captive Asian elephant and food eaten, as an approach to test for macronutrient-specific selective feeding. This study was a pilot exploration of the composition of the typical elephant diet in situations where the animal was under the care of humans.

**Chapter 3** The effects of age, sex and season on the macronutrient composition of the diet of the domestic Asian elephants.

This chapter examines the effects of age, sex class and season on the nutrient composition of food intake by 16 domesticated Asian elephants. I tested whether the domestic elephants selected a diet with the similar nutritional composition to that of their wild counterparts and whether they faced constraints in reaching their nutritional goal due to qualitative or quantitative restrictions on food availability.

**Chapter 4** Feeding preferences of the Asian elephant (*Elephas maximus*) in Nepal.

This chapter explores the feeding preferences and dietary requirements of wild Asian elephants based on feeding sign and dung analysis. I also investigated food availability by conducting a survey using point-centred quarter methods. This chapter has been published in BMC Ecology.

## Theme 2: The status of human-elephant interactions, their causes and recommendations for management

**Chapter 5** Dispersal and ranging patterns of the Asian elephant (*Elephas maximus*) in relation to their interactions with humans in Nepal.

This chapter reviews the past and present population distribution of Asian elephants in Nepal, the spatial and temporal patterns of elephant movements (migration), the history of human-elephant conflict and mitigation measures. This chapter has been published in Ethology Ecology and Evolution.

**Chapter 6** Patterns, perceptions and spatial distribution of human-elephant (*Elephas maximus*) conflict in Nepal.

In this chapter, based on the findings of chapter 5, I evaluate local human-elephant conflict in the central region of Nepal through household surveys and secondary analysis of published data.

**Chapter 7** Conclusions.

This chapter summarises findings of this research and concludes that macronutrient balance is important for the management of captive and domestic Asian elephants. Plants utilised by wild populations as important food sources should be taken into account in elephant habitat management.

# Theme 1

## Wildlife nutritional ecology and conservation strategies

**Wild bull elephant (Ronaldo) at Chitwan National Park.**

# Chapter 1

## Understanding the aspects of elephant diet and nutrition relevant to minimising human-Asian elephant conflict


**Wild elephant using trunk and tusks to destroy electric fence.**

## 1.1 Abstract

In this chapter, I review the literature on the diet and nutritional requirements of Asian elephants (*Elephas maximus*). Studies on elephant diet and nutrition have found seasonal changes in the type of food, and nutrients elephants seek. However, the relationships between food selection, nutritional requirements and elephants' feeding patterns have not yet been established. Studies on spatiotemporal changes in diet and nutrient composition of plants selected by Asian elephants are still lacking. Such information is crucial to the conservation management of this endangered species, which lives within a largely human-dominated landscape because successful management requires a reduction in often fatal conflicts between elephants and humans, which are almost always food-related and involve human retaliation against crop-raiding elephants. The relationships between macronutrients, elephant foraging and human-wildlife conflict are, however, dynamic and complex, presenting considerable challenges for research. Macronutrient content of food species varies across the year, as do observed elephant feeding patterns. For example, elephant populations feed predominately on the grass in the wet season and woody plants during the dry season. The reasons for such seasonal variations have not been examined in detail. In this review, I explore the relationship between elephant feeding patterns, nutrient intake and crop-raiding behaviour. I hypothesise that crop raiding behaviour is caused by specific macronutrient deficiencies within natural forage species, specifically protein content. I

discuss the nutrient balance hypothesis, which proposes that the primary goal in the patterns of food selection by animals is to acquire a nutritionally balanced diet, which is likely an underlying driver for crop raiding by elephants. I find that elephants raid crops irrespective of available wild forage, suggesting that available forage is nutrient deficient in crop raiding seasons. By raiding crops, they obtain substantially more protein. I conclude that crop raiding corrects nutrient imbalance in elephant diets. Habitat loss and nutritionally motivated crop raiding behaviour in wild elephants are therefore the two primary causes of human-elephant conflict.

## 1.2 Introduction

Human-wildlife conflict has become one of the important aspects of wildlife management, as it represents the most widespread and intricate challenge currently being faced by conservation biologists. Such conflict has become predominant in conservation biology worldwide because of the loss and fragmentation of habitats through human activities such as logging, livestock farming, agricultural expansion and associated infrastructure development, such as roads and dams (Sukumar 2006; Fernando et al. 2005). As habitat becomes more fragmented, greater contact and conflict with humans occurs as wild animals seek to fulfil their nutritional, ecological and behavioural needs (Sukumar 1990). The damage caused by wild animals includes loss of human life and injury, threats to economic security, and reduced food security and livelihood opportunities. Rural communities with limited livelihood opportunities are often hardest hit by conflicts with wildlife (Nepal WWF 2007).

There are different social, cultural and ecological causes of human-wildlife conflict. These causes encompass a huge diversity of situations and species, from herbivores such as elephants *Elephas maximus* (Sukumar 1990) to carnivores such as tigers *Panthera tigris* (Barlow 2009). Interactions of these animals can impose a variety of significant costs upon local people. This includes depredation upon livestock (Thirgood et al. 2005), crop-raiding or loss of stored food (Pant and Hockings 2013), attacks on human (Packer et al. 2005) and disease transmission to livestock or human (Thirgood et al. 2005). This often causes people sacrifice financial or lifestyle choices because of impositions laid upon them due to the proximity of wild animals or protected areas (Woodroffe et al. 2005). Human-wildlife conflicts are rising, as booming human populations shift further to uninhabited areas, and as some species recolonise parts of their ranges in many places.(Woodroffe et al. 2005). Another situation where conflict erupts is that animal population have been increased due to the restoration of habitats (Pokhrel and Shah 2008). Investigation of possible conflict drivers (social, cultural and ecological) will advance understanding of the patterns and underlying processes of this critical conservation issue..

Among the causes of human-wildlife conflicts, food-and diet-related factors are believed to be the prominent drivers as has been demonstrated for bears (Can et al. 2014; Coogan and Raubenheimer 2016). In the foothills of the Himalayas, human-elephant conflict increases during maize or wheat maturing time (June – July) and also at paddy maturing time (September – November) (Nepal WWF 2007). A similar phenomenon has been observed in Indian elephants (Sukumar 1989; Balasubramanian et al. 1995), where elephant raiding intensifies, during ripening of paddy and millet. Similarly, in Africa, elephants are found to feed on whatever crops are available but prefer the mature growth stages (Hoare 1999). Elephant activity shows a seasonal peak when crops are maturing, with the majority of conflicts involving elephants destroying maturing food crops (Hoare 1995; Kangwana 1995). Crop raiding by elephants is mostly initiated by bull elephants; this is due to the male strategy of risk-taking that maximises reproductive success via better nutrition (Sukumar and Gadgil 1988; Hoare 1999). This behaviour can be considered consistent with the predictions of optimal foraging theory (OFT) (Schoener 1971; Pyke 1977).

Food and diet are similarly known to drive conflict with other species. For example, the annual number of bears killed due to conflicts with humans increases by an average of 20%–32% for each 50% decrease in annual Salmon biomass (Artelle et al. 2016). Similarly, Can et al. (2014) showed that food is a major cause of human-grizzly bears conflict in North America, and Coogan and Raubenheimer (2016) presented models showing how this is related to seasonal scarcity of fats and carbohydrates in the natural foods of grizzly bears, both of which are abundantly available in many human-associated foods.

In contrast with such detailed studies on American species, in both Asia and Africa studies of human-elephant conflict are mostly limited to descriptions of the problem (Hoare 1999; Bell 1984; Hoare and Mackie 1993; Osborn 1998; Sukumar 1989; 1990; 1992). In addition, a number of studies at one or more sites examining seasonal feeding habits have been conducted. These studies have focused on plants that elephants utilise as food, as well as the abundance and distribution of native food species in national parks and forests within known elephant migration corridors (Santra et al. 2008; Pradhan et al. 2008; Baskaran et al. 2010). These studies have shown that the grass-to-browse ratio in the elephant diet is variable between seasons as well as between habitats

(Samansiri and Weerakon 2007; Pradhan et al. 2008; Santra et al. 2008), but have not attempted to relate such variation in natural foods to conflict with humans.

No study has been published quantifying the relationships between dietary intake and macronutrient foraging targets of the Asian elephant (*Elephas maximus*). In addition, no information has been published to date describing the full range of foods that Asian elephants utilise. In short, it is not known how nutritional requirements play a role in crop raiding by elephants. This is a problem because such targeted studies could help to gain an understanding of why elephants raid crops and an ability to predict the ecological conditions in which crop raiding is most likely to occur. Such knowledge would help conservationists improve their management of prime elephant habitats and minimise destructive interactions between elephants and humans. Thus, the main focus of the current chapter is two-fold: 1) to explore patterns of food selection in different countries within elephant home ranges; and 2) to explore the available primary research for evidence of a macronutritional basis for food selection in Asian elephants (Raubenheimer et al. 2015), with a view to encouraging further research that will take this approach in developing improved conservation management strategies to safeguard elephant populations.

The scope of this chapter is considerably different to previous works (Sukumar 1989; 2006), which have explored seasonal feeding habits rather than examining associations between food preferences and dietary requirements and nutritional aspects of foraging behaviours. My goal was to stimulate interest in conducting baseline studies that assess Asian elephants' nutrient intake patterns, food selection behaviours, and the distribution of favoured natural food species so that quantitative models of carrying capacity and habitat use can be developed to establish management guidelines to minimise human-elephant conflict. The ultimate goal is to understand the nutritional demands imposed on Asian elephants by their activities and, using this information, to delimit ecological areas that are essential for elephant survival, thus minimising damaging and potentially fatal encounters with humans. This knowledge, if applied to conservation management strategies, would greatly assist the Asian elephant's continued survival.

Finally, I would like to clarify an important terminological subtlety that applies in this chapter and throughout the thesis. My use of the term "nutritional demands" or "nutrition needs" does not refer to the optimal blends of nutrients that must be ingested to provide optimal health outcomes, in the sense that a zoo manager or veterinarian might use the term. This definition would be relevant if the subject of my thesis was population ecology and elephant demography, in which case the long-term effects of dietary intakes on elephant health, reproduction and populations would be relevant. However, since the goal of my thesis is to help understand, predict and manage elephant behaviour (foraging, crop raiding and human-elephant conflict), my use of the term "nutrient demands" refers to the homeostatic regulatory targets that drive feeding behaviour (Raubenheimer and Simpson 2010).

## 1.3 The role of nutritional ecology in elephant conservation

The process of finding and harvesting food dominates the lives of wild animals (Baskaran et al. 2010), and consequently foraging, and related behaviours are heavily influenced by the nutritional environment. Unfortunately, the process of optimising macronutrient intake may lead to human-wildlife conflict. In this context, nutritional ecology has received widespread attention as a field of study because of the prominence of nutrition as a factor influencing the interactions of animals with their environments (Raubenheimer et al. 2012).

For many years, studies in nutritional ecology have focused heavily on understanding how foraging behaviour and associated outcomes such as growth and reproduction differ in response to varying food quantity and simple measures of quality, such as dietary energy content (Raubenheimer et al. 2009). However, nutritional ecology has developed beyond simple comparisons, and there is now an appreciation that intake of multiple nutrients simultaneously is part of a complex animal behaviour spectrum (Raubenheimer 2011). It is also clear that nutrition often links and impacts whole populations, communities and ecosystems in significant ways (Simpson et al. 2010).

Food distribution and density are important factors influencing habitat selection by elephants (Shannon et al. 2006). Existing information demonstrates that selection of plant species and plant parts (stems, leaves, roots, bark, etc.) by elephants can be driven by nutritional content (Field 1976). However, the ways in which nutrient content has an impact on elephant density and range have not yet been determined. Therefore, studies on how nutritional composition influences elephants’ food choices could help to understand elephant habitat requirements, habitat quality, carrying capacity for elephants and conservation challenges, such as human-elephant conflict.

# 1.4 Elephant diet and foraging strategies

## 1.4.1 Plant selection

Elephants are generalist herbivores (IUCN 2013); in other words, they are both grazers and browsers, and seasonal variations in their food selection occur (Sukumar 1989). Previous studies on the diets of wild and domestic elephants have been carried out at several sites across Asia and Africa (Bax and Sheldrick 1963; Sukumar 1990; Chen et al. 2006; Himmelsbach et al. 2006; Baskaran et al. 2010). A preliminary understanding of Asian elephant feeding ecology in three specific habitats, short, tall and mixed/tall grasslands, was obtained by Sukumar (1989) in South India. The study found that during the dry season, the majority of the elephant diet consisted of woody plants, while grasses comprised the majority of the elephant's diet during the wet season (Sukumar 1989; 1992; 2006). In moist tropical forests, such as rainforests, the Asian elephant's diet was found to be almost entirely composed of woody plants and fruit (Sukumar 2006). In contrast, grass dominates the diets of elephants all year round in dry deciduous and dry thorn forests (Baskaran et al. 2010).

Comparable seasonal feeding patterns have been documented in the foothills of the Himalayas by Pradhan et al. (2008) and Lahkar et al. (2007), and very similar results have been reported for African elephants in Uganda (Field and Ross 1976). In contrast, woody plants form a major proportion of the elephant diet year-round in the rainforests of Malaysia (Oliver 1978), north-eastern India (Sukumar 2003) and the state of Bihar, central India (Daniel et al. 1994).

The majority (68%) of plants consumed by adult Asian elephants are species of seven families: Fabaceae, Poaceae, Malvaceae, Sterculiaceae, Tiliaceae, Palmae and Cyperaceae (Sukumar 1992). The plant genera most preferred are *Acacia*, *Bambusa*, *Dendrocalamus*, *Arundo*, *Ficus*, *Musa*, *Dalbergia*, *Mallotus*, *Saccharum* and *Themeda*. Thirty-three plant species eaten by elephants are common to elephant habitats in Asia, and 25 of these species form about 85% of these animals' dietary intake (Sukumar 1992). There is some variation in the proportions of the 25 species consumed by elephants due to variation in regional and seasonal availability of fodder. However, in nine studies spanning six years and five nations, Nepal, India, China, Sri Lanka and Myanmar, some plant species appear consistently in elephants' diets, despite wide regional, seasonal and climatic variations in availability (Steinheim 2005; Chen et al. 2006; Himmeslbach et al. 2006; Samansiri and Weekaron 2007; Lihong et al. 2007; Pradhan et al. 2008; Joshi and Singh, 2008; Baskaran et al. 2010; Koirala et al. 2016). Details are available in Appendix 1.

The regionally consistent presence of certain plant taxa in elephant diets suggests that the same variables, e.g., plant availability, distribution across habitat types, and plants' macro- and micronutrient content, influence plant selection by elephants (Oliver 1978). Of these factors, a nutritional value likely exerts a major influence on the elephant's choice of foods, but disentangling the role of nutrition and other factors is challenging. For example, certain plant genera, which are characterised by containing many highly nutritious species, are distributed widely across regions and are therefore readily available. One such example is the protein-rich genus *Acacia*, which has a wide distribution across the Indian sub-continent (Chakrabarty and Gangopadhyay 1996). Although there is regional variation in the occurrence of different *Acacia*, for example, *A. catechu* and *A. pennata* are limited in range to the Himalayan foothills, and the related taxa. *A. catechu* and *A. pennata* are limited in range to the Himalayan foothills. Related taxa *A. chundra*, *A. intsia* and *A. leucophloea* occur only in southern India and Sri Lanka. Interestingly, only elephants in China utilise *A. megaladena*, although it is available in other regions. Perhaps this non-uniform consumption is due to the lower nutritional value of *Acacia* compared with more nutritive plants that are more universally used by Asian elephants in regions other than China. Indeed, *A. megaladena* and *Musa* spp. have been recorded as containing low levels of protein (Chen et al. 2006; Lihong et al. 2007). In other regions, however, *A. megaladena* and *Musa* spp. are reported to contain higher amounts of crude protein (Lihong et al. 2007; Roy and Choudary 2014), but are nonetheless under-utilised. Although the reason is not understood, this example illustrates that understanding the role of particular foods in the diets of elephants requires information not just about that particular food, but also the compositions and availability of other foods within the animals' home range.

### 1.4.2 Macronutrient in the elephant diet

Previously recorded differences in elephant plant selection could also be due to site variations or seasonal fluctuations in protein content. More likely though, the differing plant parts sampled by researchers measuring protein content may have influenced results. For example, in India crude protein in *Acacia catechu* varies by plant part has been shown to vary substantially across plant parts, with leaves containing 13.8%, compared to the protein-rich pods, which contain 34.3% crude protein (Verma et al. 2014). Thus, preferential consumption of a number of plant foods may or may not show a statistically significant relationship with anyone plant's nutrient composition.

However, the relative prevalence of the majority of commonly grazed plants in the diet of Asian elephants is highly correlated with crude protein content (Sukumar 1990). A crude protein content of 10%–14% is found in bamboo (*Dendrocalamus* spp.), which is sought after by elephants (Chen et al. 2006; Sukumar 1990). Bamboo grass *Arundo donax* also contains high amounts of crude protein, 11%–14% (Chen et al. 2006; Lihong et al. 2007; Roy and Choudary 2014). Elephants in India, China and Myanmar consistently consume a greater volume of these plant species than other, less protein-rich species (Chen et al. 2006; Himmelsbach et al. 2006; Baskaran et al. 2010). Similarly, crude protein content in *Ficus* spp. is ranging from 8%–20.7% (Chen et al. 2006; Lihong et al. 2007; Roy and Choudary, 2014), which might explain why *Ficus* species form a high proportion of the elephant diet (Chen et al. 2006; Baskaran et al. 2010). Furthermore, the consumption of *A. catechu* and *A. pennata* has also been found to be directly related to crude protein content (Pradhan et al. 2008; Roy and Chaudhary, 2014).

Many studies have shown that woody plant species found in the wild elephant's diet contain higher levels of crude fat than the woody species in the diet of captive elephants (Chen et al. 2006). Of the various nutrients, fat seems to play the most significant role in reproductive physiology (Nilsson et al. 2014; Rodney et al. 2015). Some fruits in the wild are high in lipids (Debussche et al. 1987). Generally, plant fats are rich in unsaturated fatty acids; the seasonal attraction of elephants towards these fruits and fat-rich plant species may be a particular strategy to promote energy accumulation when they require the highest energy inputs, such as during migration. Indeed, this behaviour has been observed in elephants that constantly selected fat-rich *Ficus*, *Mallotus* and *Musa* species across regions (Chen et al. 2006).

A diet consisting exclusively of grasses and commercial foods (used at zoos) may be deficient in lipids (Lehnhardt 2006), but this deficiency may not be of significance because elephants are confined and therefore require less energy than migrating animals. The recommended level of crude fat content in captive elephants' diet is 1.2%–1.8% (British and Irish Association of Zoos and Aquariums (BIAZA 2006). However, the required crude fat content for wild elephants may be as high as 5.5%, reflecting their higher level of activity (Chen et al. 2006). In fact, the consumption of woody plants, especially bark, by wild elephants is thought to compensate for any deficiency in fatty acids (Sukumar 1992), which provides structural basis for cell membranes and also signalling roles in reproduction (Nilsson et al .2014)

Besides dietary lipids, many wild plants and fruits are rich in simple carbohydrates, such as sugars and starch, both of which are important sources of energy for herbivores. Complex carbohydrates, namely fibre, are also important. Fibre plays a significant role in the digestive physiology of the Asian elephant, a hind-gut fermenter. Indeed, the neutral detergent fibre (NDF) content in the wild Asian elephant diet ranges from 36%–96% (Das et al. 2014), depending on the type of plants available and their condition.

A more in-depth study of Asian elephant diet is needed to investigate whether Asian elephants eat complementary combinations of foods to meet their high nutritional requirements, as has been demonstrated for many species in captive experiments (Raubenheimer and Jones 2006) and baboons in the wild (Johnson et al. 2013). This finding gives rise to two important questions. First, is nutritional choice due less to variability in plant nutrient content than to regional distribution and availability? Second, is the nutritional composition of food eaten by elephants consistent year round? Answering these questions will help us understand whether the crop-raiding behaviour is a result of nutrient-specific foraging to balance the diet in the face of constraints on the quality of natural foods, as opposed to the opportunistic targeting of a spatially concentrated resource. Such knowledge may allow conservationists to delimit specific ecological areas that are essential for elephant survival, thus minimising human-elephant conflict. However, the observed inconsistent availability and intake of plants in different regions make it difficult to judge what a balanced diet is for wild Asian elephants. Therefore, further studies are needed to quantify ratios of macro and micronutrients that are targeted by wild Asian elephants.

### 1.4.3 Human-elephant conflict and nutrition

Human-elephant conflict is defined as an interaction between people and elephants that causes damaging impacts on people, elephants and their environments (Pant and Hockings 2013). This conflict is one of the greatest impediments to Asian elephant conservation. Conflict incidents are increasing due to human population growth, elephant habitat fragmentation and habitat degradation. Fragmentation of habitat and lack of forage during periods when most woody plants shed their leaves, and grass biomass is lower are thought to cause crop-raiding behaviour (Owen-Smith 1988; Osborn 1998). Eating crops improves nutrient intakes of elephants during periods of nutrient deficit in natural forage (Sukumar 1989). In particular, forage quality fluctuates seasonally, generally declining in the peak dry season.

A study carried out in Africa (Osborn 2004) and in Southern India (Sukumar 1989) indicated that the onset of crop raiding and the quality of wild food toward the beginning of the cool dry season are linked. Sukumar (1989;1990) further commented that protein content of wild grass plants dropped far below 2.5% the minimum level needed by an elephant for maintenance during that season. Similarly in hot dry season, which is also the peak raiding season, in northern India, the maturing crops like paddy contains much higher protein levels (Das et al. 2014).

Interestingly, raiding of crops by elephants also seems to occur irrespective of the availability of natural forage (Sukumar 1989; Hoare 1995; Chiyo et al. 2005). Cultivated crops are thought to be much richer in macronutrients and mineral salts compared to wild plant varieties of the same taxa (Sukumar 1989), and thus, if within their range, cropped varieties will attract elephants. However, the nutritional balance that wild elephants seek is not known, and so it is difficult to predict and thus prevent crop raiding by elephants. To date, no predictive tools have been found that can resolve this issue. I believe that recent advances in wildlife nutritional ecology can be used to address these crop-raiding conflicts. The development of a “nutritional geometry” or “geometric framework” (GF) approach to explain temporal and spatial patterns of nutrient intake ( Raubenheimer 2011; Raubenheimer et al. 2015) can enable researchers to study nutrient intake patterns and interactions between different nutrients, and how an animal resolves potential conflict between over-eating one or more nutrients and under-eating others during periods of dietary imbalance.

## 1.5 Frameworks for understanding nutritional ecology

Understanding how an animal regulates its nutrient intake, which nutritional strategies it adheres to and how these affect its fitness are important goals in nutritional ecology. The various schools of thought in nutritional ecology advocate that animals’ food selection fulfils different primary nutritional goals (Felton et al. 2009). However, there is limited information on how specific nutrients and their ratios in foods and diets affect the homeostatic and performance responses of animals. Most studies are based on unidimensional theory dealing on one component like nitrogen (protein) maximisation, energy maximisation, regulation of fibre intake, avoidance of secondary compounds (Zhao et al. 2013). In many cases, these are derived from theoretical proposition rather than an experimental outcome (Raubenheimer et al. 2009). Thus it is necessary to have an integrative framework in nutritional ecology which systematically identifies the individual and interactive roles of different food components.

Most relevant among the above concepts to discuss in this context is the maximisation of energy intake (Schoener 1971); this concept is an assumption within optimal foraging theory (OFT) which proposes that an animal's nutritional goals revolve around maximising energy intake per unit time feeding (Zhao et al. 2013). This model has been used in a number of herbivorous studies and resulted in reasonably correct predictions of foraging decisions by these species (Belovsky 1986; Van Wieren 1996). However, the use of a single currency (energy) in evaluating diet may result in concealment of the functional roles and relative importance of different macronutrients (carbohydrates, proteins and fats) which constitute major components of energy. Thus, OFT does not seem to fulfil the criteria required to build a nutritionally clear framework (Raubenheimer et al. 2009).

Evolution of another relevant approach is the classical insect nutritional ecology (CINE) framework which developed around the view that variation in the nutrient composition of plants is central to the patterns of food choice and performance responses by plant-eating insects (Painter 1936). A dietary self-selection paradigm was introduced to CINE theory by Waldbauer et al. (1984). It has since been demonstrated by using this approach that dietary self-selection is ubiquitous among animals (Raubenheimer et al. 2009). The paradigm of dietary self-selection provided a means to demonstrate cases where animals feed non-randomly on foods differing in composition, and to identify nutrients that are involved in food selection patterns. However, the modified CINE theory cannot deal with the critical interactive effects of nutrients on food selection patterns. Nor can it deal with nutrient-specific post-ingestive and performance responses (Raubenheimer et al. 2009).

Another common framework, ecological stoichiometry (ES), grew out of the realisation that there are complexities to ecological systems that cannot be captured using models based on energy alone (Reiners 1986), and therefore frameworks are needed that model interactions among multiple currencies. Ecological stoichiometry is the study of the balance of chemical elements in ecological interactions, principally carbon, nitrogen, and phosphorus (Cherif and Elser, 2016). ES theory has provided a useful multi-currency tool for ecological studies, but its focus on elements and body composition as a substitute for fitness has reduced its utility for organismal studies.

According to the nutrient balance hypothesis, animals aim to reach a certain nutrient balance in compensating for an imbalanced nutritional state by increasing or decreasing the intake of certain foods. Nutritional Geometry (NG) is a state-based modelling approach to investigate the nutritional strategies of animals (Raubenheimer & Simpson 1993; Simpson & Raubenheimer 2012). In NG models, individual animals, foods and their interactions are deciphered through a nutrient space built on two or more axes, represented graphically in a geometric space (a nutrient space). As animal consumes diet its position in the nutrient space changes according to nutrient consumed and its responses to multiple dietary nutrients can be explored to compare observed and predicted patterns of nutrient intake. The development of Geometric Framework (GF) enabled the nutrient balance hypothesis to be rigorously tested (Simpson and Raubenheimer, 2012). The GF is an analytical framework that unites several nutritional theories using simple geometric models and enables researchers to study the pattern of nutrient intake in animals (e.g., macronutrient – protein, carbohydrate and fat), interaction between the different nutrients, and how animals resolve the potential conflict of overeating one or more nutrients and under eating the others during the period of nutrient imbalance (Felton et al. 2016). The use of the GF in tests of the nutrient balance hypothesis has provided unexpected insights for a variety of taxa, including herbivores, omnivores and predators (Simpson and Raubenheimer 2012), but so far GF has not been applied to elephants.

## 1.6 Primary research on animals using geometric modelling

Although nutrient balance in large herbivores has previously been demonstrated using the GF in only one species (captive moose (captive moose; Felton et al. 2016), there have been other observations which indicate how important a mixed diet is for ungulates and other groups of animals (Westoby 1974; Berteaux 1998). In the first instance, animals forage to seek a nutritional balance; however, the optimal nutritional composition can vary across taxa. Many earlier studies show that animals maintain protein intake at a relatively constant level, but allow the non-protein intake to vary. This "protein-leverage effect" has previously been reported for mice (Sörensen et al.

2008), spider monkeys (Felton et al. 2009) and humans (Gosby et al. 2011). In contrast, gorillas' patterns of macronutrient intake suggest that they prioritise intake of non-protein energy over protein (Rothman et al. 2011). Studies of food intake and foraging strategies by captive moose (Felton et al. 2016), wild pine martin (Remonti et al. 2015) and grizzly bears (Coogan and Raubenheimer 2016) support the nutrient balance hypothesis, as these animals utilise mixed foods in specific proportions to provide a particular ratio of macronutrients in their diets. Similarly, the nutritional variability and foraging performance of the masked booby (*Sula dactylatra tasmani*), a large carnivorous seabird of the gannet family, showed that in spite of variations in the nutritional composition of foods available, males consistently captured prey with higher protein-to-lipid ratios and lower lipid-to-water ratios (Machovsky et al. 2016). Clearly, as the above studies show, despite variation in their optimal diet composition, the right balance of nutrients is crucial for all animals.

## 1.7 Conclusion

In this chapter, I have discussed spatiotemporal variation in the availability and intake of food by Asian elephants. The material reviewed suggests the likelihood that elephants do target specific macronutrient combinations in their diets, but this has yet to be demonstrated. In most places, food selection by elephants is positively correlated with higher protein content in plants food. The strategy of switching seasonally between grass and woody plants seems aimed at maintaining protein intake in the face of variation in the macronutrient composition of these foods (Sukumar 1990). However, many other factors could play a role, including relatively low fibre and secondary plant compound content in crops, their high spatial density, or simply the fact that they are available. Clearly, systematic studies of the nutritional basis of diet selection by elephants are needed, to better understand the nutritional motives underlying crop raiding and other forms of foraging behaviour by Asian elephants. In chapters that follow, I apply the nutritional geometry framework in an attempt to meet this need

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# Chapter 2

## Diet composition and macronutrient prioritization in a captive Asian elephant

‘Burma’- A captive female Asian elephant at Auckland Zoo.

## 2.1 Abstract

Compared with their wild counterparts, animals in captivity often experience limited scope for food selection. It is therefore important that the food and feeding regimen provided to animals in captive facilities allow them to meet their nutritional requirements. In this study, I analysed the food intake, food mixing and the resultant dietary macronutrient and fibre composition of a female Asian elephant ("Burma") in the Auckland Zoo, New Zealand. My study period included days in which Burma was fed exclusively on provisioned foods and days in which she was walked in a patch of forest and allowed to browse on forest foods. I found a positive correlation between Burma's daily intake (Spearman's rho = 0.941, p = 0.01, n = 12 days) and availability of food within the provisioning environment, suggesting that food intake was influenced by availability. Geometric analysis, however, showed that the proportion of Burma's daily energy intake from macronutrients and neutral detergent fibre (NDF) was different to the proportion found in the daily mixture of provisioned foods, indicating that she fed selectively from available foods and food parts so as to achieve a diet that differed in composition from that provided. Similar to what has been recorded for animals from several other species, Burma appeared to prioritise the ratio of protein: non-protein energy in her diet, with the ratio of non-protein macronutrients to NDF varying so as to maintain a more constant proportion of dietary protein.

## 2.2 Introduction

Important factors that separate animals nutritionally are the nutrients they require and the ability to meet these requirements from vastly different food sources. Over the past decade, a large body of work has demonstrated that macronutrient balance provides a powerful concept for understanding the diversity in the nutritional strategies of animals. A modelling framework, nutritional geometry, has been introduced to study the relationships between food compositions, nutrient requirements, and the ability of animals to combine foods in proportions that meet their nutrient requirements (Raubenheimer 2011; Simpson and Raubenheimer 2012; Raubenheimer et al. 2015). This approach has been applied in tightly controlled laboratory studies to demonstrate that many species of animal regulate feeding to achieve specific intakes and ratios of macronutrients, and some studies have shown that the selected diet maximises particular components of fitness (Jensen et al. 2012; Simpson and Raubenheimer 2012). Recently, this approach has been applied to field studies of nonhuman primates (Felton et al. 2009; Rothman et al. 2011) and used to understand the food choices and to optimise the diets of several species of domesticated animals (Ruohonen et al. 2007; Hewson-Hughes et al. 2011; 2012; 2013).

In most zoos, captive animals are not fed strictly in accordance with their food choices in natural conditions, often because of logistical and financial constraints. This is especially true for captive elephants (Crandall 1964), with reports suggesting that some facilities feed their elephants a low diversity of foods throughout the year and that some captive animals were fed inadequate quantities (Vanitha 2007). Although diets for herbivorous zoo animals are often based on a commercially manufactured, nutritionally-complete feed for which the nutrient specifications are readily available from the manufacturer, the nutritional composition of the diet as a whole (i.e. including non-commercial supplementary feeds and treats) can be more difficult to determine. Few papers on macronutritional feeding priorities of captive display animals have been published (Dierenfeld 1997). It is particularly important to understand the feeding priorities of animals in these circumstances because in the absence of natural food choices their nutrient intakes are tightly constrained by the foods that they are provisioned.

The primary objective of this study was to determine the macronutrient composition of the preferred diet of a captive female Asian elephant (*Elephas maximus*). I used nutritional geometry to analyse the patterns of nutrient intake, examining whether feeding selection tended to maintain particular combinations of energy-yielding dietary components (macronutrients and NDF) constant in the face of variation in available foods. This made it possible to investigate the extent to which the feeding regimen of the captive elephant allowed it to select a consistent proportion of nutrients by regulation of diet intake, or whether nutrient intake was simply a passive consequence of availability (i.e. proportional to the foods provisioned).

## 2.3 Material and methods

### 2.3.1 Feeding observations

The study was carried out at Auckland Zoo, New Zealand, in November 2012 and March 2013. Twelve full-day feeding observations were conducted on a captive female

Asian elephant named “Burma”. Feeding observations were conducted over four sessions of three consecutive days each (Appendix 2). Burma was housed in an enclosure with little opportunity for independent foraging as access to other foods was restricted to small quantities of a few seasonal kinds of grass, contributing less than 5% of the total diet. The only significant independent feeding she could do was during days when she was walked in a small patch of forest in the zoo and allowed to graze and browse on available natural foods for approximately two hours. In the elephant house, the provisioned foods were mainly hay, lucerne, various species of browse, and commercial zoo feed. To quantify Burma’s dietary intake, individual food items provided in the elephant house were weighed separately in the morning, midday and the evening and the total leftovers were weighed in the following morning. In the forest, food intake was estimated from direct observation. Feeding observations, including both in the elephant house and forest, were made continuously from 8:30 am to 5 pm (8.5 h total) daily.

### 2.3.2 Sample collection and nutritional analyses

Samples of commonly eaten foods were obtained each day during the data collection period. Samples of fresh feeds (hay and Lucerne) were collected from internal portions of different bales after opening from separate bags. To estimate the weight of food eaten in the forest, the average weight per mouthful of each type of food was calculated by weighing five mouthfuls that were taken from the mouth of the elephant while browsing and grazing prior to mastication. For woody browse, I used the unit-count method following Rothman et al. (2012), which takes as a reference a pre-defined length and breadth of eaten parts. For a subset of feeding days, faecal samples collected twice daily were matched to recorded intakes for a total of 24 times during the data collection period. Faecal samples were obtained after pooling and mixing the internal part (removing the outer layer). These nearest matching dung samples were collected within a gut passage time of 24 to 54 hours (Fowler and Miller 2008). Feedstuffs and faecal samples were separately labelled in double-sealed plastic bags and stored at 4–5 °C for < 72 h prior to laboratory analyses.

Samples were analysed at the Massey University Institute of Natural and Mathematical Sciences' Nutritional Ecology Laboratory for determination of dry matter (DM), nitrogen (N), acid detergent insoluble nitrogen (ADIN), available protein (AP), fat (ether extract; EE), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL) and ash. Prior to analysis, samples were ground in a Wiley Mill and passed through 1 mm sieve to standardise particle size, especially for fibre analysis. Samples of foods and faeces were oven dried at 55°C. A portion of the samples dried at 105 °C for about 16 hours in a forced air oven to determine DM concentration (Rothman et al. 2012). Crude protein was determined using total nitrogen (N) contents using the Kjeldahl method (AOAC official method). The average nitrogen content of wide varieties of proteins is 16 g N/100 g protein and the crude protein (CP) is calculated from N by multiplying by 100/16 (or 6.25) (Robbins 1993; Barboza et al. 2008). Available protein (AP) was estimated by subtracting ADIN as determined through Kjeldhal analysis of nitrogen in ADF residues (Rothman et al. 2012) from CP. Fibre analysis (NDF, ADF, ADL) was carried out using the methods proposed by ANKOM technology (ANKOM A 200 fibre analyser). I estimated hemicellulose by subtracting ADF from NDF, and cellulose by subtracting ADL from ADF (Blair 2007). EE analysis was conducted according to AOAC standard methods recommended for animal feed. Crude fat (CF) was estimated by subtracting one percentage point from the measured percentage of EE to account for indigestible lipids (Palmquist and Jenkins 2003; Rothman et al. 2012). All samples were analysed in duplicate, most of which had a < 5% coefficient of variation (CV) for protein and < 10% for fat and NDF. The dry matter percent of non-structural carbohydrates (NSC) in feedstuffs was estimated using the following equation: % NSC = 100 - (% CP + % NDF + % EE + % Ash). All analyses and calculations were made on a dry matter basis.

To estimate the energy contribution of macronutrients and fibre to total energy intake, I used the following conversion factors based on the Atwater general factor system (Merrill and Watt 1973): 4 kcal/g (17 kJ/g) for AP; 9 kcal/g (37 kJ/g) for EE; 4 kcal/g (17 kJ/g) for NSC; and for NDF 3 kcal/g 12.56 kJ/g (Conklin and Wrangham 1994; Van Soest 1994; Hohmann et al. 2006). An NDF energy conversion was used to account for hindgut bacterial fermentation of structural carbohydrates (hemicellulose and cellulose (Clauss et al. 2003). Since the fibres hemicellulose and cellulose are carbohydrates, the conversion factor of 4 kcal/g (17 kJ/g) could theoretically be applied to them, but the anaerobic microbial digestion and fermentation process keep about 1 kcal/g (4 kJ/g) of fibre for their growth so as such this leaves up to 3 kcal/g for the host (Conklin & Wrangham, 1994; van Soest, 1994). To estimate DM apparent digestibility, I compared the proportion of ADL in the diet to the proportion of ADL in the faeces using the following calculation adapted from Van Soest (1994).

NDF digestibility DM = 100 - (100 * % ADL in diet / % ADL in faeces * % NDF in faeces / % NDF in diet)

I have used ADL as an internal marker to calculate apparent digestibility. This is a widely used method and has been used in a number of hindguts (Ullery et al.1979; Reichard et al. 1982; Miraglia et al. 1999) and foregut fermenters (Fahey and Jung

1983). Earlier studies have shown that the incomplete lignin recovery has resulted in the underestimation of digestibility in ruminants (Fahey and Jung 1983; Merchen 1993). However, elephants are adapted to eat high fibre diet, and the discrepancy is expected to be less due to less inconsistency in lignin recovery. In my study, the lignin concentration was found to be more than 5%, and acceptable results can be obtained using ADL as an internal marker (Fahey and Jung 1983; Van Soest 1984).

I used SPSS (IBM SPSS Statistics 22) to make statistical comparisons using independent sample t-tests. Proportional data (i.e. % availability and intake from macronutrient or NDF values expressed as a proportion) were transformed using a “logit” transformation to approximate normality before running the independent sample t-test (Warton and Hui 2011).

### 2.3.3 Nutritional modelling

I used right-angled mixture triangles (RMTs) (Raubenheimer 2011; Raubenheimer et al. 2015) to visualise food and dietary proportions of macronutrients and NDF. The RMT is a proportion-based application of nutritional geometry used to investigate the nutrient balance of individual foods, food mixtures, and diets, and has previously been used in several studies of wild animals (Coogan et al. 2014; Aryal et al. 2015; Panthi et al. 2015). In my first RMT examination of the balance of metabolisable energy from different macronutrients, I modelled energy from the non-protein macronutrients (NSC + CF) and NDF in Burma’s foods and daily diet intake on the *x*- and *y*-axes, respectively, as a percentage of energy derived from the sum of these components. Metabolisable energy from AP was represented on the implicit axis of the RMT model, the values of which decrease with distance from the origin. I created additional RMTs exploring different nutrient dimensions of Burma's diet, including the balance of hemicellulose and macronutrients on a dry mass basis, and the dry mass ratios and proportions of the different components of measured fibre (hemicellulose, cellulose and lignin).

## 2.4 Results

### 2.4.1 Diet and feeding regimen

Burma was first provisioned with pelleted food at around 8 am, as well as with fruits/vegetables and some browse, followed by hay and lucerne. The daily average food consumption is shown in Table 2.1. Fruits and pellets were frequently (up to seven days a week) used as positive reinforcement in training for public display. On days when she was not taken to walk in the forest, the daytime food included hay/lucerne and some browse in the elephant house, and the evening diet comprised mainly hay/lucerne and fresh browse of varying combinations of species, from a single to a maximum of four species in one day. Among all groups of foods, about 55–60% of the available foods (mainly browse) were supplied during the evening. She was maintained on the same feeding regimen on days when walked in the forest, and she could supplement with browse and grass selected ad libitum in the forest.

Table 2.1: Total fresh and dry weight (kg) of each food available and eaten by Burma and the mean dry weight (kg/d)of each food consumed/day with the number of days each supplied.

| **Food** | **Fresh weight available (kg)** | **Fresh weight eaten (kg)** | **Dry weight eaten (kg)** | **Mean dry weight (kg/d)** | **Days food provided** | **SD** | **SE** |
|---|---|---|---|---|---|---|---|
| Willow | 233.0 | 159.5 | 145.5 | 20.8 | (n=7) | 10.4 | 3.9 |
| Grass | Free foraging | 21.0 | 19.4 | 3.9 | (n=5) | 1.0 | 0.5 |
| Hay | 180.3 | 178.8 | 165.5 | 13.7 | (n=12) | 4.2 | 1.2 |
| Lucerne | 73.2 | 72.7 | 65.8 | 5.4 | (n=12) | 1.8 | 0.5 |
| Pellet | 35.8 | 35.8 | 31.3 | 2.6 | (n=12) | 0.2 | 0.6 |
| Fruits /vegetables | 144.1 | 133.0 | 111.7 | 9.3 | (n=12) | 1.0 | 0.2 |
| Phoenix palm | 72.5 | 63.5 | 58.4 | 14.6 | (n=4) | 7.4 | 3.7 |
| Banana palm | 140.2 | 130.0 | 118.2 | 29.5 | (n=4) | 10.5 | 5.2 |
| Small bamboo | 307.2 | 186.0 | 172.5 | 24.6 | (n=7) | 15.1 | 5.3 |
| Fig | 146.1 | 118.0 | 106.1 | 35.4 | (n=3) | 14.5 | 8.4 |
| Bamboo (large). | 60.4 | 10.0 | 9.2 | 6.2 | (n=2) | 2.5 | 1.4 |
| Puka | 53.0 | 48.0 | 42.8 | 21.4 | (n=2) | 5.0 | 3.5 |

Altogether, Burma was observed to feed on 24 different food types, including both provisioned and forest foods (i.e. hay, lucerne, browse, grass, pellets, fruits, vegetables and supplements). The total daily intake of provisioned food was 30–180 kg (mean = 91, SD = 38) by fresh weight (Fig 2.1). The intake of provisioned lucerne, hay, pellets and fruits was almost 98% of that provided, while there was only 82% intake of provisioned browse in relation to availability. There was a significant positive relationship between total daily food intake and availability ($p$ = 0.01).

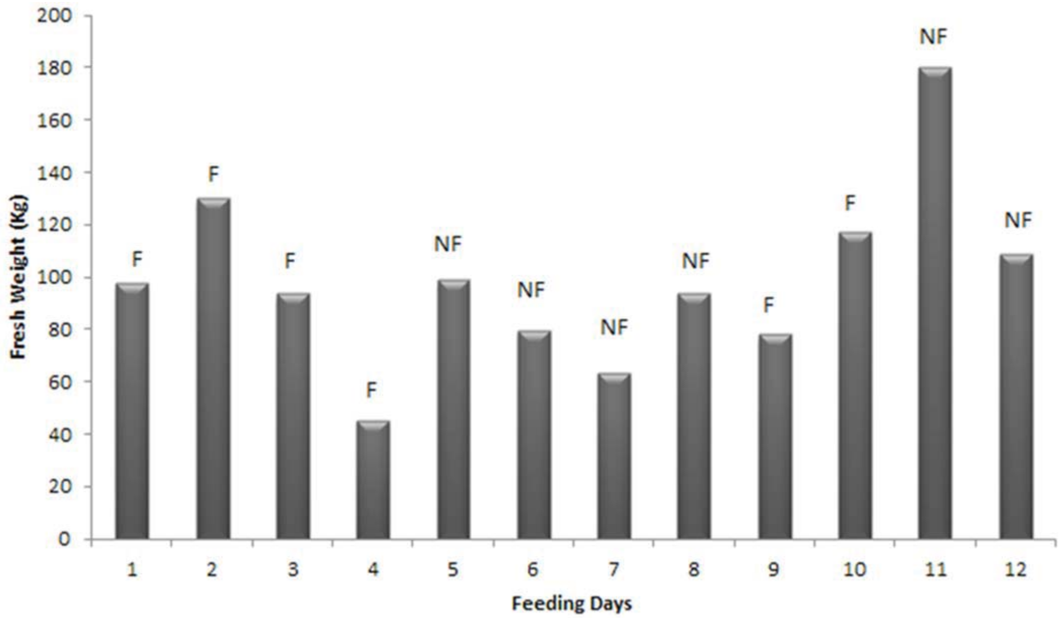



Figure 2.1: Daily consumption of fresh weight (kg) of major available foods provisioned to Burma in Auckland zoo in forest days (F) and non-forest days (NF).

Average daily total dry matter intake (DMI) was 89.3 kg or 2.8% of body weight, and digestible dry matter intake was 60 kg, with an apparent digestibility of 67%. Of the individual foods, the DMI contribution from small bamboo (*Arundo donax*) was the highest, followed by hay, willow (*Salix* spp.), fruits and vegetables, banana palm (*Musa* spp.), fig (*Ficus rubiginosa),* lucerne, phoenix palm (*Phoenix caranensis*) and puka (*Meryta sinclairii)* (Table 2.1). Browse formed 62% of DMI, while zoo food (mainly hay, lucerne, pellets and fruits) comprised 36% and grass 2%. Fifty-two percent of total DMI was consumed during non-forest feeding days (days 5, 6, 7, 8, 11 and 12), with the remaining 48% consumed during forest feeding days (days 1 2, 3, 4, 9 and 10); this difference was not statistically significant ($F$ = 0.48, $df$ = 5, $p$ = 0.22).

It was apparent from direct observation that Burma fed selectively on specific plant parts of some species. Among the provisioned food, almost all zoo foods (pellets, hay, lucerne and fruits) were entirely consumed, while the harder parts of browse (especially the pith of stems) were left uneaten. Bamboo stems were totally discarded. Foliage, tender branches, and the bark of most stems were eaten whole. The branches of fig bearing fruits were observed to be eaten more than the branches with only foliage. Observations during forest feeding suggested that Burma specifically targeted a few plant species, including houpara (*Pseudopanax lessonii*), kawakawa (*Macropiper excelsum*), nasturtium (*Tropaeolum* sp.), and graminoids such as tall fescue (*Festuca* sp.), *Phalaris* sp., sedge (*Carex* sp.) and onion grass (*Romulea* sp.), almost invariably eating them when encountered.

### 2.4.2 Nutrient composition of food

The macronutrient and fibre composition of foods consumed by Burma varied considerably (Table 2.2). For example, CP in foods ranged from 1.3% dry matter in apple (*Malus domestica*) with AP of 0.8%, to 21.5% CP (20.1% AP) in tall fescue grass. In browse, kawakawa had the highest levels of CP (16.7%), followed by willow (*Salix* sp.) leaf (15.3%). NDF content varied from 10.9% in apple to 70.0% in hay. The lowest ADL content (1.0%) was found in carrot (*Daucus carota*), and the highest (17.9%) was found in willow bark. The EE content of all foods was low (maximum 4.8% in kawakawa); however, foods specifically targeted by Burma in the forest were among the highest in EE (i.e. kawakawa and onion grass, and to a lesser extent *Phalaris* sp., *Carex* sp. and houpara), AP (tall fescue, nasturtium, and kawakawa) and NDF (*Carex* sp. and *Phalaris* sp.; Table 2.2).

Table 2.2: Percentage dry matter and nutritional content (% of dry matter) of foods consumed by Burma in Auckland Zoo. See * for the key to column headings. * DM, dry matter; EE, ether extract; CF, crude fat; CP, crude protein; AP, available protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin; Ash; NSC, non-structural carbohydrates.

| Common name | Scientific name | DM% | EE% | CF% | CP% | AP% | NDF % | ADF% | ADL% | Ash % | NSC% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hay | ___ | 92.6 | 1.3 | 0.3 | 6.6 | 6.0 | 70.0 | 36.0 | - | 7.7 | 14.4 |
| Bamboo (small) | *Adrundo donax*. | 91.9 | 2.6 | 1.63 | 14.2 | 12.6 | 67.6 | 34.3 | 1.2 | 10.9 | 4.7 |
| Willow | *Salix* sp. | 91.9 | 2.7 | 1.7 | 15.3 | 11.2 | 43.1 | 26.4 | 10.3 | 10.6 | 28.2 |
| Bamboo (large) | *Bambusa* sp. | 92.7 | 2.9 | 1.9 | 14.9 | 13.3 | 66.2 | 31.4 | 2.7 | 14.3 | 1.7 |
| Lucerne | *Madicago sativa* | 90.5 | 1.9 | 0.9 | 18.9 | 18.0 | 38.9 | 28.0 | 3.5 | 8.2 | 32.9 |
| Phoenix palm | *Phoenix canariensis* | 92.0 | 2.0 | 1.0 | 15.9 | 14.3 | 61.3 | 39.6 | 11.0 | 4.5 | 16.3 |
| Puka | *Meryta sinclairii* | 89.3 | 2.5 | 1.5 | 9.1 | 8.1 | 37.7 | 28.8 | 12.3 | 14.8 | 36.9 |
| Leaf fig | *Ficus rubiginosa* | 90.0 | 3.2 | 2.2 | 11.8 | 5.7 | 43.7 | 30.0 | 14.5 | 13.0 | 28.4 |
| Banana palm | *Musa* sp. | 90.8 | 2.3 | 1.3 | 8.0 | 3.6 | 68.7 | 44.8 | 2.0 | 15.3 | 5.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tall fescue | *Festuca* sp. | 89.7 | 2.2 | 1.2 | 21.5 | 20.5 | 58.1 | 27.0 | 8.0 | 14.9 | 3.3 |
| Carex | *Carex* sp. | 94.8 | 3.1 | 2.1 | 9.1 | 7.2 | 63.6 | 31.2 | 1.6 | 10.1 | 14.1 |
| Phalaris | *Phalaris* sp. | 93.1 | 3.0 | 2.0 | 9.8 | 8.7 | 67.4 | 34.9 | 4.4 | 11.6 | 8.3 |
| Houpara | *Pseudopanax lessonii* | 88.7 | 3.1 | 2.1 | 6.5 | 5.0 | 33.3 | 23.5 | 10.4 | 10.3 | 46.9 |
| Onion grass | *Romulea* sp. | 88.3 | 4.5 | 3.5 | 5.8 | 3.1 | 47.6 | 33.6 | 13.0 | 8.8 | 33.3 |
| Kawakawa | *Macropiper excelsum* | 89.6 | 4.8 | 3.8 | 16.7 | 15.4 | 33.0 | 32.9 | 11.5 | 4.4 | 41.1 |
| Apple | *Malus domestica* | 86.2 | 3.0 | 2.0 | 1.3 | 0.8 | 10.9 | 7.7 | 1.4 | 2.7 | 82.1 |
| Banana fruit | *Musa* sp. | 84.9 | 1.5 | 0.5 | 6.1 | 4.6 | 11.5 | 8.2 | 3.1 | 7.3 | 73.6 |
| Orange | *Citrus* sp. | 88.4 | 1.4 | 0.4 | 4.5 | 4.1 | 17.0 | 10.5 | 2.4 | 4.2 | 72.9 |
| Celery | *Apium gravioveolens* | 88.0 | 1.9 | 0.9 | 17.3 | 16.8 | 16.7 | 13.0 | 4.3 | 22.2 | 42.0 |
| Carrot | *Daucus carota* | 88.4 | 1.1 | 0.1 | 5.7 | 5.2 | 11.5 | 9.2 | 1.0 | 6.8 | 74.7 |
| Willow bark | *Salix* sp. | 90.7 | 3.1 | 2.1 | 12.9 | 6.8 | 48.7 | 39.7 | 17.9 | 8.5 | 26.8 |
| Nasturtium | *Tropaeolum* sp. | 88.4 | 1.0 | 0 | 18.7 | 16.5 | 21.6 | 27.2 | 6.9 | 16.4 | 42.5 |
| Pellet | NA | 87.5 | 1.5 | 0.5 | 17.9 | 17.1 | 40.0 | 25.4 | 1.9 | 11.4 | 29.2 |
| Water melon | *Citrullus lanatus* | 88.5 | 1.2 | 0.2 | 10.1 | 9.6 | 38.8 | 35.3 | 3.2 | 3.8 | 46.1 |

### 2.4.3 Macronutrient and fibre proportions

RMT analysis of the macronutrient proportions of foods available to Burma shows that she was offered nutritionally diverse foods which varied most in the content of NSC + CF, spanning approximately 15% to 95% of available energy, although the majority occupied the higher end of this spectrum (Fig 2.2). The contribution to foods of available energy from NDF ranged from < 5% to > 50%, while AP content of foods showed the least variation, ranging from approximately 1% to 43% energy (Fig 2.2).

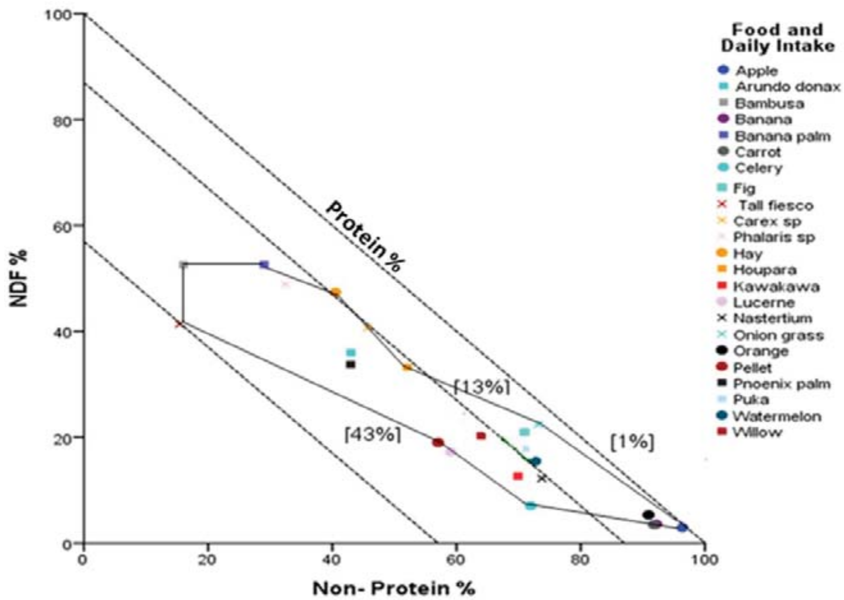
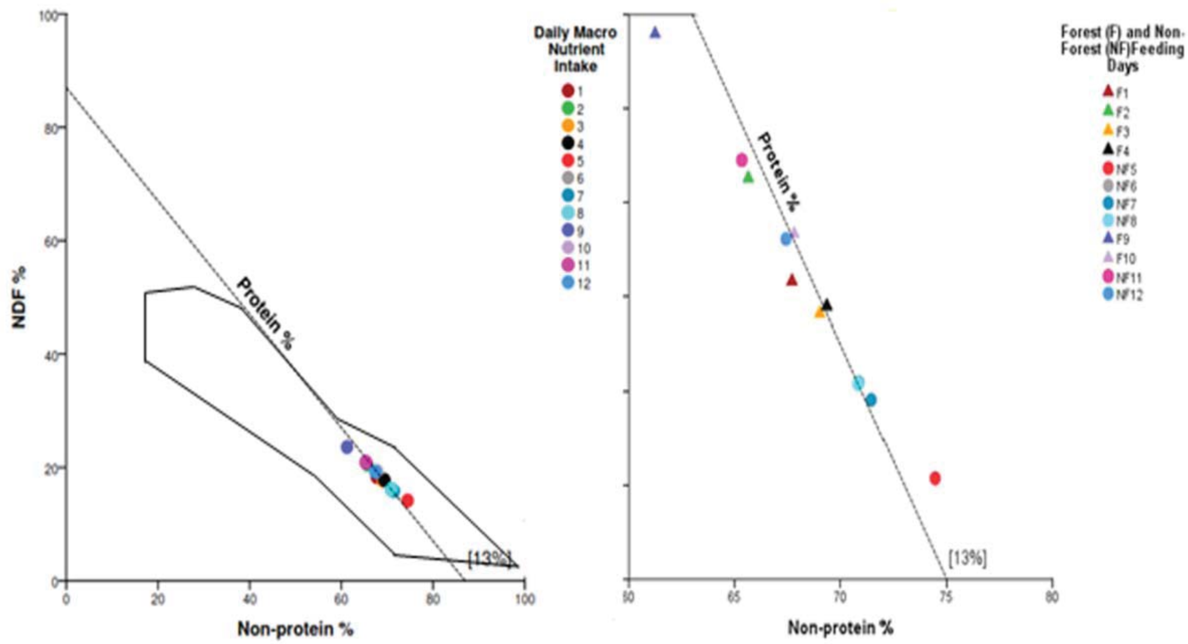



Figure 2.2: Right-angled mixture triangle (RMT) showing the percentage contribution to total metabolisable energy from natural detergent fibre (NDF), non-protein macronutrients (i.e. The sum of non-structural carbohydrates (NSC) + crude fat (CF)), and available protein (AP) in foods consumed by Burma in Auckland zoo. AP is shown on the implicit *z*-axis, the value of which increases across the negative-sloped dashed lines (protein isolines) with decreasing distance from the origin. For reference, protein isolines for 43%, 13% and 1% of available energy are labelled. The polygon drawn around food composition points delimits the range of food compositions available to Burma**.**

Despite this variation in the nutritional composition of the foods offered, Burma's daily diet maintained a relatively stable macronutrient and NDF composition as suggested by the pattern of intake points within the food space polygon in Fig 2.3A. AP intake seemed to be more closely regulated than NDF or non-protein macronutrients, as suggested by the tighter spread of daily intake points along the implicit axis (the negative diagonal lines) relative to the *x*- and *y*-axes (Fig 2.3). Averaged across all feeding days, the macronutrient and NDF balance of Burma's diet was 13.3% AP (± 0.26 SE), 68.4% NSC + CF (± 0.99 SE), and 18.3% NDF (± 0.75 SE).

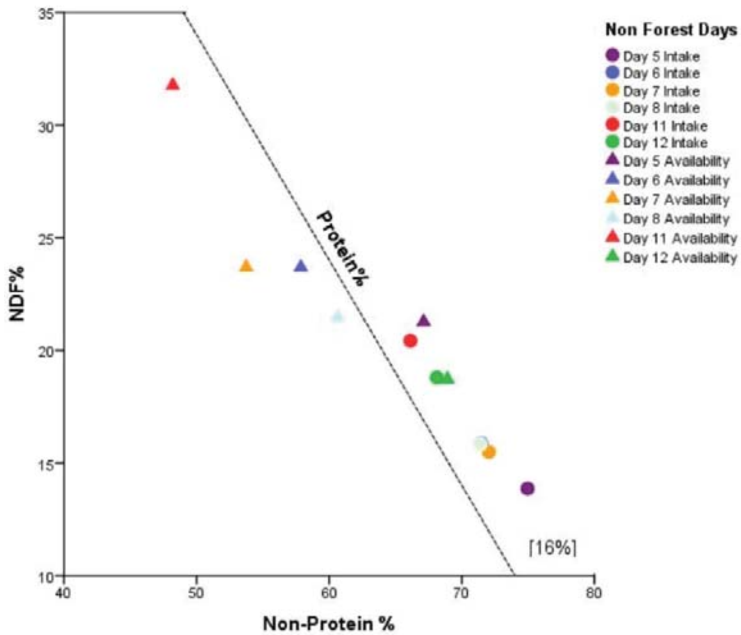
RMT analysis showed an overlap in the spread of Burma's intake points between forest and non-forest feeding days (Fig 2.3B). The data aligned most tightly along the AP axis, with the exception of days 5 and 9, which were relatively lower and higher in AP respectively. In contrast with the relatively constant proportional intake of protein, the proportion of metabolisable energy ingested from NDF tended to be higher on forest feeding days and from NSC + CF higher energy on non-forest feeding days (Fig 2.3B).



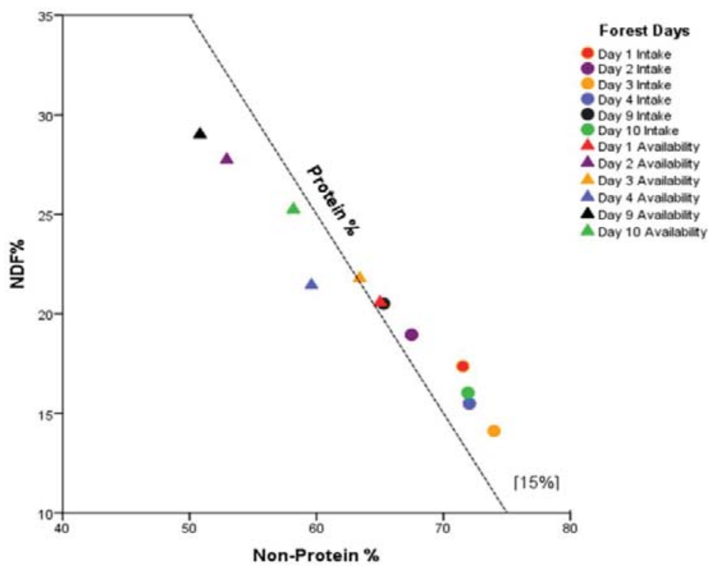

A B

Figure 2.3 A: Right-angled mixture triangle (RMT) showing the percentage of Burma's daily energy intake from NDF, non-protein macronutrients (NSC + CF), and AP over four 3-day foraging observation sessions (*n* =12 days total), including both provisioned and forest foods. The polygon outlines the range of food compositions available from which to compose her daily intakes (redrawn from Fig 2.2). B. An expanded view of Figure 2.3A: Symbols distinguish forest (triangles) versus non-forest (circles) feeding days, and colours distinguish daily observation sessions. Days 1, 2, 3, 4, 9 and 10 (triangles) were days Burma was allowed to forage in the forest in addition to feeding on provisioned foods. Days 5, 6, 7, 8, 11 and 12 (circles) were days on which Burma was restricted to provisioned foods only.

On non-forest days, Burma's intake of macronutrients and NDF appeared to be different than what she would have consumed if she simply ate the foods in the proportions they were offered (AP, $t$ = 3.8, $p$ = 0.003; non-protein, $t$ = -3.0, $p$ = 0.01; NDF, $t$ = 3.7, $p$ = 0.004) (Fig 2.4A). Generally, Burma adapted her feeding among available foods so as to consume a diet lower in AP and NDF (and higher in NSC + CF) than she would have if she fed indiscriminately. This pattern of non-random feeding suggests selective feeding on available foods. One exception was on day 12, in which Burma consumed foods in similar proportions to what was offered.




**A**




**B**

Figure 2.4 A: Right-angled mixture triangle (RMT) showing the proportional contribution to metabolisable energy intake if Burma fed proportionally to what was available (triangles) versus her actual intake (circles) for days she was restricted to provisioned (i.e. non-forest) foods. B: Equivalent data for forest feeding days. Note that in B availability and intake do not include forest foods because it was not feasible to estimate the availability of foods in the forest.

Burma's intake of provisioned foods only (i.e. not including forest foods) on forest feeding days showed similar patterns in macronutrient and fibre intake to what was observed on non-forest feeding days (i.e. she tended to consume less AP and NDF, and more NSC + CF, than was available; Fig 2.4B). Burma's total (i.e. including forest foods) proportional intake of NDF, however, on forest feeding days was higher than on non-forest feeding days. Interestingly, if Burma ate provisioned foods proportionally to availability, she would have consumed a similar proportion of NDF to what she actively selected when including forest foods. Importantly, however, this diet would also be higher in the proportion of AP energy than what was selectively consumed (Fig 2.3A), as would be expected if intake regulation of protein balance plays a dominant role over regulation for NDF and non-protein macronutrients. That is, the AP content of provisioned foods may have deterred Burma from consuming the proportion of NDF she consumed during forest feeding days so as to avoid ingesting a surplus of protein.

The metabolisable energy component of NDF was likely to be primarily from hemicellulose. Foods which were highest in hemicellulose relative to AP and NSC + CF on a dry matter basis, whether provisioned or available in the forest enclosure, made up approximately half of Burma's daily DMI (Fig 2.5). The proportional contribution of cellulose (~ 50% ± 0.87 SE dry matter), hemicellulose (~ 39% ± 0.77 SE) and lignin (~11% ± 0.77 SE) to daily total fibre intake (dry mass) remained relatively constant despite variation in the proportions of these fibre components in available foods (Fig 2.6).

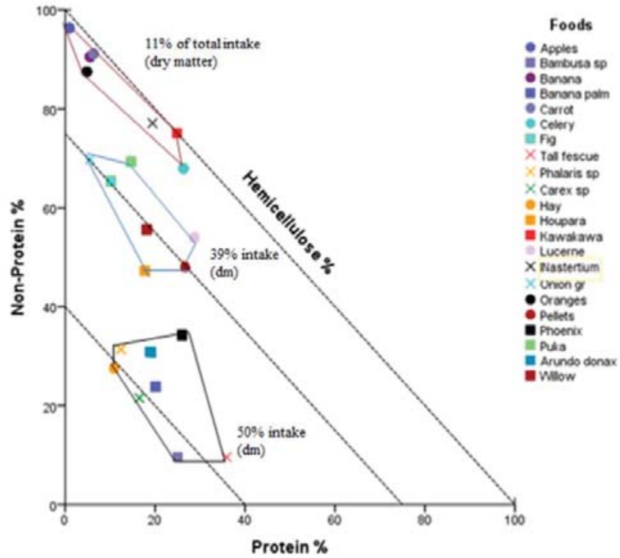



Figure 2.5: Right-angled mixture triangle (RMT) showing the balance of available protein (AP), non-protein macronutrients (CF + NSC), and hemicellulose of plants consumed by Burma as a percentage of the sum of each (AP + (CF + NSC) + hemicellulose) on a dry matter basis. Groups of foods comprising 50%, 39% and 11% of Burma's daily dry matter intake are indicated.

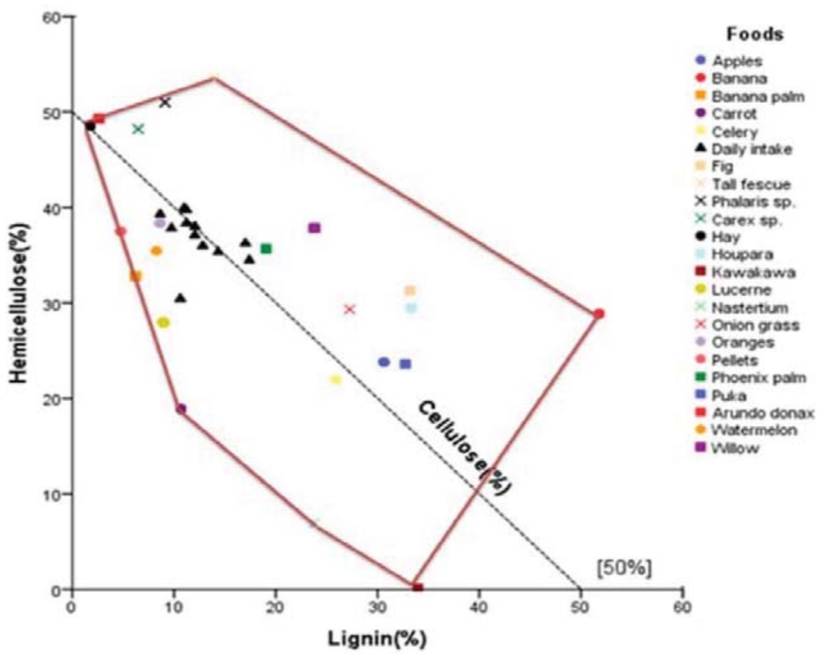



Figure 2.6: Right-angled mixture triangle (RMT) showing the percentage contribution of fibre components (hemicellulose, cellulose and lignin) relative to total fibre intake (dry matter basis) in Burma's daily diet. Cellulose is shown on the implicit *z*-axis, with the dashed reference line indicating 50% cellulose.

## 2.5 Discussion

As expected, I found a positive correlation between Burma's intake and the availability of provisioned foods, which at first glance might suggest that her diet was simply a consequence of availability. Closer inspection using nutritional geometry, however, suggested that despite the constraints, Burma spread her feeding across available foods to achieve relatively constant proportions of macronutrients and fibre, particularly the ratio of protein to non-protein energy. Such prioritisation of the proportion of dietary energy to protein has been observed in several studies in diverse taxa (Irwin et al. 2015; Erlenbach et al. 2014; Solon-Biet et al. 2014). Notably, digestible structural carbohydrate (i.e. fibre) seems to play an important role in regulating protein intake relative to non-protein energy. The energy contribution of digestible fibre, therefore, should not be overlooked when designing diets for captive elephants or when examining the foraging ecology of wild elephants. It should be borne in mind, however, that fibre digestibility of browse species may differ from grass species and variation is present within browse species and within grass species. I consider this is the critical but poorly quantified role of the fermentation of fibre in the hindgut fermenter (Conklin et al. 2006). I relied on the general assumption of poor fibre digestibility and hence assigned lower fibre conversion factor to elephants. This would unlikely add significant error. Thus designing future studies to refine the energy calculation from NDF based on different digestion coefficient is desirable.

Compared with in the wild, animals in captivity may experience limited scope for food selection because they are restricted to what is provisioned. Captive animals, therefore, may be restricted in their ability to balance their nutrient intake by mixing their diet if they are not supplied with a variety of nutritionally complementary foods. In Burma's case, the addition of foods obtained during forest feeding days (such as tall fescue, nasturtium, kawakawa, houpara and phoenix palm) allowed her to obtain a variety of foods higher in crude fat and protein which likely assisted her in composing a balanced diet.

My analysis using nutritional geometry has provided information that can be used to ensure that Burma is provisioned with complementary foods that allow her to regulate her protein to non-protein energy intake on days in which she is not able to forage in the forest. For example, day 5 (non-forest day) was lowest in terms of protein among all days, probably because fig was the only browse supplied in addition to the usual zoo foods. Such a nutrient imbalance can lead to obesity and poor health if an animal overeats low-protein foods, thereby increasing energy intake, to obtain a preferred amount of protein (Raubenheimer et al. 2014). At the same time, it is important to balance the nutrients contributing to non-protein energy. For example, adequate dietary fat is vital for elephants' reproductive health (Nilsson et al. 2014). Furthermore, dietary macronutrient balance has been strongly linked to the rate of ageing and longevity in several species (Solon-Biet et al. 2015).

Burma's diet was in line with the recommendation that natural foods should comprise 75% of the diet of captive elephants, with the remaining 25% being composed of concentrated pellets (Romain et al. 2014). Burma's DMI (2.8% of body weight), however, was more than for wild Asian and African elephant (1.5–1.9% and 1.0–1.9%, respectively (Ullrey et al. 1997), and comparable with captive Asian and African elephants housed in European zoos with similar weight and diets (0.7–2.9% of body weight). Intake will, however, vary according to different factors, such as age, activity level, and diet composition (Hackenberger 1987).

The comparison of the similar nutritional baseline data of Burma in Auckland zoo with the data of domestic elephants in Chitwan, Nepal can help to understand the nutrient regulation in elephants. Auckland's climate is classified as subtropical with warm humid summers (NIWA 2015) while, Chitwan in Nepal has tropical monsoon climate (DNPWC 2015). The nutritional composition of food available to elephants is different in these two regions. However, the patterns of macronutrient intake by elephants are consistent in these locations. Elephants were found to be targeting 11-15% protein in their diet, and they were found to be maintaining this target from the different ratio of non-protein energy and NDF. This indicates that the nutrient intake regulation found in this study is likely general for Asian elephants.

Despite the limitations of studying a single animal, an advantage is that it more readily facilitates intensive, longitudinal observations of an identified individual, and thus can provide insightful perspectives into nutritional ecology (Johnson et al. 2013). This study contributes important information on the nutritional ecology of captive Asian elephants, for which relatively limited information is available. This research, therefore, may be useful for elephant husbandry as well as providing information that can be integrated into the formulation of conservation and management strategies.

One avenue for future research is to investigate the role of micronutrient balance in the diet of elephants, as well as the building blocks of macronutrients, such as amino acids and fatty acids. Furthermore, investigating the macronutrient preferences of different sex, age and reproductive classes of Asian elephants across a larger sample size would be worthwhile.

Finally, although theory and data suggest that regulated nutrient intakes will correspond with evolutionary fitness (broadly, reproduction) (Raubenheimer et al. 2016), this might not correspond with management goals for captive animals. For example, the self-selected diet of several invertebrate species maximises reproduction at a cost to lifespan (Simpson and Raubenheimer 2012), and for non-breeding display animals, long lifespans might be the more important management priority. In such cases, it might be necessary to manage the diet of the animal to achieve a composition other than that which would be self-selected if given the opportunity. Similarly, some species are likely to be adapted to ecological circumstances in which limited availability of specific nutrients enforces a diet composition that is different from and more beneficial than the diet that would be self-selected in unconstrained circumstances (Raubenheimer et al. 2016). A high priority is, therefore, to establish for captive species whether the self-selected diet actually is optimal and whether the benefits that accrue from it align with management goals.

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# Chapter 3

## The effects of age, sex and season on the macronutrient composition of the diet of the domestic Asian elephants

**The baby domestic elephant in elephant breeding centre.**

## 3.1 Abstract

Limited data are available on the relationship between seasonal diets and macronutrient and energy intake of domestic Asian elephants. The effects of age, sex and season on the nutrient composition and intake of food were investigated using 16 domesticated Asian elephants of different ages and sexes. The parameters considered include nutrient digestibility, dry matter intake (DMI), macronutrient energy balance and metabolised energy. There were no significant seasonal differences in the protein content of the major food plants. However, a seasonal variation in the intake of protein was evident. Digestibility did not vary with respect to age-class or sex. I used geometric modelling of non-protein (NP) neutral detergent fibre (NDF) and protein to examine seasonal nutrient variability within different ages, sexes and physiological states. I found nutrient variability among individual elephants in all seasons, with the majority of the elephants showing distinct grouping during winter, pre-monsoon and monsoon seasons. Dry-season diet of each elephant was the most widely spread, with distinct clustering within individuals, suggesting between-individual heterogeneity in macronutrient intake was less than within-individual intake. The model suggested that males utilised more protein than females. Lactating and non-lactating females consume protein more than pregnant females. Overall, this study found that the majority of individual elephants maintained their recommended metabolisable energy intake from the self-selected diet across all seasons. However, I had anticipated less energy intake from the poor diet due to less

protein and higher NDF availability in the feeding ground during winter pre-monsoon and monsoon seasons. Despite eating a lower variety of plants with less protein and higher NDF, elephants maintained a consistent pattern of diet intake in these seasons, suggesting that they acquired the recommended energy intake by regulating their diet, most likely through over-ingesting low-quality, non-complementary food as they did not have the opportunity to select from a variety of plants.

## 3.2 Introduction

Domesticated elephants in Nepal play an important role in the conservation and management of national parks and their surrounding forests (DNPWC 2011). Government-owned elephants are mainly used for patrolling and for research purposes within the park, whereas privately-owned elephants are for the most part used for recreational riding by tourists in the buffer zones of parks and reserves (Kharel 2005). Due to the increasing demand for elephants for patrolling and park management duties, and the difficulty in legally procuring elephants from India, an elephant breeding centre was established in Chitwan National Park in 1986 (Pradhan et al. 2011). These semi-wild domesticated elephants are provisioned with food in the camp and are also allowed to forage in the national park and the buffer zone forests during daily excursions guided by mahout (elephant keeper).

Despite intensive conservation efforts, there is a lack of available information on the food preferences and macronutrient composition of the diets of the elephants that have access to these two food sources. Of particular importance is how the selected diets compare to the recommended nutrient intakes for elephants. Appropriate nutrition is critical for normal growth and the maintenance of good health by elephants (Stevenson and Walter 2006), and nutrient requirements may vary according to age, sex, season and workload (especially for domestic elephants). A better understanding of elephant diet in Nepal is especially important considering the poor health of a sizable number of domestic elephants in that country, and their role in the harbouring and spread of tuberculosis (DNPWC 2011). Furthermore, the dietary or nutrient requirements of free-ranging elephants have not been definitively established (Ullrey et al. 1997). This is a complex challenge because it requires an understanding of food supply, nutritional characteristics of foods, food digestibility, and the animal's nutritional requirements (Rothman et al. 2011).

This study aims to examine the diet and macronutrient compositions of the foods consumed by domestic elephants in Nepal and whether age, sex, season or disease status (tuberculosis) affect these patterns of nutrient composition using a proportion-based nutritional geometry framework, the right-angled mixture triangle (RMT). Information from this study will aid in the dietary management and thus the husbandry and conservation of these animals in terms of the management and restoration of their provisioned food and their natural habitat respectively.

## 3.3 Materials and methods

### 3.3.1 Study area

The Chitwan National Park (Fig 3.1) is located in the lowland Terai region of Nepal. The core area of the park covers 932 $km^2$ and is surrounded by a buffer zone of 750 $km^2$ (55% agricultural land and 45% community forest) (Straede and Helles 2000). The park is ecologically diverse, spanning early stages of succession on alluvial flood plains along the Narayani, Rapti and Rew watersheds to climax forest in the foothills and on the slopes of the Churia Range (Chanchani et al. 2014). The forests are composed predominantly of deciduous and semi-deciduous species. Sal (*Shorea robusta*) dominates in the Chitwan National Park, whereas the low-lying areas alongside the rivers are covered by a variety of riverine forests dominated by simal (*Bombax malabaricum*), vellar (*Trewia nudiflora*) and tall grasslands (DNPWC and PPP 2000; Bhattarai and Kindlmann 2012).

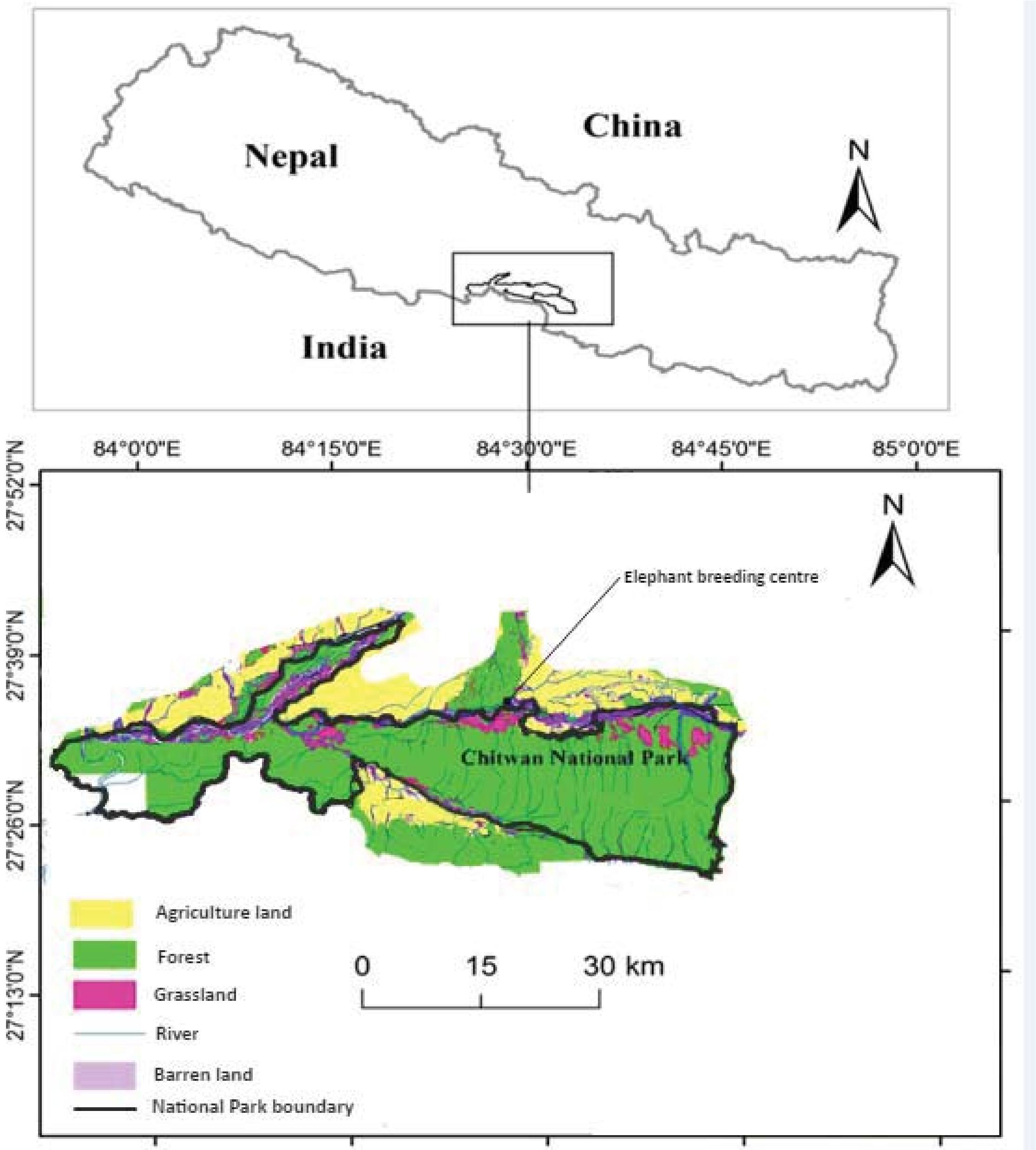


Figure 3. 1: map of study area (Chitwan National Park) in nepal.

### 3.3.2 Daily activity and feeding regimen of domesticated elephants in the elephant breeding centre

Domestic elephants are taken by their keepers (mahouts) to forage in nearby forests daily at around 5:30 am and returned to the camp around 9:30 am. The mahouts also collect fodder and woody browse en-route, which they feed the elephants during the morning and to a lesser extent in the evening. At around 10 am, elephants are ridden by mahouts into the National Park where they are allowed to forage freely, and returned to the camp at approximately 4 pm. From around 4:30 to 5:00 pm the elephants are provided with food pellets, locally called kucchi (Locke 2011), which consist of a mixture of grain, molasses and salt, wrapped with grasses such as siru (*Imperata cylindrica*). At this time, they are also provisioned with fodder-like grasses and woody browse and individually tethered with 1–2 m chain to separate wooden posts under cover of a tin roof until the following morning (Varma and Ganguly 2011).

### 3.3.3 Data collection

I surveyed a total of 16 domesticated elephants of which 5 of them had tuberculosis. This was surveyed across four different seasons (dry, winter, pre-monsoon and monsoon), The information on the disease status of the elephants was collected from the national park office. My study included young and adult males, and adult females (pregnant, lactating and non-lactating). The elephants were classified into three age-based categories: category 1: 8-16; category 2: 22-32; and category 3: 43-69 years old. Elephants were observed in all four seasons: Eight elephants were surveyed during the dry season, seven in winter, nine in pre-monsoon, and eight in monsoon season. Each elephant was observed consecutively for three to four full days in grassland and sal (*Shorea robusta*) mixed-forest from morning through evening. I completed a total of 116 observation-days, spanning all four seasons between 2012 and 2013. Details of the observed elephants are provided in table 3.1.

Table 3.1: Name, age, sex, season surveyed and disease status of 16 domestic Asian elephants in the elephant breeding centre in Chitwan, Nepal.

| **Name** | **Sex** | **Age (years)** | **Age category** | **Surveyed seasons** | | | | **Disease status** |
|---|---|---|---|---|---|---|---|---|
| | | | | Dry (1st season) | Winter (2nd season) | Pre-monsoon (3rd season) | Monsoon (4th season) | |
| 1 Aisweryamala | F | 26 | 2 | × | × | × | × | TB +ve |
| 2 Narayankali | F | 13 | 1 | × | × | × | | TB -ve |
| 3 Karnalikali | F | 15 | 1 | × | × | × | | TB -ve |
| 4 Ganesh kali | F | 16 | 1 | × | | | × | TB -ve |
| 5 Parasguj | M | 12 | 1 | × | × | | | TB -ve |
| 6 Narayanguj | M | 8 | 1 | × | | | | TB -ve |
| 7 Lambodar Pd | M | 58 | 3 | × | × | × | × | TB +ve |
| 8 Gyanendra Pd | M | 30 | 2 | × | | | | TB -ve |
| 9 Prenakali | F | 27 | 2 | | × | | | TB +ve |
| 10 Dipendraguj | M | 46 | 3 | | × | | | TB -ve |
| 11 Bhola Pd | M | 46 | 3 | | | × | | TB +ve |
| 12 Sundermala | F | 69 | 3 | | | × | × | TB -ve |
| 13 Binayakguj | M | 32 | 2 | | | × | × | TB -ve |
| 14 Ramguj | M | 25 | 2 | | | × | × | TB -ve |
| 15 Bahadur guj | M | 22 | 2 | | | × | × | TB -ve |
| 16 Komalkali | F | 43 | 3 | | | | × | TB +ve |

The duration of daily feeding and feeding breaks were recorded. Two types of feeding breaks were defined: 1) long breaks, which were more than 15 min without any ingestion of food; and 2) short breaks of 5–15 min between feeds. Data on the plant species consumed by the elephants and the number of mouthfuls of each species were obtained by continuously following the animals while they were feeding. To estimate mouthful size of grasses, a minimum of five mouthfuls were removed from the elephants' mouths before ingestion. Average was used to calculate an estimated mouthful weight for each type of grass species consumed. For the browse and woody parts, a unit count was done using a pre-defined length and breadth of the eaten part for reference (Rothman et al. 2012). To avoid disturbance, the animals were observed from a distance of 5–10 m (Chandra et al. 1990). The local names of the ingested plants were provided in the field by field assistants when possible. Samples of each plant species were gathered and sent to the National Plant Herbarium, Kathmandu, for scientific identification. All samples were collected on the day of consumption from the actual plants or several adjacent plants of the same species. Plants were weighed immediately in the field using an Ohaus Scout Pro Portable Electronic Balance. The samples were oven dried to constant weight the following day at 60$^{o}$C for 12 hours at the National Trust for Nature Conservation (NTNC) office at Sauraha, before being transported to the feed analysis lab at the National Agricultural Research Centre in Kathmandu. The samples were ground in a Wiley mill using a 1 mm sieve before nutritional analysis.

Availability of the natural food plants was estimated using data collected from a recent survey of wild elephant foods in the area (Chapter 4, Koirala et al. 2016).

### 3.3.4 Nutritional analysis

Nutritional analyses were run in duplicate, including those for dry matter (DM), crude protein (CP), ether extract (EE), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), ash and non-structural carbohydrate (NSC). All analyses and calculations were performed on dry matter basis. The CP concentration was determined using the Kjeldahl method (AOAC 1990). The CP was calculated by multiplying nitrogen (N) by 6.25. All macronutrient analysis was conducted according to AOAC standard methods recommended for animal feed (Rothman et al. 2012). NDF, ADF and ADL content of food items were measured by sequential analysis (Goering and Van Soest 1970; Van Soest et al. 1991). NSC was calculated using the following established equation: % NSC = 100 – (%CP + %NDF + %EE + %Ash) (Rothman et al. 2012). Crude fat (CF) was calculated by subtracting 1% from the EE value (Rothman et al. 2012) to account for indigestible waxes and fats.

DM digestibility was estimated by comparing the proportion of lignin in the diet to the proportion of lignin in the faeces using the following calculation adapted from Van Soest (1994):

Diet digestibility DM =1 – proportion of ADL in diet / proportion of ADL in faeces.

The NDF digestion coefficient was estimated using the following calculation:

NDF digestibility DM = 100 – (100 * %ADL in diet / %ADL in faeces * % NDF in faeces / %NDF in diet)

### 3.3.5 Energy intake and balance

According to an energy balance study by Pagan and Hintz (1986), metabolised energy averages 87% of the relative digestible energy (DE) intake in non-ruminant herbivores. In this study, DE and metabolised energy (ME) were estimated by the basal metabolic rate. Thus ME =MJ per kg$^{0.75}$per day, with the DE converted to ME using efficiency of 87% - i.e. ME=DE x 0.87 (Pagan and Hintz 1986). Based on this DE: ME ratio, the relative DE intake recommendations thus become 0.68 (DE) MJ per kg per day. This estimate of relative DE for maintenance was used to assess the adequacy of DE intake in the current study because it is commonly used to evaluate requirements of other hindgut fermenters such as horses, rhinos and tapirs (Romani et al. 2014).

The energy conversion values used were 17 kJ/g (4.0 kcal/g) for protein, 37 kJ/g (8.9 kcal/g) for fat, 17 kJ/g (4.0 kcal/g) for carbohydrates (FAO 2002) and 12.56 kJ/g (3.0 kcal/g) for NDF (Hohmann et al. 2012).

I used the right-angled mixture triangle (RMT), a multi-dimensional approach for modelling nutritional mixtures (Raubenheimer 2011), to visualise and compare the proportions of macronutrients and fibre in the foods and diets of elephants across different disease status, age-sex groups and seasons. Using this approach, I modelled energy from NDF and non-protein macronutrients (NSC + CF) in foods and daily diet intake on the *y* and *x* axes, respectively. Energy from CP was represented on the third axis (*i*-axis; Raubenheimer 2011). These nutrients were modelled as a percentage of energy that each contributes to the sum of energy from all energy-giving nutrients included in the model (i.e. NDF + (NSC + CF) + CP). The *i*-axis variable (in this case CP) is implicit given the values of the *x*- and *y*-variables since $\%x + \%y + \%i = 100\%$ of energy and therefore once %*x* and %*y* are stipulated so too is %*i* (Raubenheimer 2011). I used SPSS (IBM SPSS Statistics 22) to make comparisons of the macronutrient composition of the diet across seasons, female physiological state, age class, disease (TB) and gender pattern of intake and balance of crude protein (CP), NDF and non-protein macronutrient energy (CF + NSC) using one-way ANOVA and independent sample t-test. I ascertained TB status of the elephants using the veterinary records of individuals. Proportional data (i.e. % energy from macronutrient or fibre values expressed as a proportion) were transformed using a “logit” transformation to approximate normality before running the ANOVA (Warton and Hui 2011). Spearman’s correlation was used to look for a relationship between the availability of provisioned foods and their intakes by elephants.

## 3.4 Results

### 3.4.1 Feeding regimen

Across all seasons 70% of the diet was provisioned food (browse, grass and pellets) while natural feeding (browse and grass) formed 30% of the elephant's diet. In the dry season, browse formed 72% of the overall total diet, and pelleted food and grass contributed 21% and 7%, respectively. In other seasons, approximately 90% of the diet comprised grass, with the remainder being pelleted food and browse. The list of food types eaten in each season is given in table 3.2.

Table 3.2: List of natural and provisioned foods (browse grass and pellet) eaten by elephants in different seasons of the year.

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| Dry season | Food Type | Winter season | Food Type | Pre-monsoon season | Food Type | Monsoon season | Food Type |
|---|---|---|---|---|---|---|---|
| *Cycas pectinata* | Browse (natural) | *Cycas pectinata* | Browse (natural) | *Bombax ceiba* | Browse (natural) | *Cymbopogon* | Grass (natural) |
| *Dilenia pentagyna* | Browse (natural) | *Dilenia pentagyna* | Browse (natural) | *Impereta cylindrica* | Grass (natural /provisioned) | *Impereta cylindrica* | Grass (natural /provisioned) |
| *Ficus racemosa* | Browse (provisioned) | *Impereta cylindrica* | Grass (natural /provisioned) | Pellet | Provisioned | Pellet | Provisioned |
| *Ficus semicordata* | Browse (provisioned) | *Litsea monopetala* | Browse (natural) | *Phragmities karka* | Grass (natural /provisioned) | *Phragmities karka* | Grass (natural /provisioned) |
| *Impereta cylindrical* | Grass (natural /provisioned) | Pellet | Provisioned | *Saccarum bengalensis* | Grass (natural /provisioned) | *Saccarum bengalensis* | Grass (natural /provisioned) |
| *Litsea monopetala* | Browse (natural) | *Phragmities karka* | Grass (natural) | *Saccarum spontanum* | Grass (natural /provisioned) | *Saccarum spontanum* | Grass (natural /provisioned) |
| Pellet | Provisioned | *Saccarum bengalensis* | Grass (natural /provisioned) | *Saccharum arundinaceum* | Grass (natural /provisioned) | | |
| *Phragmities karka* | Grass (natural) | *Saccarum spontanum* | Grass (natural /provisioned) | *Themeda* sp | Grass (natural) | | |
| *Saccarum bengalensis* | Grass (natural /provisioned) | *Saccharum arundinaceum* | Grass (natural /provisioned) | | | | |
| *Saccarum spontanum* | Grass (natural /provisioned) | *Themeda arundinacea* | Grass (natural) | | | | |
| *Saccharum arundinaceum* | Grass (natural) | *Zizypus* sp | Browse (natural) | | | | |
| *Semecarpus anacardium* | Browse (natural) | | | | | | |
| *Spatholobus parviflorus* | Browse (natural /provisioned) | | | | | | |
| *Themeda arundinacea* | Grass (natural) | | | | | | |

### 3.4.2 Seasonal differences in the nutritional content of key plants

Of the 45 food items consumed, I analysed the nutrient content of the 35 plant species and pellets that were observed to occur most commonly in the diet. In addition, eight composite dung samples for each individual were collected in each season for nutritional analysis.

There was no significant seasonal difference in the CP content for any of the key food items consumed by elephants ($F_{3, 31}$ = 1.72, $p$ = 0.179) (Fig 3.2). There was, however, a wide variation among species in the CP content. The highest CP content (20.6%) was found in narkat (*Phragmites karka*) followed by kutmiro (*Litsea monopetala*; 17.4%) in the dry season (1st season) (Fig 3.2), with the lowest concentration of CP found in dhaddi (*Saccharum bengalensis*; 0.5%) in premonsoon (3rd season).

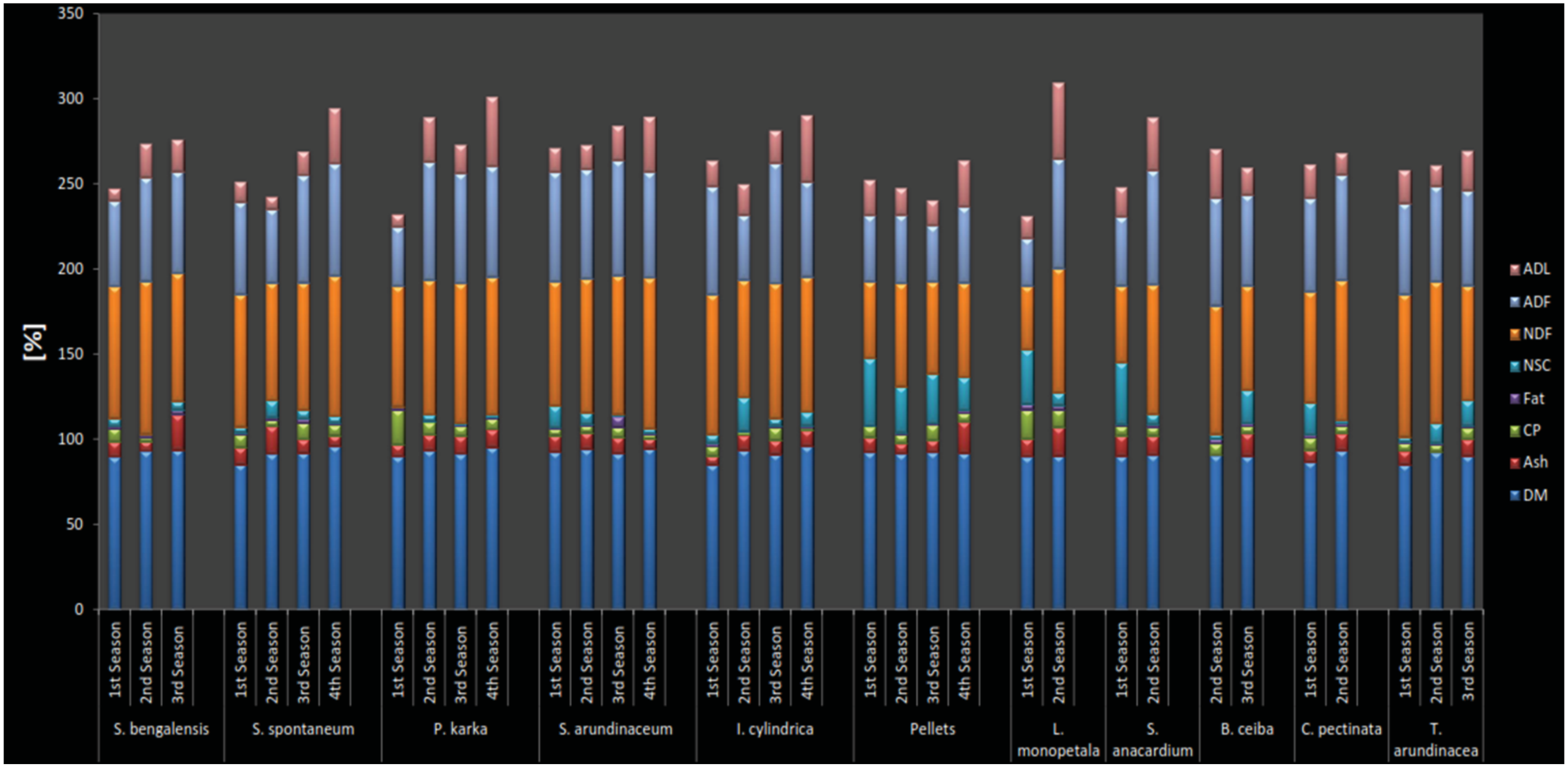



Figure 3. 2: Seasonal nutrient content percentages of top ten most important key food items.

NDF content in food was highest in the monsoon season ($4^{th}$ season) (mean = 77.5, SD = 12.7), and lowest in the dry season (mean = 66.2, SD = 16.6) (Fig 3.2). There was, however, no significant seasonal difference in the NDF content of food ($F_{3, 31}$ = 0.98, *p* = 0.411). Among species, the highest NDF content was found in dhaddi (*Saccharum bengalensis*) in winter (2nd season) with 89.9% (Fig 3.2), followed by barua (*Saccharum arundinaceum*) during the monsoon season with 88.6%. The lowest NDF was found in kutmiro (*Litsea monopetatla*) in the dry season with 37.2%, followed by debre lahara (*Spatholobus parviflorus*) with 41.9%.

### 3.4.3 Seasonal differences in nutrient intake

I found a significant correlation (Spearman's rho = 0.79, *p* = <0.01) between availability of provisioned foods and the intake of these foods within the provisioning environment. However, there was no correlation between availability and intake in the free-ranging environment (Spearman's rho = 0.42, *p* = 0.165).

There was significant seasonal variation in dry matter intake (DMI) ($F_{3, 28}$ = 6.38, *p* = 0.002), with higher DMI intakes as a percent of body weight being observed in the dry season compared with other seasons (*p* = 0.008). There was a negative correlation between DMI and NDF in the diet across all seasons (*r* = –0.504, *p* = 0.003).

Dietary CP varied significantly across seasons ($F_{3, 502}$ = 12.55, *p* = ≤ 0.01). In the dry season, average dietary CP energy content was 13% (±0.57 SE), in winter 12% (± 0.37 SE), pre-monsoon 11% (±0.56 SE) and in the monsoon season 15% (±0.62 SE). The consumption of NDF energy varied widely across seasons ($F_{3, 502}$ = 6.13, $p = \leq 0.01$), being lowest during the dry season and highest during winter (see Fig 3.4A–D).

### 3.4.4 Diet digestibility

Using lignin as an internal marker, the overall DM digestibility of foods consumed by elephants was not found to vary by season ($F_3$, 28 = 0 .65 $p$ = 0.584), age or sex ($p$ = 0.8). However, the protein digestibility varied significantly with season ($F_3$, 28 = 10.02, $p$ = <0.001). Overall, diets were less digestible in dry months with more browse, with NDF and ADF digestibility of 22% and 5%, while highest digestibility was seen in the pre-monsoon season where digestibility of NDF and ADF were 38% and 36% respectively. Table 3.3 compares the comparative digestibilities observed in this study with findings from captive elephants in India, Europe and New Zealand. In my study, the overall average CP, NDF and ADF digestibilities were 59.8%, 29.9% and 19.1% respectively, which are relatively less than other reports of diet digestibilities in elephants. Also, the fat digestibilities observed in my study were comparatively higher than for most of the captive elephants studied except for the Indian elephants (Nair and Ananthasubramaniam 1979). I analysed digestibility based on a wide range of food plants, while other researchers analysed digestibility based on a single plant species. Despite not being directly comparable, these comparisons can still give some insight into variation in digestibility and the relationship with the type of food provisioned.

Table 3.3: Comparative digestibility of different nutrients in Asian elephants' diets

Data source Clauss et al. 2003 and Auckland Zoo, Koirala 2015 (Chapter 2).

| Study | Diet type | No. of elephants | BW (kg) | DMI % Body weight | Apparent digestibility (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | DM | CP | EE | NDF | ADF |
| Nair and Ananthasubramaniam (1979) | Palm leaves | 4 | 1555 | 4.43 | 72.8 | 81.2 | 69.2 | | |
| Reichard et al. (1982) | Oat hay | 2 | | | 35.0 | 24.0 | 22.5 | 20.0 | 10.5 |
| Foose (1982) | Grass hay | 2 | 2665 | 1.2 | | 86.5 | | 44.9 | 39.3 |
| Foose (1982) | Alfalfa hay | 1 | 3402 | 1.1 | | 95.5 | | 46.1 | 45.2 |
| Hackenberger (1987) | Grass hay | 37 | 2502 | 1.3 | 43.1 | 59.0 | 29.9 | 42.6 | 41.2 |
| Clauss (2003) | Grass hay | 5 | 2472 | 1.5 | 33.7 | 51.9 | 46.7 | | 23.3 |
| Auckland Zoo | Zoo diet | 1 | 3300 | 2.6 | 67.1 | 69.2 | 41.7 | 31.0 | 29.7 |
| This study | Grass, browse and pellets | 16 | 2903 | 1.7 | | 59.8 | 51.5 | 29.9 | 19.1 |

### 3.4.5 Energy intake and macronutrient balance

The estimated daily intakes of DE (expressed as MJ/kg$^{0.75}$) are summarised by age-sex class and compared with Thailand domestic elephants and with the recommended energy intake from Pagan and Hintz (1986) in Appendices 3 and 4(A–D). In the present study, the relative DE calculations (MJ per kg per day) were based on apparent DE and varied between 0.4 MJ and 1.7 MJ per kg$^{0.75}$ per day. In the dry season (1st season), data revealed that all elephants in the study, except elephant 7, had DE intake higher than the recommendations (Pagan and Hintz 1986) (Appendix 4A). Likewise, in winter (2nd season) and the pre-monsoon season (3rd season), all elephants had higher DE intakes than the recommendations (Appendix 4BC). In the monsoon season (4th season), all elephants except elephant numbers 4 and 12 had higher DE intake than the recommendations (Appendix 4D). The average daily gross energy intake (GEI) ranged between 740 and 1494 MJ per day (Appendix 4A–D), and the apparent DE ranged between 208 and 609 MJ per day.

A positive correlation was found between body weight (BW) and GEI ($r$ = 0.30, $p$ = 0.09). The DE intake was found to vary with age class ($F_{2, 15}$ = 4.6, $p$ = 0.02): the age class between 8 and 16 years was found to be ingesting most energy (0.95 MJ (DE) per $kg^{0.75}$ per day), and the age class between 43 and 69 years had the lowest energy intake (0.68 MJ (DE) per $kg^{0.75}$ per day).

### 3.4.6 Geometric analysis

Geometric modelling suggested that overall dietary energy from CP varied less than energy derived from NDF and non-protein macronutrients (Fig 3.3), both in terms of absolute variation (standard error) and variation standardised for the mean (coefficient of variation). Averaged across all feeding days, % CP contribution to energy of the multi-season diet was 12.4% CP (±0.94 SE, CV=0.14), 27.5% NSC + CF (± 5.9 SE, CV=0.42) and 60% NDF (± 6.2 SE, CV=0.21).

Variance in the ratio of % fibre: non-protein energy was in part due to seasonal variation (Fig 3.3). The most pronounced seasonal difference was apparent during the dry season, where the diet of elephants tended to be higher in NSC + CF energy and lower in NDF energy than during other seasons.

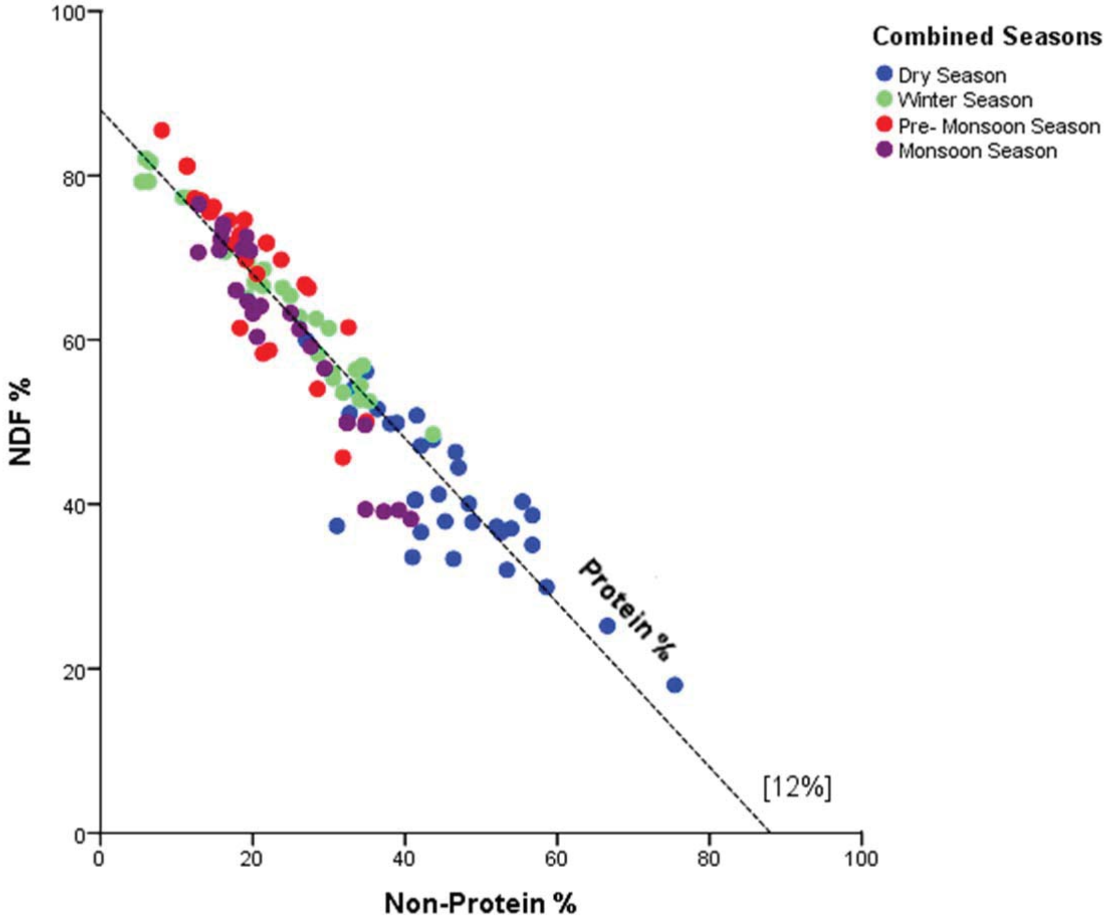
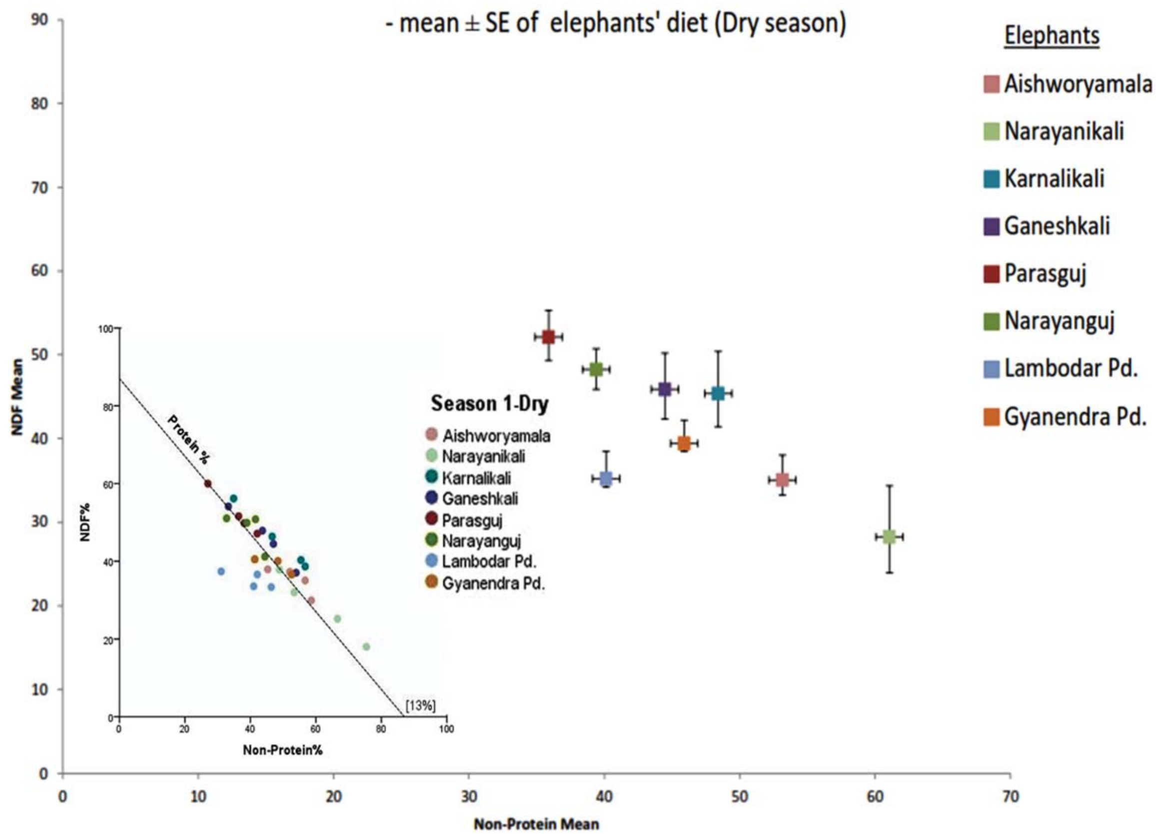


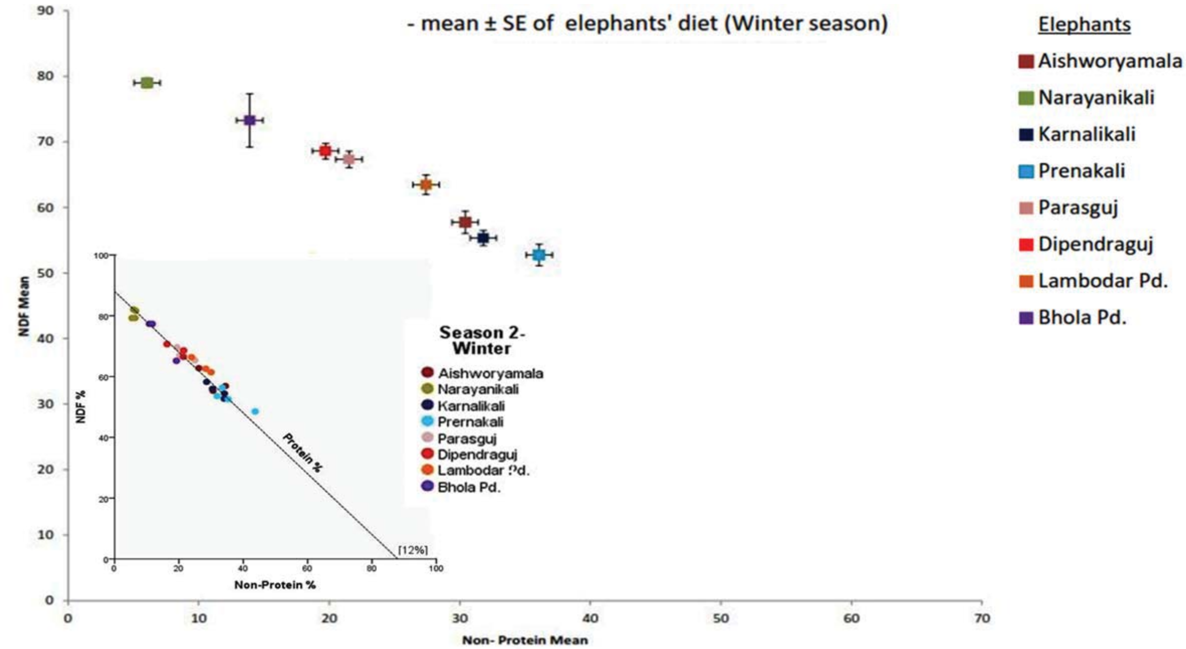

Figure 3. 3: Right-angled mixture triangle (RMT) showing the seasonal balance of crude protein (CP), Neutral detergent fibre (NDF) and non-protein macronutrient energy (CF + NSC). Protein is shown on the implicit *z*-axis, with the dashed reference line indicating 12% crude protein.

To examine the variance in macronutrient balance within seasons, I examined plots of individual intakes for each season, which suggested that there was more between-individual than within-individual variance (Fig 3.4). In the dry season, three elephants (Narayanikali, Ganeshkali and Karnalikali) had wider ranges of intakes, while others showed more consistent intake ratios. There is no significant difference in both non-protein and NDF intake between individuals ($t_{14}$ =1.20, $p$ = 0.25) (Fig 3.4A). In the other seasons, there were significant differences in the intake of non-protein and NDF intake between individuals (winter: $t_{14} = -0.85$, $p = <0.001$; pre-monsoon: $t_{14} = -11.1$, $p = <0.001$; monsoon: $t_{14} = -7.3$, $p = <0.001$) (Fig 3.4B–D).

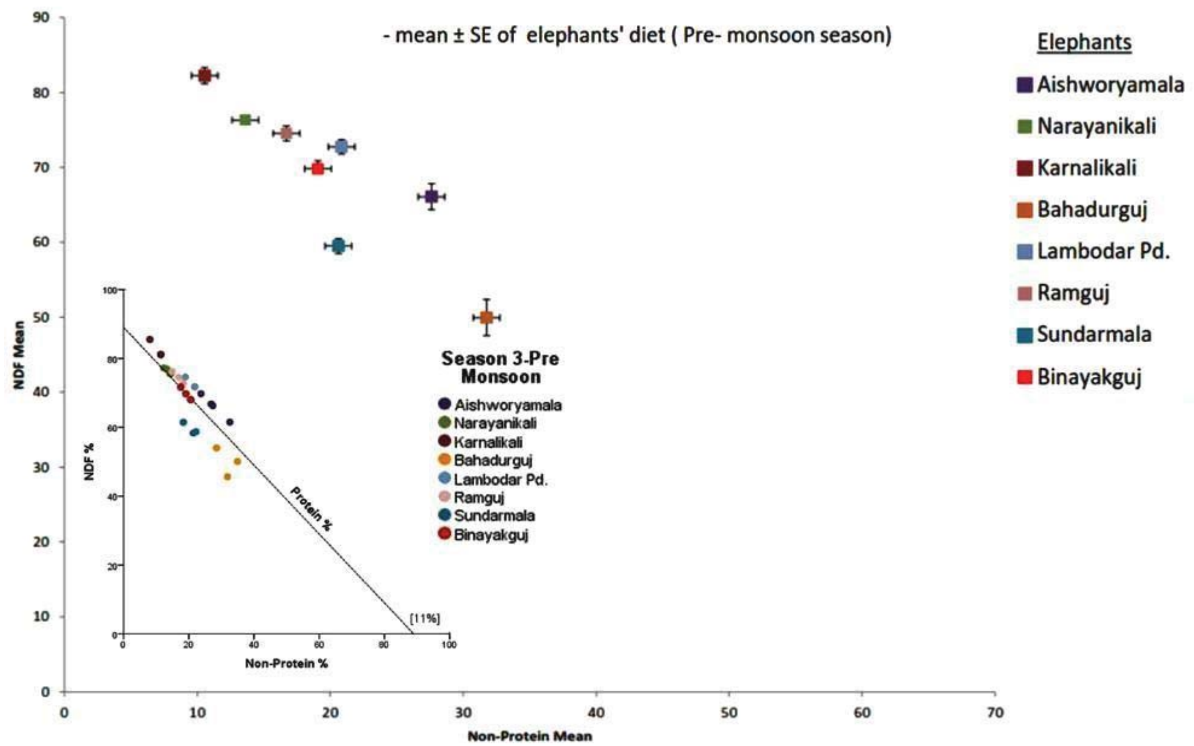
The dietary %protein energy varied across seasons from 11 to 15% (Fig 3.4A–D). The dietary % protein energy for elephant, Ganeshkali in the monsoon season was high with the lowest intake of NDF energy.



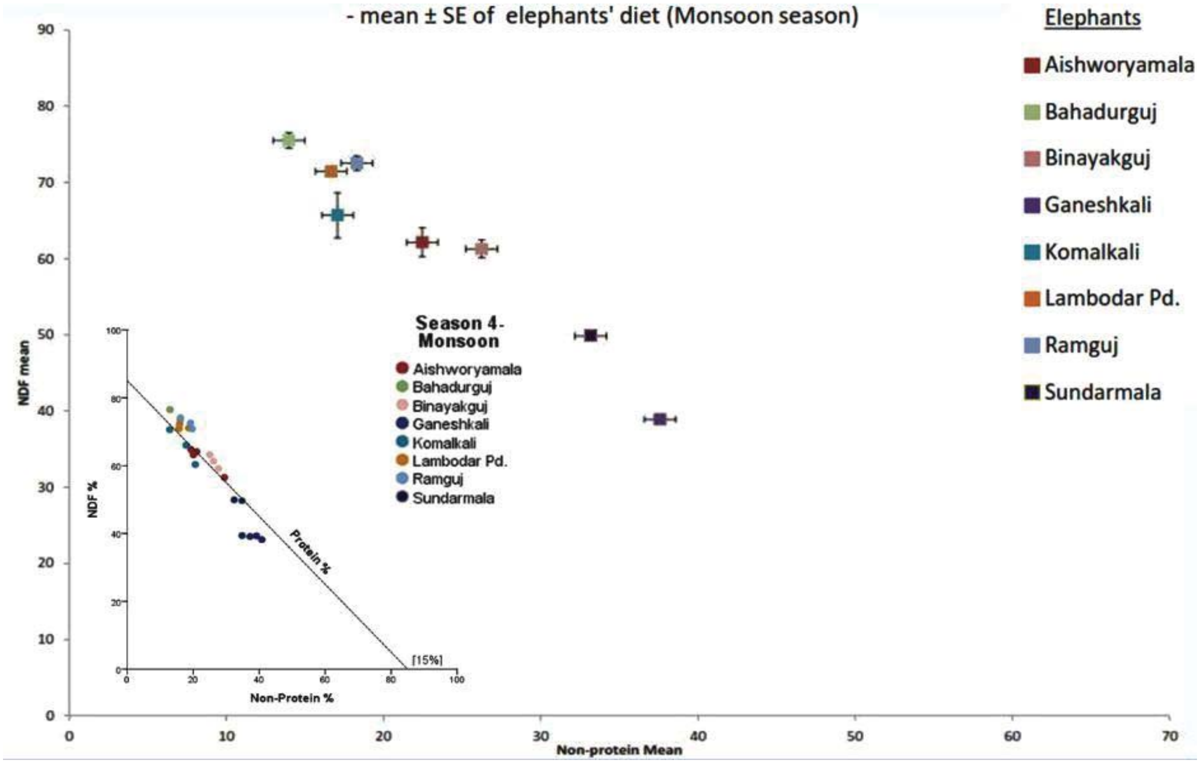

A


- mean ± SE of elephants' diet (Winter season)
Elephants
Aishworyamala
Narayanikali
Karnalikali
Prenakali
Parasguj
Dipendraguj
Lambodar Pd.
Bhola Pd.
NDF Mean
Non- Protein Mean
Season 2-Winter
Aishworyamala
Narayanikali
Karnalikali
Prernakali
Parasguj
Dipendraguj
Lambodar Pd.
Bhola Pd.
NDF %
Non-Protein %
Protein %
[12%]

B


- mean ± SE of elephants' diet ( Pre- monsoon season)
Elephants
Aishworyamala
Narayanikali
Karnalikali
Bahadurguj
Lambodar Pd.
Ramguj
Sundarmala
Binayakguj
NDF Mean
Non-Protein Mean
Season 3-Pre Monsoon
Aishworyamala
Narayanikali
Karnalikali
Bahadurguj
Lambodar Pd.
Ramguj
Sundarmala
Binayakguj
NDF %
Non-Protein %
Protein %
[11%]

C




D

Figure 3. 4 A-D: Right-angled mixture triangle (RMT) showing the seasonal variation and intake balance of macronutrient and NDF in individual elephants.

There was greater variance in NDF ($F_{2.57}$ = 8.8, $p$ = <0.01) and non-protein energy ($F_{2.57}$ =14.2, $p$ = <0.01) in lactating, non-lactating and pregnant females, while protein was less variable ($F_{2.57}$ = 4.198, $p$ = 0.20). Lactating females showed higher demand of energy from non-protein (NSC+CF) and NDF (Fig 3.5).

In pregnant elephants, NDF variation was lower than non-protein, with a consistent intake of protein energy.

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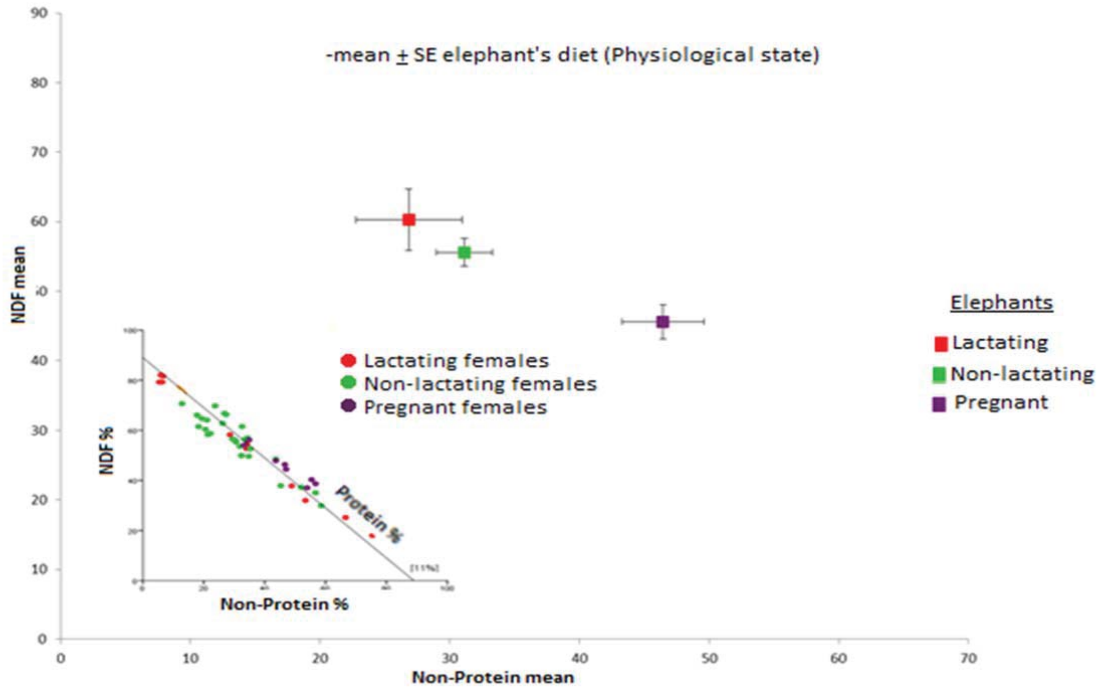


Figure 3.5: Nutrient balance of different reproductive status of female elephants.

Overall, females had an average of 11% of energy ingested as protein, while males had a higher intake at 14% ($t_{111}$ = –2.32, $p$ = 0.02) (Fig 3.6).

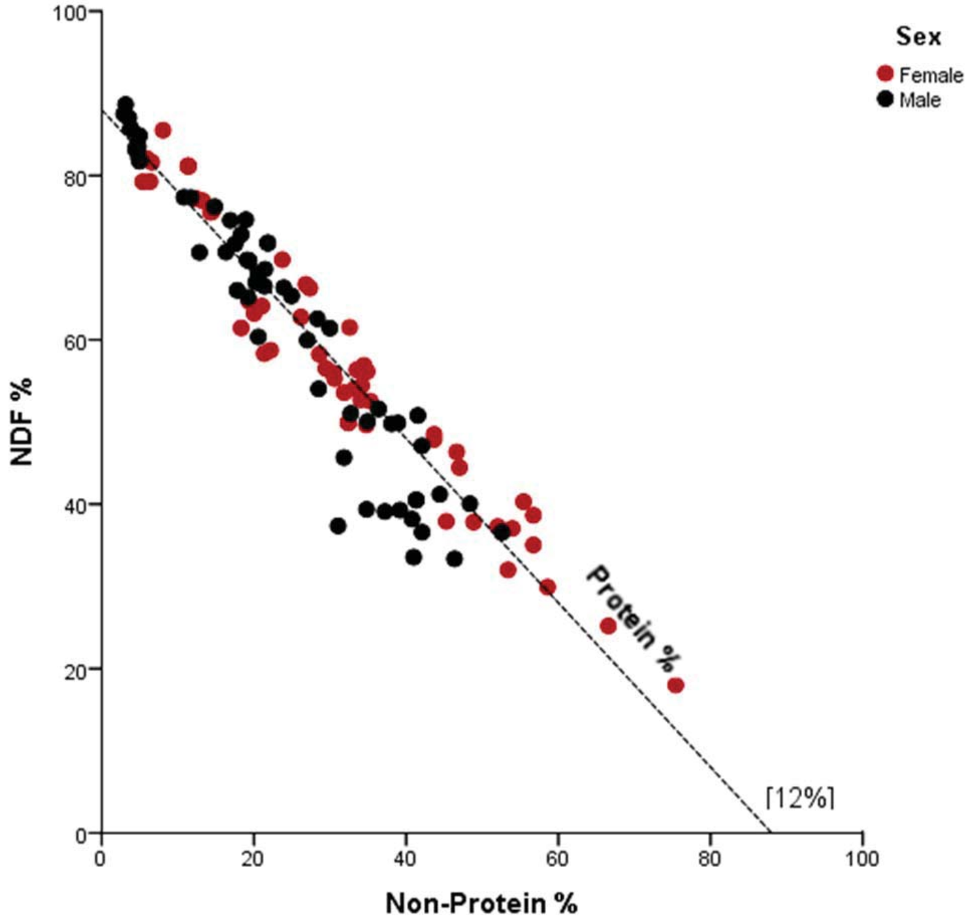


Figure 3. 6: Right-angled mixture triangle (RMT) showing the comparative percentage of male and female daily energy intake from crude protein (CP), NDF and non-protein macronutrients (NSC + CF).

Tuberculosis-positive individuals had a lower proportion of energy intake contributed by CP than did elephants that did not have TB ($t_{78} = -1.95$, $p = 0.05$) (Fig 3.7). Age class 1 (aged between 8 and 16 years) was found to consume more protein, NSC and NDF energy than other age groups (Fig 3.8).

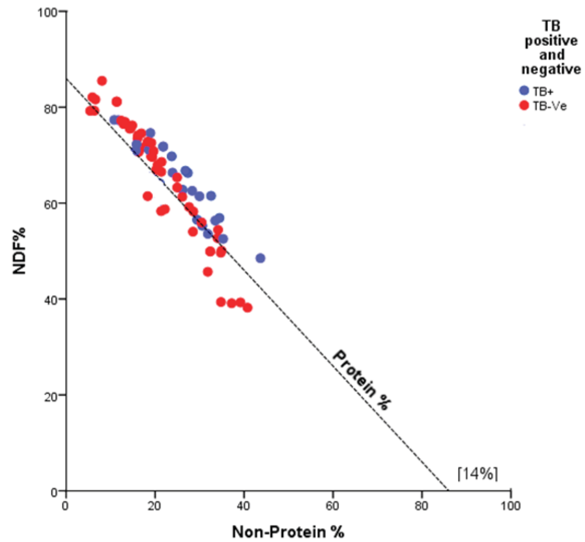


Figure 3.7: Right-angled mixture triangle (RMT) showing the comparative percentage of tuberculosis-positive and tuberculosis-negative individuals' daily energy intake from crude protein (CP), NDF and non-protein macronutrients (NSC + CF).

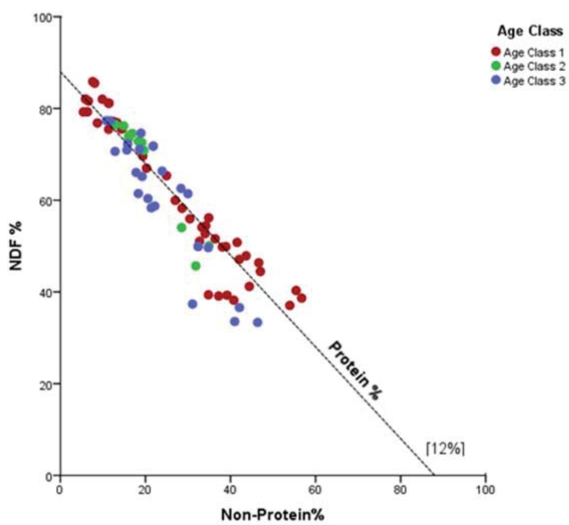


Figure 3. 8: Right-angled mixture triangle (RMT) comparing across the different age groups the percentage of daily energy intake from crude protein (CP), NDF and non-protein macronutrients (NSC + CF**).**

## 3.5 Discussion

### 3.5.1 Adequacy diet

#### 3.5.5.1 Seasonal nutrient content and intake

This study indicates there was no significant seasonal difference in nutritional content in any of the key food plants eaten by elephants. In a similar study, seasonal variation was found in selected plants eaten by wild elephants in northern India (Datta 2009). However, in that study, the percent nitrogen content did not vary (Datta 2009). The percent NDF content in elephant food in Assam India did not vary significantly by season, while there was variation in NDF in food plants among some forested and non-forested sites (Das et al. 2014). The differences between these and my study could be attributed to the high variability in nutrient dynamics, but there are relatively few studies across different region and years (Heady et al. 1991) that would help to explain the changing patterns of the nutrient content of foods (Eviner and Firestone 2007).

My results suggest that despite having an overall low content of CP in their food, the proportion of digestible protein in the diet in winter, pre-monsoon and monsoon feeding seasons was relatively higher than in the dry season. This higher protein dry matter intake is likely to be due to increased protein digestibility, which ranges from 29 to 80%, together with relatively more food intake with higher DDM (digestible dry matter).

Although the precise dietary requirements for particular nutrients for elephants are not well-known, because of their similarity to horses it has been proposed that an estimated CP intake for captive elephants is 8–10% of dry weight at maintenance and 12–14% and higher for the growth of juveniles and in other physiological states, such as late pregnancy and lactation (Ullrey et al. 1997).

#### 3.5.5.2 Dry matter intake (DMI)

All elephants were found to have DMI between 1.6 and 1.9% (average 1.8%) of body weight, which was within the recommended range. The broad recommendation for the DMI of an elephant is based mostly on extrapolation from the diet of a horse (Oftedal et al. 1996) and also from studies undertaken in European zoo facilities. Results from these studies indicate that the daily dry matter requirements for Asian elephants are between 1.5 and 1.9% of body weight (Ullrey et al. 1997). The variation in the DMI in my study is due to different physiological states, such as pregnancy and lactation in females, sex, age, health status (TB present/absent) and habitat. On average, in the dry season elephants had a relatively greater DMI per unit BW and a lower digestible dry matter %, with the utilisation of less protein per day due to lower protein digestibility. This result aligns with other findings of a negative relationship between dry matter intake (DMI) and dry matter digestibility across and within forages (Edouard et al. 2008). Seasonal changes in elephant feeding habits have also been reported in studies carried out in other countries (Field and Ross 1976; Sukumar 1990, 1993).

#### 3.5.5.3 Fibre content and digestibility

The difference in individual intake of non-protein (NSC + CF) and NDF in the dry season was higher than in other seasons. In the dry season, elephants used a wider range of habitat and browse and grass species. The dry season showed a relatively higher protein content and lower NDF content in food, and a higher DMI/BW than the other seasons. However, the higher proportion of consumption of woody browse with higher contents of lower digestibility of NDF during this season led to a lower consumption of digestible energy. In winter, pre-monsoon and monsoon seasons, the number of species consumed were lower, and the elephants foraged in mostly grassland habitat. The crude protein content was low, with higher NDF and lower DMI/BW than in the dry season. Elephants are thought to be adapted to eat high-fibre foods. As hindgut fermenters, it has been suggested that their response to a decrease in food quality is to increase consumption so as to maintain rates of energy and nutrient absorption (Edouard et al. 2008). Some studies have shown that digestibility falls off with forage quality (less protein and higher fibre), however, in terms of intake, these studies have found no significant relationship with forage quality (Duncan 1992; Edouard et al. 2008). In general, therefore, it seems that elephants can compensate for decreasing quality of food by eating more (Janis 1976) so as to obtain the levels of digestible energy and protein required for maintenance. The increase in consumption in winter, pre-monsoon and monsoon seasons could be related to the quality of forages, especially the % NDF dry matter content in food. There is an inverse relationship between NDF and dry matter intake; however, the increasing neutral detergent fibre digestibility (NDFD) could lead to higher consumption of dry matter. The increased NDFD is likely to be due to lower lignification in grass species during the sampling period. The lignin: ADF ratio has been used to predict fibre digestibility (Goering and Van Soest 1970). Despite having less crude protein in the food with relatively better NDFD, all individuals except two in winter, pre-monsoon and monsoon seasons met their metabolised digestible energy quantity. The higher intake of dry matter leads to the conclusion that if nutritionally balanced foods are not available in sufficient quantities to meet the daily requirements, individuals can reach their nutritional target by eating more nutritionally imbalanced complementary foods. The elephants in this study showed this trend, obtaining lower density energy sources from grasses, with 65% of energy from NDF, 14% from protein, 5% from fat and 16% from NSC.

#### 3.5.5.4 Seasonal variation in macronutrient and fibre intake

Geometric analysis of the diet across the four seasons suggests that there was a seasonal, physiological and age class influence on macronutrient intake patterns in these elephants. The model suggests that there is a seasonal difference in their intake of NDF, NP (NSC+CF) and protein. The pattern of macronutrient intake in winter, pre-monsoon and monsoon seasons suggests that there is more inter-individual heterogeneity in macronutrient intake than intra-individual heterogeneity. This may be an example of variance among individual intake targets (Senior et al. 2015). This variation among individuals and within the group of elephants showed different responses to a decrease or increase in forage quality: most of the elephants compensated for the low nutritional value of the forage by increasing intake. The influence of forage quality (digestibility, fibre content, CP) on the intake of elephants has not been well studied. The digestibility of forage did not decline consistently with forage quality (fibre and CP content). The results of my intake data analysis of the elephants in winter, pre-monsoon and monsoon seasons were consistent with those found for horses fed grass hay (Edouard et al. 2008) as there was more NDF and higher intakes of grasses in these seasons. Individual elephants can increase their intake as forage quality declines, but not all individuals respond in the same way on all forages. Thus, less inter-individual than intra-individual variation in food intake in the dry season could likely be due to the difference in individual physiological characteristics of elephants along with different and wider selection of plant foods. In the other seasons, the inter-individual variation in intake was greater than intra-individual variation as the difference in physiological variation was less with individual elephants and there were fewer plant species available for selection.

Most elephants maintained relatively constant proportional protein energy in the diet, but different individuals achieved this using different ratios of NPE/NDF energy. This protein regulation is similar to that reported for a captive elephant in Auckland Zoo, which kept protein proportion constant but used more NDF when in the forest compared with when offered provisioned food (Chapter 2). This pattern of variation suggests that elephants in winter, pre-monsoon and monsoon seasons utilised a greater percentage of NDF energy with less energy from non-protein to maintain a constant level of protein in the diet. The less variation of nutrient intake by the same individual with a tighter clustering in the protein diagonal axis suggests that elephants maintain the nutrient intake so as to have little variance in the ratio of protein:non-protein energy. To achieve an optimal protein percentage and to keep this constant when protein becomes deficient in the repeatedly grazed feeding grounds in the winter, pre-monsoon and monsoon seasons, they increased the proportional intake of energy from NDF. Positive selection of protein by ungulates (Field 1976) and African and Asian elephants has been reported by other researchers (McCullagh 1969; Sukumar 1990). The geometric models have indicated that the energy contribution by NDF in the elephant diet was crucial for regulating protein balance. The results of this regulation in macronutrient balance provide strong evidence in support of my finding that overall there was optimal digestible or metabolised energy for the majority of the elephants in my study (Appendix 4).

In comparison, the geometric analysis of the diet of the elephants in the dry season suggests that food was more diverse, and the inter individual intake variation was less than during the other seasons. The non-protein and protein energy percentages were high, while NDF was low. All elephants except one maintained the recommended metabolised energy (Appendix 4).

Although the majority of the elephants maintained their metabolised energy, however, relatively, the tuberculosis positive individual consumed less protein energy than TB negative individuals. The data showed tuberculosis positive individuals consumed almost equal amount of dry matter but less protein energy than healthy ones. Some individuals showed less apparent digestibility and few others with less protein digestibility. It is likely that digestive physiology is deterring them to consume more protein. This might contribute to instances where protein calorie deficient results in rapidly fatal tuberculosis infection (Gupta et al. 2009).

## 3.6 Conclusion

This study showed that all the elephants met the recommended DMI and variable digestible energy. However, DMI is less informative than is digestible energy intake (Romani et al. 2014). Increased NDF digestibility will result in higher energy values, and perhaps more importantly, increased forage intakes. This study revealed that in all seasons the majority of elephants acquired recommended energy intakes and reached a preferred level of nutrient composition, with tighter regulation of protein and varying balance of non-protein and NDF energy. An unexpected result was that in the winter, pre-monsoon and monsoon seasons, the elephants met recommended energy intake through higher energy contribution by NDF (through better NDFD), with a constant ratio of protein, despite having lower protein content in their food. This is likely to be because the elephants used the rule of compromise by overeating NDF to compensate for the lower energy from protein. However, likely physiological basis for the maintenance of a constant level of a nutrient is not understood for mammals. Feeding a nutritionally imbalanced food with a much higher percentage of energy from NDF may not show an immediate impact. However, the long-term imbalance of protein, NDF and non-protein energy may have associated costs and may lead to many health-related problems, which needs to be studied further. Thus, this study recommends rotational feeding in different habitats so that elephants can access a full variety of complementary balanced food rather than repeatedly grazing in an area with fewer species.

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# Chapter 4

# Feeding preferences of wild Asian elephants (*Elephas maximus*) in Nepal.

***Thysanolaena maxima*, a perennial grass preferred by elephants in central Nepal.**

## 4.1 Abstract

**Background:** Nepal provides habitat for approximately 100–125 wild Asian elephants (*Elephas maximus*). Although a small proportion of the world population of this species, this group is important for maintaining the genetic diversity of elephants and conservation of biodiversity in this region. Knowledge of foraging patterns of these animals, which is important for understanding their habitat requirements and for assessing their habitat condition, is lacking for the main areas populated by elephants in Nepal. This study investigates the feeding preferences of the Asian elephant in Parsa Wildlife Reserve (PWR) and Chitwan National Park (CNP), Nepal.

**Result:** Fifty-seven species of plants in 28 families were found to be eaten by Asian elephants, including 13 species of grasses, five shrubs, two climbers, one herb and 36 species of trees. The species that contributed the greatest proportion of the elephant's diet were *Spatholobus parviflorus* (20.2%), *Saccharum spontaneum* (7.1%), *Shorea robusta* (6.3), *Mallotus philippensis* (5.7%), *Garuga pinnata* (4.3%), *Saccharum bengalensis* (4.2%), *Cymbopogon* spp (3.7%), *Litsea monopetala* (3.6%) and *Phoenix humilis* (2.9%). The preference index (PI) showed that browsed species were preferred during the dry season, while browsed species and grasses were both important food sources during the rainy season. Elephants targeted leaves and twigs more than other parts of plants ($P < 0.05$).

**Conclusion:** This study presents useful information on foraging patterns and baseline data for elephant habitat management in the PWR and CNP in the south-central region of Nepal.

## 4.2 Background

Elephants are among the internationally endangered large mammals (Choudhury et al. 2008). The habitat of Asian elephants (*Elephas maximus)* has been decreasing throughout their range, due primarily to habitat destruction and fragmentation resulting from human land use practices (Sukumar 1990; Owen Smith 1992). Even though elephant populations have decreased, in general, the local density of elephants has increased due to habitat loss (Croze et al. 1981). This has caused resource competition among elephants (Joshi and Singh 2007), and increased human-elephant conflict Sukumar (1994). Asian elephants are generalised herbivores utilising a variety of plant species (Sukumar 1990; Dierenfeld 2006). Large herbivores such as elephants require extensive home ranges to satisfy their high food demand (Sukumar 1989). Reduction in food availability due to loss of habitat has created challenges for elephant conservation in the many regions in Asia.

Although the dietary requirements of Asian elephants have been studied, the majority of these studies (Sukumar 1990; Joshi and Singh 2007; Chen et al. 2006; Baskaran et al. 2010) have dealt with the documentation of food plant species, the rate of consumption and seasonal comparative diet overlap between sympatric elephants and rhinos (Steinheim et al. 2005; Pradhan et al. 2008). However, details regarding food choice and seasonal diet composition remain unknown. Such information is important for Asian elephant conservation in terms of habitat management and human-elephant conflict mitigation.

Nepal provides important habitat for Asian elephants. Historically habitat in the Terai range was continuous. Currently, elephants are found only in four regions of the country, eastern, central, western and far-western. In central Nepal, Parsa Wildlife Reserve (PWR) is the main elephant habitat. However, elephants were found to migrate between PWR and Chitwan National Park (CNP) since the middle of the 1990s (Ten Velde 1997). The migration of elephants between these sites was thought to be primarily due to the reduction of water availability in the Bara Forest near PWR resulting in reduced food availability and aggravated competition with livestock (Ten Velde 1997). Currently, all the four isolated population of elephants in Nepal are in the lowland Terai region. These widespread and fragmentary distributed elephants strongly prefer floodplain communities, and there is a significant shift from browse to grass-dominated vegetation between seasons in Bardia National Park (Pradhan 2007; Pradhan et al.2008). However, the diet has not been studied for other elephant populations of the country.

This study aims to investigate the food preferences and seasonal changes in foraging patterns of the Asian elephant in the PWR, CNP and adjoining forests. I predict a climate-related reduction in grass productivity in the Parsa area will correspond with a reduction of grass in the elephant diet during the dry season. Information obtained from this study will aid elephant conservation in respect to the restoration of their habitats, and will thereby contribute towards minimising human-elephant conflict.

## 4.3 Methods

The study was carried out at the Parsa Wildlife Reserve and part of adjoining reserve forest (Bara forest) in the north and Chitwan National Park and part of its buffer Zone forests. Permission for the study was acquired from the Department of National Park and Wildlife Conservation, the government of Nepal. Parsa Wildlife Reserve is the largest wildlife reserve in Nepal (Fig 4.1), consisting of 499 $km^2$ sub-tropical forests in the south-central lowland Terai ecoregion of Nepal. The PWR is located in the Churia hills, the outermost foothills of the Himalayas (Thapa et al. 2014), which are a part of the Bhabar District. The PWR is typically dry with average rainfall between 300 and 450 mm during the summer months (Ten Velde 1997; MOSTE 2013). The typical vegetation of this reserve and the adjoining Bara forest is tropical and subtropical forest types with Sal (*Shorea robusta*) forest about 90% of the vegetation. Chirpine (*Pinus roxburghii*) grows in the Churia hills. Khair (*Acacia catechu*), Sisso (*Dalbergia sisso*) and Silk cotton (*Bombax ceiba*) trees occur along water channel. Sabai grass (*Eulaliopsis binata*) grows well on the southern face of the Churia Hills (Bhuju et al. 2007; Majupuria 1998). Chitwan National Park was established in 1973 as the first national park in Nepal and was listed as a World Heritage Site in 1984. The CNP spans 932 $km^2$ and is situated in the sub-tropical lowlands of the Inner Terai, in the Chitwan district of south-central Nepal (Fig 4.1). Elevation ranges from approximately 100 m in lowland river valleys to 815 m on Churia Hill ridgetops. In the north-west of this protected area, the Narayani and Rapti rivers separate the park from human settlements (Aryal et al. 2012). The buffer zone has mostly agriculture fields and human settlements along with community forests. The typical vegetation of CNP and its buffer zone forests is Himalayan subtropical broadleaf forests with primarily Sal (*Shorea robusta*) trees covering about 70% of the national park area. On northern slopes, Sal associated with smaller flowering tree and shrub species such as *Terminalia bellirica*, *Dalbergia sissoo*, *Dillenia indica*, *Garuga pinnata* and climbers such as *Bauhinia vahlii* and *Spatholobus parviflorus* (Bhuju et al. 2007; Majupuria 1998; Direnstein and Wemmer 1988).

Both the PWR and CNP are prime habitats for wild Asian elephants, and both parks are adjacent to Valmiki tiger reserve in India (Fig 4.1). These three trans-boundary, contiguous protected areas cover a 3549 $km^2$ mixed-habitat zone containing large tracts of grasslands and humid deciduous forests, which provide suitable habitat for a large number of megaherbivores and big cats such as Asian elephants, endangered tigers (*Panthera tigris*) and greater one-horned rhinos (*Rhinoceros unicornis*).

### 4.3.1 Elephant feeding data collection

Opportunistic direct feeding observations and the observation of elephant feeding sign on food trails (elephant feeding routes) were used in the present study to determine diet selection of elephants residing in different areas and travelling on different migration routes (Chen et al.2006; Biru and Bekele 2012). The feeding routes observed to be taken by elephants were followed by field researchers, and all plant species showing signs of being eaten by elephants were recorded. Evidence of feeding sign included elephant footprints, fresh dung piles nearby to browsed foliage, and the identifying characteristics of plant damage caused by elephant browse, such as debarkation, branch breaking and uprooting. The following data were recorded to determine the feeding preferences of Asian elephants: (1) plant species browsed, (2) parts of the plant eaten (leaves, branches and/or bark), (3) habitat type and (4) global positioning system (GPS) coordinates of sample sites (Fig 4.1). The relative frequency (percentage) of feeding sign was calculated to yield a feeding sign score. Feeding sign was ranked according to the intensity of browsing, the proportion of bark, stem and foliage removed and/or the area of grass eaten.

### 4.3.2 Elephant dietary analysis from dung samples

Samples of elephant dung encountered during a total 24 days of field survey in the wet season (June–September 2012) and the dry season (February-April 2013) were collected. Visual examination of

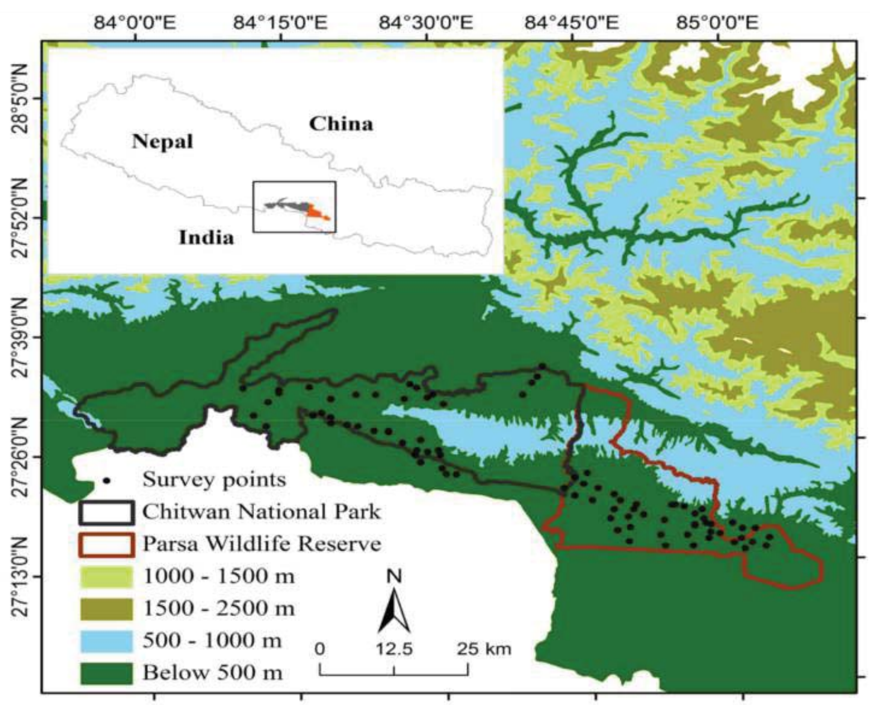


Figure 4. 1: Map of the Parsa Wildlife Reserve (PWR) and Chitwan National Park (CNP) showing locations of plots used for vegetation and feeding sign surveys.

deposited elephant dung piles were performed to identify the presence of macro plant fragments. Micro-plant fragments were identified through micro-histological analysis

(Holechek and Gross 1982; Metcalfe 1990; Aryal et al. 2012). This dual methodology is widely used for estimating the diet composition of herbivores (Shrestha and Wegge 2006). Fragments of probable food species were collected for the preparation of reference slides. The collection was made as per methods used in the previously published literature describing elephant food plants (Steinheim et al. 2005; Pradhan et al. 2008). A total of 20, non-overlapping random fragments were isolated on each dung slide and were compared with a reference slide for epidermal derivatives. Microphotographs were taken using a 100 × 4× lens and an Am Scope MT130 1.3 megapixel USB2.0 microscope eyepiece digital camera.

### 4.3.3 Food availability survey

To assess the food preferences of elephants, I carried out vegetation surveys using the point-centered quarter technique (Bryant et al. 2005) to obtain data on the relative abundance of different plant species. A total of 30 transects of 2 km length each, one each per habitat type, were created for this survey. To compare the availability of food plants within and outside protected areas, 20 of these transects were placed in the protected areas, while the remaining ten transects were located in habitats outside national parks. Each transect was surveyed twice, once in the wet season (August/September) and once in the dry season (March/April). A total of 10 sample point were assigned to each transect at 200 m intervals for the purpose of gathering data on potential forage trees. Also, 10 quadrats measuring 1 m × 1 m each were created near each sample points to collect data on density, frequency and visual estimation of cover % of dietary grass species. At each sample point, a cross was laid on the ground to divide the area into four quarters (Fig4.2). From each quarter, the closest tree from the centre was identified and the following data collected: (1) the species of the tree, (2) the distance from the tree to the centre of the quarter, (3) diameter at breast height (DBH) of the tree.

### 4.3.4 Data analysis

Elephant feeding sign survey was conducted by scoring the different signs according to the intensity of damage. The definition of scores for bark was: 1 ≤ 0.5 $m^2$; 2= 0.5-1$m^2$; 3≥ 1$m^2$; for branch score: 1= up to 5 cm diameter; 2=5-20; 3 ≥ 20; while foliage score: 1 ≤ 10% of foliage eaten; 2 = 10-40% and grass score of 1= up to 1 m diameter; 2= more than 2m; 3 = more than 5 m. Total feeding score was calculated by multiplying the frequency of each plant species showing feeding signs with total feeding sign score of that species. Total feeding score of each species was multiplied by 100 and divided by the total feeding score of all species to calculate an index equivalent to utilisation percent. The importance value index (IVI) of a plant species in each habitat was calculated by adding the relative frequency, density and dominance (basal area) for trees. The relative frequency, density and cover for grass and herbaceous species were used as an index of availability of a species in the study area (Biru and Bekele 2012). The density of browse was calculated using the distance from the tree to the centre of the quarter following Mitchell (2010).

The preference index (PI) was calculated using the following equation (Biru and Bekele 2012; Fritz 1996):

Preference index (PI)

$$\frac{\text{Utilisation percentage}}{\text{Percentage availability in the environment}} \quad (1)$$

A PI score >1 indicates food that was utilised proportionately more than its occurrence in the environment, and a PI score <1 indicates a plant food that was used proportionately less than its presence in the environment. The Chi-square test was used to test for differences in feeding preferences between plant parts, seasons and sites differences in vegetation density; Pearson correlation was used to determine the correlation between forage availability and preference. Simpson's diversity index was used to estimate the vegetation diversity, and the independent sample *t* test was applied to test for seasonal dietary intake differences in monocot and dicot plants. All tests were performed using Excel and IBM SPSS statistical version 22.

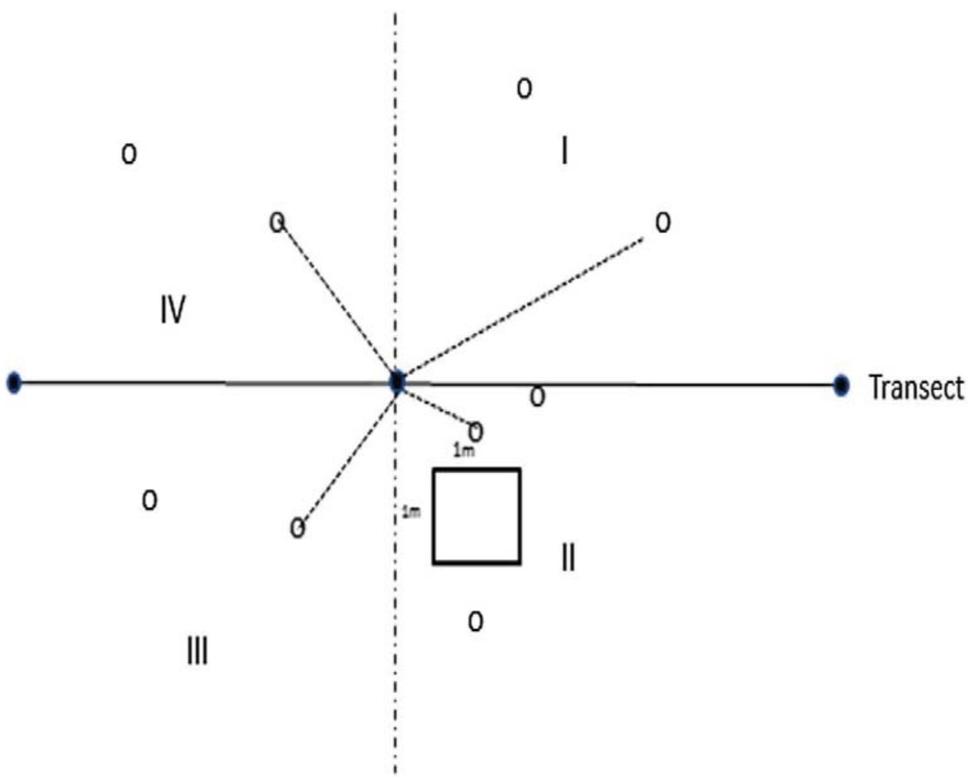


Figure 4. 2: Sample points along a transect with the nearest trees in each quarter indicated by dash lines and grass of 1 m × 1 m near each sample points.

## 4.4 Results

### 4.4.1 Elephant foraging patterns

In total, 57 species of plants (13 grass, five shrubs, two climbers, one herb and 36 tree species) belonging to 28 taxonomic families were eaten by Asian elephants. In the Parsa area, 40 species (10 grass, four shrub, two climber, one herb and 23 tree species) were consumed, and in the Chitwan area 37 species (nine grass, three shrub, one climber and 24 tree species) were utilised; the utilisation pattern suggests that 76% of all identified food species were consumed during the wet season, with only 24% consumed during the dry season (Table Appendix 3). The foliage (leaves and twigs) of both grasses and browsed trees were selected more than the stems, bark, roots and fruits during the wet season in both Parsa and Chitwan ($\chi^2$ = 10.72, df = 6, P < 0.05), whereas debarkation and uprooting were more common in the dry season ($\chi^2$ = 5.24, df = 4, P < 0.05).

### 4.4.2 Dietary analysis from dung samples

Microscopic analysis of 36 dung samples collected during two seasons showed a higher dicot-to-monocot ratio in the dry season compared to the wet season. The average dicot-to-monocot ratio was 1:0.57 in the dry season, whereas the ratio was 1:1.11 in the rainy season. The observations from the feeding sign survey and the micro-histological analysis revealed that dicots were consumed more during the dry season (t = −4.27, df = 10, P = 0.002). There was no significant difference in the presence of dicot and monocot plants in elephant diet during the rainy season (t = 1.59, df = 58, P = 0.117).

### 4.4.3 Regional food availability

There was no difference in the types of plants availability in and outside the two reserves ($P \geq 0.05$). However, species diversity was slightly lower in CNP (Simpson's diversity index, D = 0.097) than in the PWR (D = 0.091). Similarly, in both study sites and seasons, food species densities and frequencies recorded were significantly different.

There was a significant relationship of grass and browse abundance in dry and wet season in Parsa and Chitwan, indicating an association between these factors ($\chi^2 = 8.92$, df = 1, P = 0.002). Higher densities of each browse species were recorded in the PWR (mean density, 25.00/ha) than in the CNP (mean density, 20.4/ ha). Seasonally, the wet season mean density of each browse species in Chitwan and Parsa were 23.2 and 15.4/ ha, respectively. In the dry season, the mean density of browse in Chitwan was 16.3 and in Parsa 20.0/ha. There was significant difference in the frequency of grasses ($\chi2 = 20$, df = 1, $P < 0.001$) in the dry season between the parks with higher frequencies of grass species recorded in the dry season in CNP (mean frequency 3.45/q; mean density, 115.7/$m^2$) than in PWR (mean frequency, 1.57/q; mean density, 22.85/$m^2$). The mean grass frequency and density in the wet season in Chitwan were 4.5/q and 160 individuals/$m^2$, respectively. In Parsa, the mean grass frequency and density were 2.0/q and 131 individuals/$m^2$. There was a negative correlation between the availability of individual plant food species in the habitat and their utilisation by elephants ($r = -0.244$, P = 0.02).

### 4.4.4 Plant species preferences

Elephants showed a positive PI score for 26 out of the 57 utilised plant species (Fig 4.3). Elephant browse that had relatively high PI scores ranged from 1.04 (*Bombax ceiba*) to 9.2 (*Ficus racemosa*). Similarly, vine PI scores ranged from 0.02 (*Bauhinia vahlii*) to 9.32 (*Spatholobus parviflorus*). Shrubs that had relatively high PI scores were *Hypericum uralum* (1.18) and the palm *Phoenix humilis* (2.91). Grass PI scores ranged from 1.28 (*Saccharum bengalensis)* to 5.51 (*Thysanolaena maxima*). Species that were highly abundant, which may have led to lower PI scores, included *Shorea robusta, Dillenia pentagyna*, *Hemarthria compressa*, *Imperata cylindrica* and *Cymbopogon* spp.

Overall, in both sites, elephants showed the strongest preferences for common species such as *Spatholobus parviflorus*, *Saccharum spontaneum*, *Phoenix humilis, Saccharum bengalensis*, *Mallotus philippensis,* and *Phragmites karka*. In addition to these species, elephants in the Chitwan area showed a strong preference for *Cleistocalyx operculata* and *Bridelia retusa*, while Parsa area elephants showed a strong preference for *Litsea monopetala*, *Thysanolaena maxima*, *Sterculia villosa*, *Equisetum debile*, *Bambusa* spp. and *Hypericum uralum*. The availability of these species in the two parks varies. Amongst these 26 most preferred species,

17 species were preferred more by elephants in Parsa, while the remainder (nine species) were preferred relatively more by Chitwan elephants (Fig 4.3).

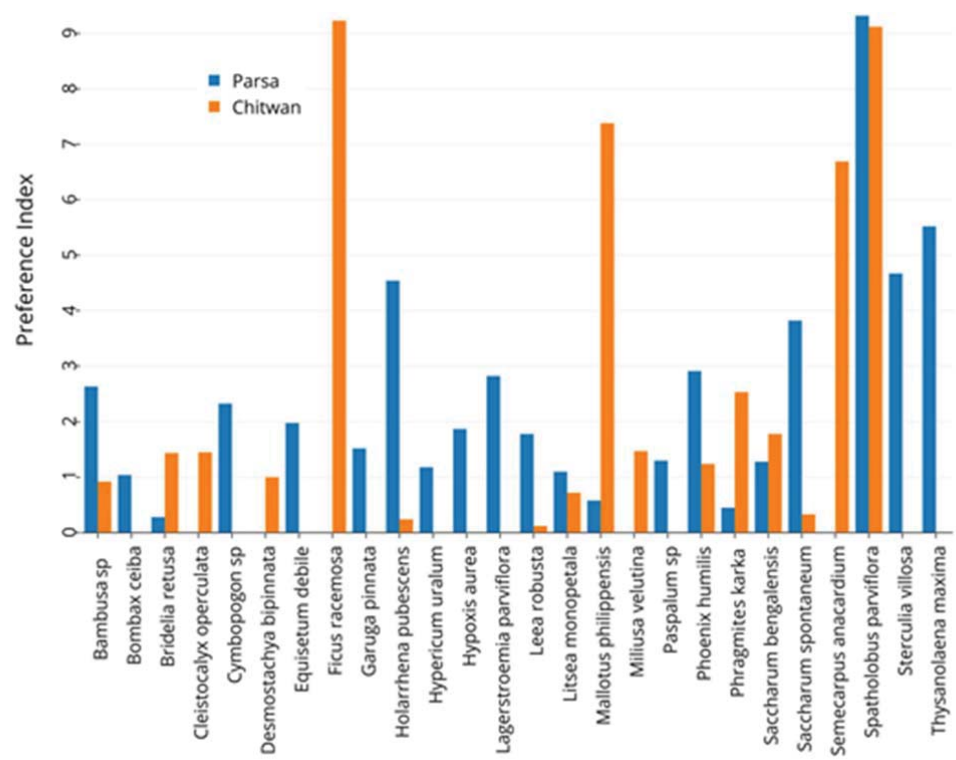


Figure 4. 3: Preference indices (PI) for the most prevalent plant species found in the diet of wild Asian elephants in the Chitwan National Park (CNP) and the Parsa Wildlife reserve (PWR) in both the rainy and dry seasons.

## 4.5 Discussion

Nepal has lost over 80% of its elephant habitat to human settlement (Joshi and Singh 2007). As a result, the resident elephant population, estimated to number between 109 and 142 individuals, is presently restricted to four isolated areas (Pradhan et al. 2011). Available diet and nutritional preference are the two most important factors that drive elephant movements, and that generate conflict with humans, especially when available elephant habitat is shrinking (Rode et al.2006). Reduction in the grass, especially in the dry seasons may result in elephant migration. Human-elephant conflict may arise mainly due to elephant migration (Chapter 5, Koirala et al. 2015). Thus, knowledge of elephant foraging patterns and seasonal food availability is important for mitigation of human-elephant conflict. The management of grass species in the dry season is crucial. In areas like Parsa where there is an environmental constraint in retaining surface water, some potential habitats could be irrigated during the dry season to maintain grass productivity.

The present study recorded 57 plant species within 28 families that were foraged by Asian elephants in the PWR and CNP. In a similar study, Sukumar (1990) reported 112 species of plants in the elephant's diet in southern India, and Chen et al. (2006) reported 106 plant species in the diets of elephants in Shangyong National Natural Reserve in Xishuangbanna, the People's Republic of China were catalogued. The wide range of results between studies may be due to differences in the number and diversity of plant species available. Divergent results may also be partly due to differences in sampling methods; variances in forest condition (disturbed versus undisturbed), composition, and sampling area could also have contributed to divergent results.

Elephants are mixed feeders, and there is seasonal variation in their food selection (Sukumar 1989). In the present study, I found that browse flora and grasses were both eaten by elephants during the wet season, while browse vegetation dominated the dry season diet. Indeed, it seems that the proportion of dicot and monocot species in the diet of elephants varies across different home ranges. In southern India, elephants are known to rely heavily on graminoids (grasses, sedges and rushes) in the wet season and almost exclusively on woody plants during the dry season (Sukumar 2006). Similar patterns of seasonal variation in feeding have been reported by Pradhan et al. (2008) in Bardia National Park in Nepal, and also for African elephant in Uganda (Field and Ross 1976). In Nilgiri Biosphere Reserve, southern India, grasses dominate the elephant diet in all seasons, while browse flora forms an important portion of their diet only during the dry season (Baskaran et al.2010). Likewise, in the foothills of the Himalayas, browse forms the majority of the diet in dry seasons (Lahkar et al. 2007). In similar studies, browse dominated the diet of elephants all year in the rainforests of Malaysia (Oliver 1978), north-eastern India (Sukumar 2003) and the state of Bihar, Central India (Daniel et al.1995).

Results of the present study are comparable to the data obtained in the studies mentioned above in terms of dry-season diet. This browse-dominated dry season diet could be due to the lower average grass biomass available when the dry season causes a reduction in grass cover. It could also be due to the need to meet specific nutrient requirements, for example, the high levels of essential minerals in the hardwood of browse plants (Pradhan et al. 2008). However, my study revealed a slightly different trend in the wet season, when a similar proportion of grass and browse were found in the elephant diets. This could be due to the migration patterns of elephants in Nepal: at the onset of the rainy monsoon season, elephants move from Chitwan to Parsa and towards upper slopes (Ten Velde 1997). As the monsoon develops, elephants migrate from grass-rich lower elevations south to the foothills of the Churia range for occasional resting. In the Churia foothills, elephants have more opportunities to eat foods other than grasses, as these foothills are rich in preferred woody species.

In the present study, I noted a difference in feeding preference for stems, leaves and twigs, bark and other parts of woody plant species. Foliage (leaves and twigs) of both grass and browse flora were eaten more than other parts of plants in the wet season, while bark dominated the dry season diet. The use of bark from various tree species by elephants might relate to macronutrient balancing (Laws et al. 1975), and for gaining moisture and mineral supplements ( Bax and Sheldrick 1963) that would otherwise have been unavailable during the dry season. The current study aligns with the findings of Pradhan et al. (2008) in Bardia National Park, Nepal, where bark consumption dominated the diet of elephants in the dry season. Differences in forest structure, methodologies used and spatial and temporal availability of different groups of plants could explain the variance in PI between the two studies, which are both based on elephant populations in Nepal.

Spatially and temporally, PI can vary between species. In the present study, widely abundant foods such as *Shorea robusta, Mallotus philippensis, Imperata cylindrica* and *Saccharum bengalensis* were avoided by elephants in some seasons and locations, despite their high availability (Appendix 5). Therefore, it is important to examine independently the PI scores of species that are of high availability (or rare) to determine whether the score could be due to the methodological limitations of this index alone (Johnson 1980), or could involve other factors. The PI scores derived from Parsa and

Chitwan could be obtained from multiple rather than single factors (Ishwaran 1983). Factors such as seasonal availability (Mwalyosi 1990), palatability (Caister et al. 2003), nutritive value and plant tissue toxicity are all important influences on the selection of food plants by elephants (Oliver 1978).

Although in both the PWR and the CNP, elephants prefer common plants such as *Spatholobus parviflorus*, in fact, *Saccarum spontaneum, Phoenix humilis, Saccharum bengalensis*, *Mallotus philippensis* and *Phragmites karka*, there are some less common species such as *Acacia catechu*, *Bombax ceiba*, *Bamboosa* spp and *Ficus* spp that are important food for elephants. In the present study, feeding patterns observed in both areas revealed that Parsa elephants ate a more diverse, species-rich diet than did Chitwan's Asian elephant population. The Parsa area has a higher number of elephants, possibly suggesting that nutrition is superior in PWR due to greater dietary diversity. However, further study on habitat preference in all seasons is needed to further investigate this. In addition, the present study has also yielded new data supporting previously unrecorded Asian elephant preferences for *Thysanolaena maxima, Sterculia villosa, Equisetum debile, Semecarpus anacardium* and *Hypericum uralum.*

## 4.6 Conclusion

Asian elephants have a diverse diet including monocot and dicot plants. Their diet in the dry season (February– April) contained a higher proportion of dicots compared to that of the wet season (June–September). There was a negative correlation between availability of plants and preference by elephants, suggesting food selection by elephants is not passively driven by relative availability, but related to specific preferences (Raubenheimer 2011). Further studies are needed to understand this feeding selectivity and its implications for the elephants. The current study provides baseline information about different types of natural food available in the Parsa and Chitwan regions of Nepal, and their relative importance in the diets of elephants in and around the PWR and CNP. This information is important for realising successful outcomes for the conservation of Asian elephants and improved seasonal management for the long-term protection of this endangered species and its shrinking habitat.

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# Theme 2

## The status of human-elephant interactions, their causes and recommendations for management

**To ensure long-term human-elephant coexistence requires mitigation of the negative impacts of elephants on people and vice versa.**

# Chapter 5

## Dispersal and ranging patterns of the Asian elephant (*Elephas maximus*) in relation to their interactions with humans in Nepal

**Elephant movement route in Parsa national park.**

## 5.1 Introduction

The increase of human populations and associated development have reduced and fragmented wildlife habitats, frequently resulting in human-wildlife conflicts. Although several species of Asian megafauna, including tigers (*Panthera tigris*), snow leopard (*Panthera uncia*), rhinoceros (*Rhinoceros unicornis*) and elephants (*Elephas maximus*), are involved in such conflicts (Aryal et al. 2012; 2014a; 2014b; 2015; Bhattarai and Fisher 2014), elephants are of particular concern because of the relatively high frequency and severity of their adverse interactions with humans in South Asia.

The Asian elephant is distributed in many types of habitats throughout its range, which spans across 13 countries (Alfred et al. 2012; WWF 2013). The distribution of elephant is widely influenced by the distribution and seasonality of its natural food plants. In tropical regions during the dry season, the diet is dominated by browse, while grasses comprise the majority of the diet when they are plentiful during the wet season (Sukumar 1989). In recent decades, large-scale conversion of forests to agricultural land and human settlements (Sukumar 2006) has significantly reduced the area of elephant habitat, resulting in reduced accessibility of natural fodder (Alfred et al. 2012) and water (Leuthold 1977), and increasing seasonal forest fires (Joshi and Singh 2008). Such factors are forcing a large percentage of these animals to migrate to areas outside of their historical range and to target alternative foods (Sukumar 1989).

The movement patterns of elephants are flexible and have changed over the generations that they have been migrating. They might, for example, move to a patch for a specific food species or a particular phenological phase, such as leafing, flowering and/or fruiting (Swanepoel 1993; Gadd 2002). Due to their large body size and high water-turnover rate, elephants' movement patterns are crucially influenced by water availability and distribution (Stokke and du Toit 2002; Shannon et al. 2009).

Therefore, elephants are likely to actively select habitats (e.g. riverine) that provide a range of different resources including water, forage and shade (Shannon et al. 2006). Elephant movement patterns have also been associated with specific nutrient needs. For example, elephants have a high demand for sodium due to the copious amounts of water they drink, and consequently, their movement is influenced by the spatial and temporal distribution of plants with high salt content (Rode et al. 2006).

Habitat fragmentation and degradation exerts a strong influence on the home ranges and movement patterns of elephants and is mostly caused by the expansion of agricultural land, the intensive harvesting of timber for fuel and other forest products, and over-grazing. Increasing food production for humans is one reason for the conversion of natural habitat into agricultural land. When forest habitats are altered or cleared, elephants are caused to expand and shift their ranges in search of alternative resources. Habitat fragmentation increases the contact between elephants and agriculture, with the intensity of conflict due to such contact usually being higher in more fragmented habitats. In terms of management, therefore, fragmented forest habitats should be connected to secure habitats that are large enough to sustain the elephant population (Alfred et al. 2012).

In elephants, spatial distribution is primarily determined by the availability of limiting resources (Fernando et al. 2007). This has been validated by the work of Kumar et al. (2010), who showed that the high concentration of locations of two herds in Sholayar River and its tributaries in South India during the dry season reflects the influence of water and food availability on spatial distribution. Sukumar (1989) also emphasised that small home ranges are associated with rich and diverse habitats. Conversely, when in habitat patches that contain reduced and scattered natural food plants, elephants extend their range to satisfy their dietary requirements. This frequently results in crop raiding and consequently the emergence of conflict with human settlements. Such conflict is a major constraint in efforts to conserve these elephants (Samansiri et al. 2007). It has, furthermore, been suggested that cultivated crops are more palatable and contain more proteins and minerals than the wild foods (Chapter 1; Sukumar 1989; Osborn 1998), perhaps explaining why some elephants may continue to raid crops irrespective of the availability of natural forage (Rode et al. 2006).

Here I review the literature on human-elephant interactions in Nepal. I focus, in particular, on the movement patterns of elephants in human and nonhuman landscapes of the Terai region bordering India, with the aim of identifying the probable factors causing these movement changes.

## 5.2 Overview of elephant-human conflict in Nepal

Before large-scale conversion of forest and expansion of agricultural areas, elephants were distributed across most parts of the Terai, a belt of marshy grasslands, savannahs and forests located south of the outer foothills of the Himalayas, and Siwalik Hills of Nepal (Fig 5.1). The Terai region stretches for 900 km along an east-to-west belt at the lower foothills of a mountain range near the Indo–Nepalese border. It covers 17% of

Nepal's total land area and consists of flat plains, wetland and tropical forests (NBS 2002). The Terai is well known for its extensive 'Sal' forest (*Shorea robusta*), which is endemic to the area (Fig 5. 1; NBS 2002).

In Terai, malaria was prevalent until the 1940s, so this area was less suitable for the extensive settlement of people. With the eradication of malaria, in the 1950s there was significant interregional migration and immigration of people to Terai (Aryal et al. 2012). The subsequent rapid growth of the human population accelerated the encroachment on the forest of agriculture and other development works. Consequently, fragmentation of habitat divided the Terai elephants into two resident populations inhabiting a highly fragmented landscape in the central and western regions of Nepal (Ten Velde 1997).

In addition to the Terai populations, the country is also inhabited by an eastern and a far western population of elephants, as detailed further below (Figs 5.1 and 5.2; Pradhan et al. 2011). The current estimate of the total number of wild elephants in Nepal is between 109 and 142 (DNPWC 2008). The area occupied by elephants is spread over 135 village development committees (VDC) in 19 districts (17 in lowland Terai and two in the hills) of Nepal, covering about 10,982 $km^2$ of forest (DNPWC 2008).

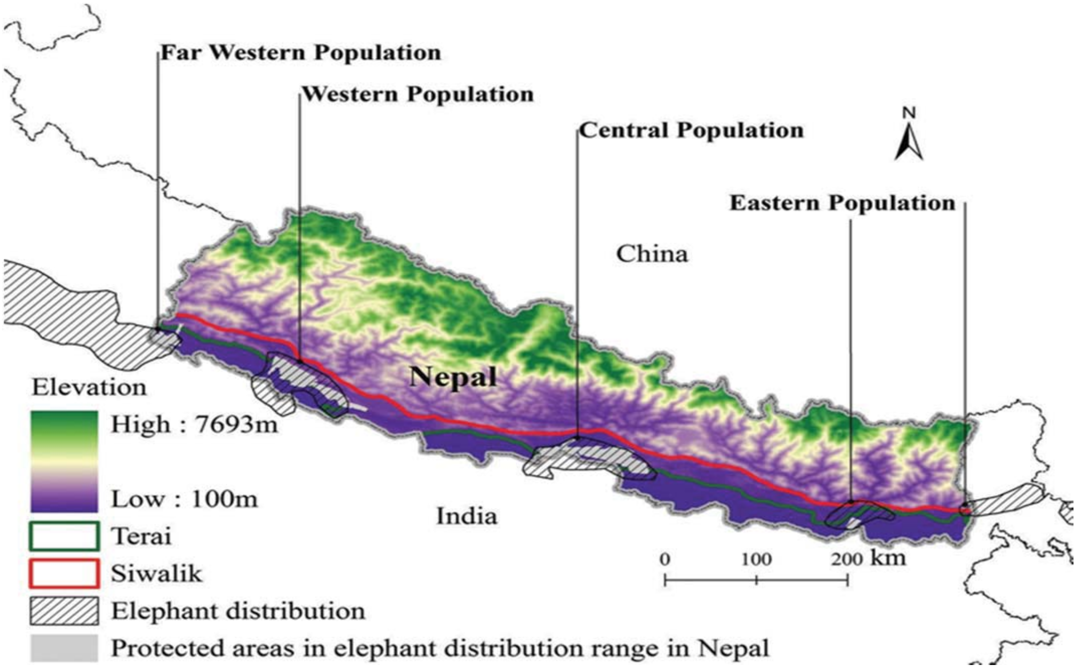


Figure 5. 1: Distribution of Asian elephant populations in Nepal (based on IUCN 2008). Also shown is potential elephant habitat, all of which is in Terai and Siwalik regions of Nepal. The eastern region comprises of fewer resident elephants while the migratory herd comprises of around 100 individuals. This region is the highest impact area of human–elephant conflict in Nepal. The western and far western population is also comprised of a fair number of migratory populations, and the impact of conflict is less than that in the eastern region.

The government of Nepal has put in place a variety of policies in an attempt to conserve this endangered species. These include the listing of elephants as a protected species in the National Parks and Wildlife Conservation Act 1973 (NPWCA 1973), producing the Elephant Conservation Action Plan (2008) and, importantly, adopting the Terai Arc landscape-level conservation programme. This programme aims to manage the elephants as a metapopulation through the restoration of corridors, and improve their chances of long-term survival in their current habitats (DNPWC 2008). Currently, human-elephant conflict is one of the biggest conservation challenges in Nepal and calls for urgent action by the government. This conflict is associated with substantial losses of agricultural crops and high rates of human mortality from elephant attacks. It has been reported that 66 human and 18 elephant deaths occurred during a period of 16 years 1986–2002 (Yadav 2007). Nine people were killed by elephants in the 4 years following 2009 (CNP 2012). A compensation programme has been implemented, but compensation is unable to decrease the level of the problem. One of the problems with the effective implementation of the programme is its vulnerability to fraudulent claims of damage. If the assessment of claims can be reliably made, there may be a case for locally administered relief schemes which involve food distribution rather than monetary compensation. Alternative forms of repair or replacement may be appropriate where other types of elephant damage occur, for example to water supplies, food storage facilities, livestock or fences (IUCN 1997).

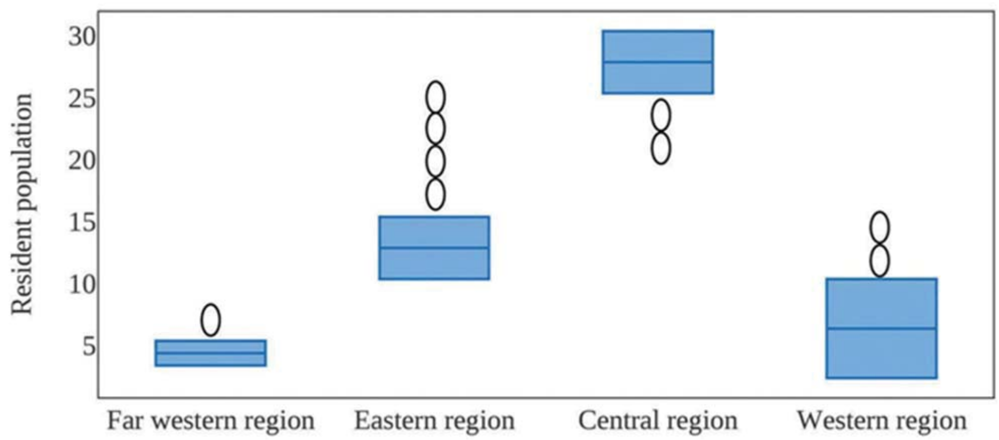


Figure 5. 2: The distribution of resident elephant population number (shown in box plot) and conflict status (**0**) in Nepal. Symbols (**0**) represent the ratio of conflict as compared to other regions. The eastern region has the highest human-elephant conflict (**0000**), where there is a small resident population presence as compared to central (**00**) and western regions (**0**). In the far western region, there is very low human-elephant conflict (**0**), with the lowest population. The western region has < 10 resident population; however, there are > 80 migratory herds frequently visiting in the region.

## 5.3 Status of elephant populations in Nepal

As mentioned above, there are currently four elephant populations in Nepal, the eastern, central, western and far western populations (Fig 5.1). The circumstances of these differ, each warranting attention in its own right.

*Eastern population.* The eastern region contains very small protected areas (125 $km^2$) for the elephant compared to other regions (Fig 5.1). The area is interspersed with human settlements, agricultural fields, tea plantations, patchy forests and roads, and is now a hotspot in Nepal for human-elephant conflict.

The eastern population is dominated by migratory herds venturing into Nepal from India during the period between May and November, but also includes approximately 15 resident animals (Fig 5. 2; Yadav 2007; DNPWC 2008). Such movement is likely associated with the availability of domestic crops and water (Ten Velde 1997). The severity of economic loss from the wild elephant in Jhapa (eastern population) is high. The eastern population is connected with the migratory animals from North Bengal (India), which have herd sizes ranging from a few individuals to over 100 animals.

North Bengal is one of the more important elephant habitats, with nearly 400 resident elephants. The protected and reserve forests in Northern West Bengal house 90% of the elephants in the state, and link with the habitat of the northeast Indian elephant population (WWF India 2012). However, the zone is interspersed with human settlements, tea plantations, rail and roads, and is also a hotspot in India for human-elephant conflict.

The recent extension of the range of these elephants farther west up to Udaipur district of Nepal (Ten Velde 1997) from the eastern boundary of the country can be attributed to the elephants' pursuit of suitable habitat with low disturbance. However, the lack of optimal habitats in the western part of eastern Nepal resulted in further movement, with these animals returning to the east. Human-elephant conflict is on the rise and is currently at an all-time high in the eastern part of Nepal in the region of the Indo–Nepal border. The growing human population and associated encroachment on the elephant habitat on both sides of the international border has both degraded and fragmented the habitat. This is due largely to the dependence of local people living in a subsistence economy on the nontimber forest produce, livestock grazing and conversion of natural forest into monoculture plantations of tea. The conflict has arisen on both sides of the border, especially around the movement of elephants through corridors outside forest that mostly pass through tea plantations and other agricultural areas.

*Central population.* The central population is distributed in and around Royal Chitwan National Park and the Parsa Wildlife Reserve. This population has benefited from relatively intact reserve forests surrounding the national parks, which act as buffer zones between the protected areas and crops (Fig 5.1). Over the past two decades, the ranges of elephants from Parsa have extended towards Chitwan (ten Velde 1997). The availability of water in the Churia foothills is believed to be one of the main causes for these animals to reside permanently in Nepal rather than migrating to India, as do other populations. Adjacent to these two protected areas lies the Valmiki Tiger Reserve in Bihar State, India, which has about 25–30 elephants (Fig5.2; Ten Velde 1997; DNPWC 2008). There are only a few human settlements along the fringes of this tiger reserve.

Therefore, this cross-border region offers unique possibilities for cooperative protection of one of the few remaining natural elephant habitats in the region.

*Western population.* The Royal Bardia National Park lies in the Bardia and Banke districts of the southwestern Terai region (Fig 5.1). The park covers a total area of 968 $km^2$ which makes it the largest protected area in the Terai. Due to its topography which ranges from the slope of the Chure hill to the banks of the Karnali River, the area consists of numerous ecosystems (NBS 2002). The parks are connected with the corridor forests in the southwestern border connecting with the two protected areas in India, Kataniyagaht Wildlife Century and Dudhawa Tiger Reserve. The western population consists of 80 elephants (Fig 5.2; Pradhan et al. 2011), with two bulls being resident within Bardia National Park (Ten Velde 1997). The human-elephant conflict in the western flood plain area is mainly due to 2–3 bulls (Ten Velde 1997), and the severity of damage here is higher than in Sukla and Chitwan.

*Far western population.* The Sukla Phanta Wildlife Reserve (SPWR) is a protected area in the Terai of the far western region, Nepal, covering 305 $km^2$ of open grassland, forests, riverbeds and tropical wetlands at an altitude of 174–1386 m (NBS 2002). A small part of the reserve extends north of the East-West Highway to create a corridor for seasonal migration of wildlife into the Siwalik Hills. This corridor has provided a continuous forest patch for elephant movements taking place in and around its core area. The area borders districts of the Indian state of Uttar Pradesh. The far western population is believed to have 3–5 individuals permanently resident inside Nepal (Fig 5.2), while the rest migrate seasonally between Nepal and the bordering districts in India. These elephants are believed to be part of a population of 1500 elephants in the Indian states of Uttarakhand and Uttar Pradesh (Rangarajan et al. 2010). The percentage of annual economic loss to elephants in SPWR was significantly less than that in Bardia (western region) and Jhapa (far eastern region) (Fig 5. 1; WWF Nepal 2007). The contiguous edge forests and lower numbers of elephants in the far west reserve of SPWR could be the reason for the relatively low intensity of human-elephant conflict there. This indicates that human-elephant conflict may intensify in the future unless preventative steps are taken.

## 5.4 Distribution of human-elephant conflict in Nepal

There are marked differences in the nature and intensity of human-elephant conflict between eastern and western Terai. In the western Terai, the slower economic development activities coupled with the later migration of humans from the mountains might have minimised the rate of habitat degradation compared to the eastern Terai. Comparison of the percentage of annual loss across four population areas showed that annual loss from elephants in SPWR was significantly less than in Bardia (western region) and Jhapa (far eastern region; WWF Nepal 2007). Jhapa and Bardia were about equally affected by human-elephant conflict in terms of crop damage, with households here having lost nearly 25% of their total annual income from crop production. Jhapa and Bardia had about an equal amount of forests in the 'edge habitats', which is less than SPWR (WWF Nepal 2007). Thus, it is highly likely that the more fragmented landscape in Jhapa and Bardia could be one of the primary causes for the high level of human-elephant conflict. The economic loss in Chitwan and Parsa is lower compared with that in the eastern part, although over the past few years' human casualties and crop raiding have increased, due to a single bull and a family herd of few individuals, respectively.

## 5.5 Elephant populations and crop raiding

Studies conducted in South Asia revealed that only some elephants in a population raid crops (Balasubramanian et al. 1995). However, in some populations, such as in northern West Bengal (India), the majority of elephant raid crops and the situation is similar in eastern Nepal, which is continuous with West Bengal. In the rest of the elephant areas in Nepal, almost all the crop raiding and other conflict are associated with solitary and bull herds (Ten Velde 1997). The bulls are more aggressive during a periodic physiological stage called 'musth', but not all bulls raided crops, despite their easy accessibility (Williams et al. 2001). While crop-raiding bulls have larger home ranges than other bulls, they eat crops in a restricted area within their home range and for only part of the year (Ten Velde 1997; Williams et al. 2001). Ten Velde (1997) revealed that the same bull elephants were raiding crops in both Parsa and Chitwan areas and also in the adjoining reserve forests. This trend has continued, with one of the bull elephants in central Nepal being responsible for most of the human-elephant conflict incidents from 2010 onwards (Pant et al. 2015).

In Sri Lanka, elephants that inhabit areas of high usage by humans had relatively larger home ranges (male: 183.6$km^2$; female: 157.9$km^2$) than those that did not (male: 53.6 $km^2$; female: 48.3 $km^2$) (Weerakoon et al. 2004). In the high human usage zone of eastern Nepal and western North Bengal in India, the elephant population is believed to have large home ranges which overlap with those of the northeastern India elephant populations (Choudhury 1999). The chances of losing a part of a large home range to the human endeavour is high (Williams et al. 2001), making it the most important trigger of conflict (Balasubramanian et al. 1995; Madhusudan 2003).

Elephants are capable of withstanding a great deal of environmental stress (IUCN 2006) and tend to remain committed to their home range even if the habitat suffers some degree of fragmentation or transformation (Datye and Bhagwat 1995a; 1995b). When the available natural foods within their home range are no longer adequate, they make up the deficit in their dietary requirements by eating crops (Balasubramanian et al. 1995; Madhusudan 2003). Compared with forest-living elephants, the elephants that had lost habitat ate crops the most. This led to the conclusion that habitat loss results in some elephants eating crops, although others in the same area and with overlapping home ranges do not do so even when they have the opportunity (Balasubramanian et al. 1995). In Africa, Chiyo et al. (2005) concluded that factors other than total food availability are responsible for the crop-raiding behaviour of elephants. Crop eating could be a learned behaviour (Sukumar 1985), with young learning from the adults in the herd (Whitehead et al. 2004), and young bulls that disperse from herds that do not eat crops may learn by associating with bulls that do (Osborn 1998). This could explain the difference in behaviour of different animals living together, providing another possible explanation why some elephants of a population eat crops while others in the same vicinity do not (Balasubramanian et al. 1995; Williams et al. 2001). In Nepal, crop raiding and other casualties are associated with solitary bulls in the musth period, solitary bulls in non musth, small herds of few individuals and large migratory family herds. The foraging and ranging behaviour of these populations have not been assessed. The qualitative and quantitative data on spatial and temporal patterns of change in foraging and ranging behaviour of these resident and migratory elephant populations are inadequate. The distribution of conflict is highly variable and localised, but there have been few regional assessments of damage.

## 5.6 Conclusions and management recommendations

In many parts of Nepal, the expansion of subsistence agriculture, commercial agriculture (tea plantations) and developmental projects (dams, roads, settlements and industries) has resulted in the loss and fragmentation of habitat. Prevention of crop raiding and other conflicts with elephants, especially solitary males both during and outside of musth, is an emerging issue which from a conservation perspective should, where possible, be addressed through biological or translocation approaches rather than culling.

It has been suggested that the wide variation in home range size displayed by elephants could be attributed to their being generalists (Choudhury et al. 2008) with the ability to adapt to and survive in a wide spectrum of habitats with differing resource availability (Fernando et al. 2007). Similarly, habitat fragmentation of elephant ranges outside protected areas (Roth and Douglas-Hamilton 1991; Blanc et al. 2007) presents a major challenge for elephant conservationists and managers. This underscores the importance of preventing fragmentation in the first place through appropriate land-use planning and the creation of incentives for the continued protection of large and contiguous forest patches.

However, a lack of current protection measures coupled with the unpredictable behaviour of elephants and their ability to quickly modify their foraging strategies is also believed to contribute to increasing human-elephant conflict. The growing human population, together with the declining space for both humans and elephants, is bringing people and wildlife into closer contact, with adverse impacts on both. Therefore, addressing the burden to communities from large mega herbivores like elephants is one of the greatest conservation challenges faced by many countries. Crop raiding and, more recently, human casualties have become major issues related to human-elephant conflict (Pradhan et al. 2011). On a positive note, the increasing number of recolonising elephant populations in Nepal and the use of corridor forests and new refuge areas are attributed to the implementation of the Terai Arc landscape initiative, which is a productive step in conserving this large herbivore.

The problem in eastern Nepal is similar to the situation on the other side of the international border, including the nature and extent of cultivation patterns, crop types and seasonality. An important priority is to better understand the causes of elephant migration in this area. For example, surveys are needed of the area used by elephants, and elephant population sizes, to assess the year-round use of the resources. If the number of elephants is increasing, then from a conservation perspective this is encouraging but requires management to mediate the increased risk of conflict. On the other hand, if the crop raiding is due to decreased or degraded habitat and population isolation, then it is a lose-lose situation.

The spatial and temporal nature of conflict is different in different regions due to factors such as the degree of forest fragmentation, food choice, number of problematic bulls during the musth period, population dynamics and so forth. There is, however, no specific model stipulating which combinations of factors predicts the observed spatial and temporal pattern and the extent of a conflict between human and elephants.

A high priority is to conserve habitat for these elephants, but to do so in the face of competing land requirements by local human populations, information is needed on the resources required to sustain elephant populations. To accomplish this in the

Nepalese context, the following measures are suggested:

- Further research on modelling of elephant spatial organisation in Nepal, dispersal patterns and local conflict with problematic herds
- A rigorous scientific research programme on the relation to seasonal need of optimal quantity and quality of nutrients needed by these elephants, and the year-round or seasonal availability of the nutrients in the natural foods
- Geo-spatial analyses of land-use cover and degree of forest fragmentation and edge habitats in potential and actual elephant habitat
- Identification of the villages that are impacted most heavily on the migratory elephant route, and implementation of local elephant management plans
- Regeneration and plantation of the most preferred food plants in the degraded elephant migratory forest patches (corridor recovery)
- Plantations of less preferred foods in the agricultural fields near the fringe areas of the migratory forest patches (compatible land-use planning)
- Implementation of an appropriate compensation programme
- Use of available physical barriers

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# Chapter 6

# Patterns, perceptions and spatial distribution of human-elephant (*Elephas maximus*) conflict in Nepal

**Crop damage by elephants in the buffer zone of Chitwan National Park.**

## 6.1 Abstract

An assessment of human-elephant conflict was carried out in the buffer zones of Chitwan National Park and Parsa Wildlife Reserve, Nepal, through a questionnaire-based survey of local residents, focal interviews and secondary data collection. Human conflict with *Elephas maximus* was intense in the pre-winter season and was concentrated along the southern forest boundary; conflict decreased with increasing distance from the park/reserve. Crop damage by elephants occurred in the pre-monsoon and winter seasons, with the most impact being on rice (the major crop). Forty-four percent of local residents surveyed suggested bulls (single or in pairs) were involved in crop raids, 48 % property damage and 8% human casualties, and family herds were only recorded to have raided crops (39%) and damaged properties (36%). The average herd size recorded was 10 individuals, with a maximum group size of 22 elephants. Generally, conflict intensity as measured per elephant was high in western Nepal; however, conflict in terms of human and elephant casualties was highest in central and eastern regions of Nepal.

To reduce human-elephant conflict, 53% of local residents surveyed suggested re-vegetating internal parklands and park boundaries with native elephant food plants, 40% suggested planting alternative crops along park boundaries, 6% favoured elephant translocation, and only 1% were in favour of culling elephants. Mitigation measures already in place included wooden watch towers used by villagers to detect elephant

incursions. Low-impact traditional averting techniques, such as drumming and the use of flame torches, were used to deter intruding elephants at the areas surveyed.

Potential mitigation measures I suggest include identifying elephant refugia and migration routes and assessing the year-round availability and protection of more preferred food plants. In addition, I advocate introducing an equitable compensation system to gain support from local communities adjacent to protected areas.

## 6.2 Introduction

The Asian elephant (*Elephas maximus*) is one of the largest living land mammals and is endangered according to the International Union for Conservation of Nature (IUCN) red list (IUCN 2008). There are approximately 50,000 Asian elephants in the wild, distributed across 13 Asian countries, and 16,000 in captivity (Sukumar 1989; Alter 2004). Elephant populations in most of their natural range have been declining with the increase in human population and land development causing erosion and degradation of forest habitats. Such habitat degradation is thought to be the main trigger of human-elephant conflict (Riddle et al. 2010), which is hindering conservation efforts in some regions (Hoare 1999; Perera 2009). Thus, mitigating human-elephant conflict is a priority in ensuring the long-term survival of wild populations of Asian elephants (Hoare 2000; Sukumar 2006).

Nepal provides habitat for an estimated 100–125 Asian elephants (Chapter 4, Koirala et al. 2016). However, the recent loss of over 80% of elephant habitat to human settlement (Joshi and Singh 2007) has eroded its carrying capacity. In the past, elephants were distributed throughout Terai forests (Pradhan and Wegge 2007). These forests, which spanned Nepal from east to west, have been reduced to 24% of their original size of 593,000 hectares (Satyal 2004). The country's elephant population is now limited to only four areas due to vast anthropogenic pressure and dwindling resources (Pradhan et al. 2011). Human activities, which encroach on elephant habitat, also force elephants into direct contact with humans, which results in exacerbated human-elephant conflict (Hoare 1999; Sukumar 2006).

The spatial and temporal nature of conflict varies within Nepal (Chapter 5, Koirala et al. 2015). In central Nepal, the elephant population is mostly resident. Conflict arising from crop raids was first recorded in the Parsa Chitwan area in 1994 when a single bull elephant moved into cultivated agricultural lands (Ten Velde 1997). The conflict has increased substantially since then, which poses a serious threat to local people as well as to resident elephant populations (Pant and Hockings 2013). In Nepal alone, 66 people and 18 elephants died as a result of human-elephant conflict during a period of 16 years from 1986 to 2002 (Yadav 2007). In central Nepal, nine people were killed over a period of 5 years from 2008 to 2012 (Chitwan National Park 2012).

Human-elephant conflict is the main conservation issue throughout an elephant's home range (Hoare 1999). The nature and extent of damage caused by these animals to humans, and vice versa, are poorly understood. In this study, I examine multiple aspects of human-elephant conflict in Nepal, mostly focussing on central Nepal. To the best of my knowledge, the spatial and temporal factors that drive human-elephant conflict have not previously been studied in Nepal. The primary aim of this study was therefore to assess the magnitude and nature of human-elephant conflict and to understand the opinions and perceptions of local people regarding mitigating impacts of elephants and enhancing elephant conservation. Also, for comparison, I explored spatial and temporal distribution patterns and the driving forces of human-elephant conflict in other regions in Nepal. To explore these issues, research questions were asked about type, frequency and trends of elephant visitations and damage, with an overall goal of finding local solutions to minimise conflict with humans.

## 6.3 Material and methods

An assessment of human-elephant conflict was carried out from July/August 2012 to December 2014 in villages throughout the northern and southern buffer zones of the Chitwan National Park and the Parsa Wildlife Reserve (Fig 6.1).

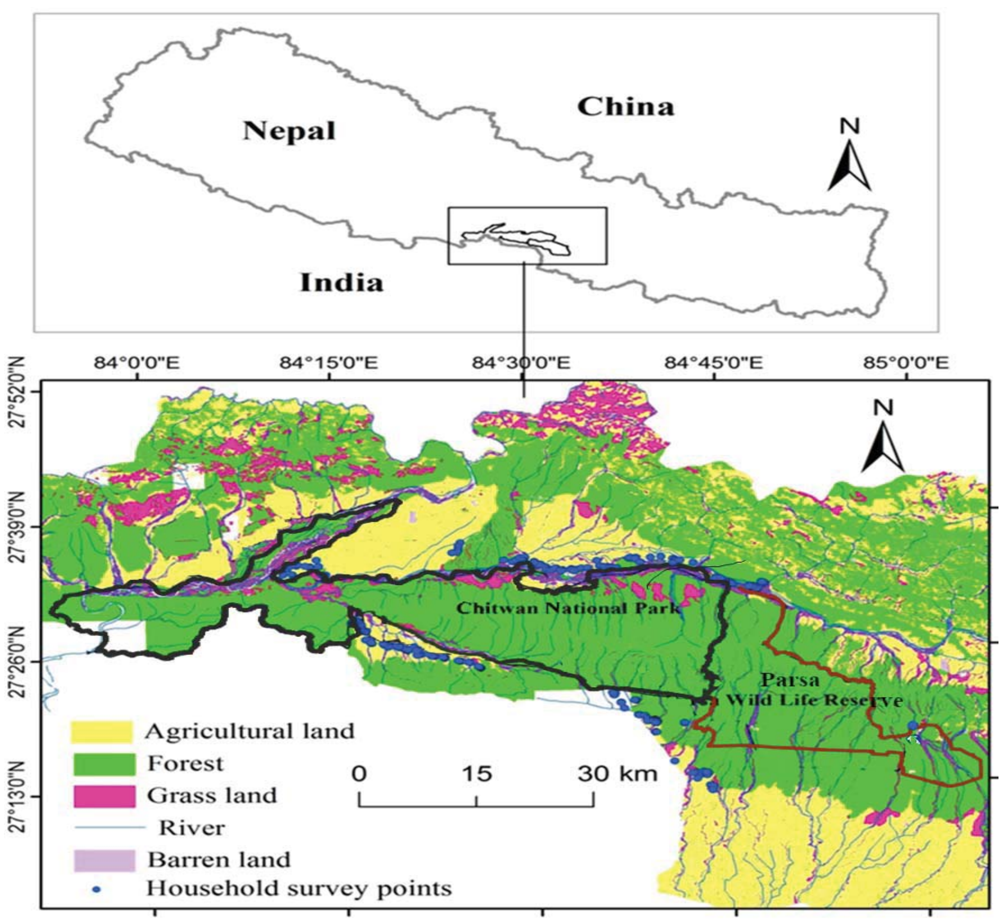


Figure 6. 1: study areas. Blue circles are the spatial position of the household surveyed in the buffer zones of Chitwan national park and parsa wildlife reserve.

Information on the human-elephant conflict was collected through questionnaire survey (Appendix 6). Qualitative and ethnographic data were collected following the research methods described by Bernard 1995; LeCompte and Schensul 1999; and Ogra and Badola 2008. A structured and semi-structured questionnaire with closed and open-ended questions were formulated. Questions related to family background, current agricultural practices and problems encountered with elephants and included questions about the major forms of damage sustained from elephant visitations. Data collected included details of the spatiotemporal nature and extent of crop and property damage and human and elephant casualties. Also, detailed information about the period and frequency of damage, major crops and plant parts eaten and locals' mitigation methods were collected.

Every effort has been made to minimise the number of non-respondents, so questionnaires were kept as simple as possible (White et al. 2005). The trained interviewers are able to ensure that the responses given weren't biased. It was assumed that this type of survey would provide a fair and reliable assessment of the problem from a stakeholder's perspective. However, Kangwana (1995) has cautioned that conclusions should not be drawn based entirely on farmers' and householders' replies to a questionnaire. To validate the household survey, secondary information was collected from official records of conflict in the park and buffer zone office, and focal interviews were conducted with key informants (Bernard 1995) from the community and park and buffer zone officials. Their experience and knowledge of the existing elephant population, causes of human-elephant conflict, mitigation measures already being taken and their effectiveness, as well as their suggestions for possible solutions to the problem, were recorded. The permit for questionnaire surveys were permitted by the department of National park and Wildlife Conservation, the government of Nepal as part of the permit for the PhD project.

Also, data of human-elephant conflict were collected from the literature and used to analyse spatial-temporal patterns of conflict throughout Nepal. Among four elephant distribution areas (Fig 5.1, chapter 5), eastern region was covered by forest remnants, and only 175 $km^2$ was under protection. Edge habitat covered 12,892 ha (Nepal WWF 2007) while in central Nepal intact forest under protection totalled 3,549 $km^2$ with 28,500 ha edge habitat in the Chitwan National Park buffer zone (Baidya et al. 2009). While in the western region covering Bankey and Bardia National Park, patchy forest remnants were distributed in south and south-western part of the parks. A total area of 1,437 $km^2$ was under protection at the time of my study. Forest edge habitat totalled 12,979 ha.  The far western area in Suklaphanta wildlife reserve supported a 305 $km^2$ area of intact, fully protected forest. Forest edge habitat covered 33,554 ha, the largest forested edge habitat in Nepal (Nepal WWF 2007).

The per capita elephant damage rate was calculated and used as an index of conflict intensity (CI):

$$\text{Conflict intensity (CI)} = \frac{\text{Total number of incidents}}{\text{Total number of elephants}}$$

I analysed records of human-elephant conflict that was published over a 10-year period (2002–2012). In addition, relative conflict intensity among villages was calculated by the relative presence of different categories of conflicts. The conflict intensity of 1 was the lowest and 3 was the highest intensity and included a combination of different types of conflict.

In total I surveyed 302 households, focussing more on villages near park boundaries. Every fifth household within each village affected by elephant visitations was selected, and interviews were conducted with the head of the household. If the head of the household was not present, the most senior member of the family was chosen for an interview. If no one was at home, the next house was selected for an interview. Verbal consent of the respondent was obtained before conducting the interview (Pant and Hockings 2013), and none of the respondents declined to participate in the survey. All information received was treated as approximate, since it was based on respondents' estimates and memories as far back to 10 years time (Kulkarni et al. 2010). Altogether, 75 villages under the auspices of 17 village development committees (VDC) were surveyed within four districts (Chitwan, Parsa, Makwanpur and Bara). Village development committees (VDC) are a local government body in rural Nepal, equivalent to municipalities in urban areas. The geographical coordinates of the households where interviews were conducted were obtained by marking their location using a Garmin eTrex Venture global positioning system (GPS) unit.

## 6.4 Data analysis

GPS location data of human-elephant conflict incidents were used to prepare a detailed map in ArcGIS version 10.1. I used a Chi-square test to look for trends in the respondents' attitudes about elephant damage and local perceptions on elephant conservation. Pearson correlation tests were conducted to determine the relationship between the number of crop raiding/property damage incidents and human casualties and the spatiotemporal relationship between elephant damage and the spatial location of villages. The IBM statistical package for social sciences (SPSS) version 22 was used to analyse data.

## 6.5 Results

### 6.5.1 Respondents and their major conflict experiences

Of 302 respondents, 258 (85.4%) were males and 44 (14.6%) were females. A total of 170 (56.2%) interviewees resided in the buffer zone of Chitwan National Park, and 132 (43.7%) were within the buffer zone of the Parsa Wildlife Reserve. The mean age of respondents was 45.25 years (n = 302, SD = 10.8), and ages ranged from 21 to 73 years. Interviewees were distributed unevenly between the 17 village development zones: representation by zone ranged from a low of 1.7% in the Bhandara area in Chitwan to a high of 12.6% in the Nirmal Basti village development committee in the Parsa buffer zone.

Respondents viewed crop raids as being the most common form of human–elephant conflict, comprising 76.7% of total human-elephant conflicts, followed by property damage (22.5%) and human casualties (0.7%) (Fig 6.2).

Nearly half (45.5%) of the respondents indicated that property damage had increased in the last 10 years, 46.4% of interviewees had not noticed any changes in occurrence of property damage, 7.9% had observed a decrease in occurrence of property damage and 3% of respondents did not answer the question (Fig 6.3). The majority of respondents (72.2%) reported an increase in crop raids, 21% did not notice any change and 6% indicated a decreasing trend.

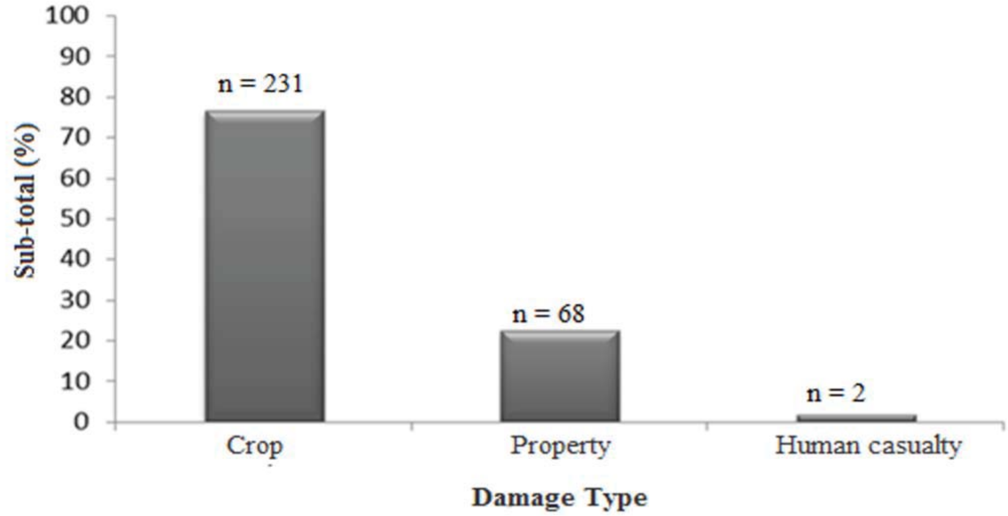


Figure 6. 2: Respondents’ view on the trend of types of human-elephant conflict in the buffer zones of Chitwan National Park and Parsa Wildlife Reserve.

A minority of respondents (22%) indicated an increase in human casualties, 60.0% did not notice any change, and 10% indicated a decreasing trend. More than 80% of respondents could not provide information about elephant mortality in relation to human-elephant conflict, and only 10% indicated a decreasing trend in elephant casualties (Fig 6.3).

In summary, local perceptions indicated a more significant increase in crop raids than in other types of damage ($\chi^2$ = 95.0, df = 3, $p$ = <0.001).

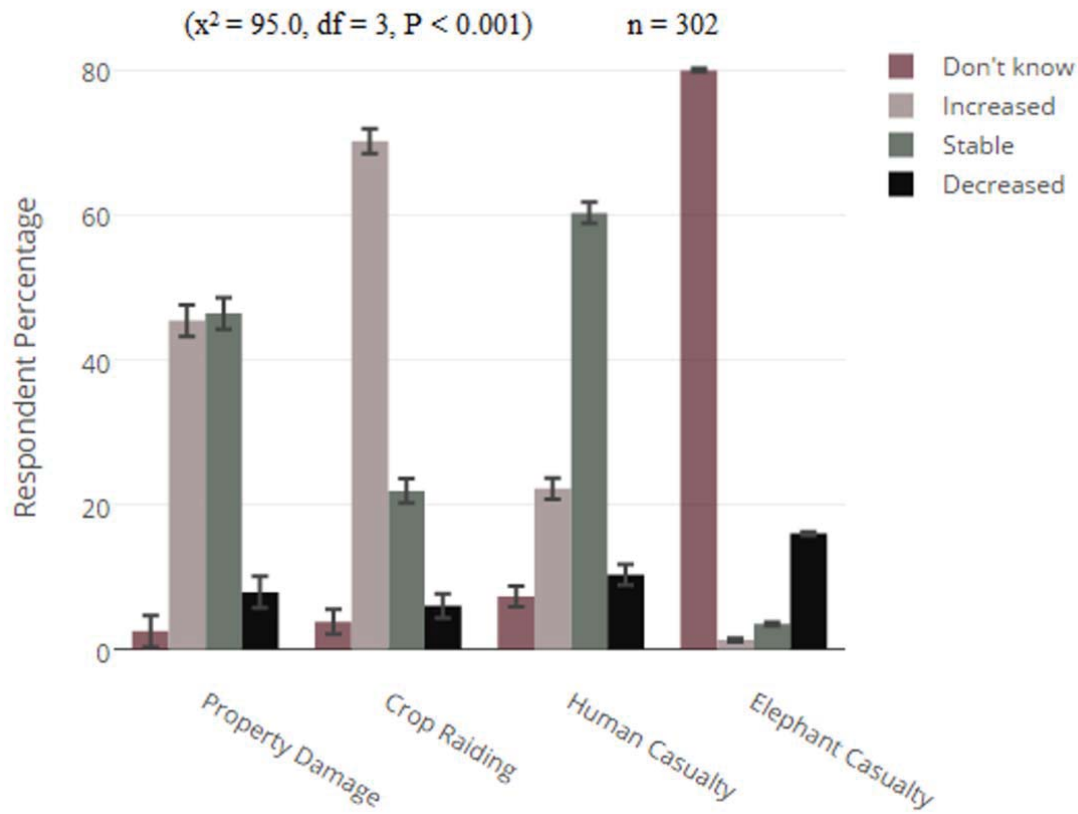


Figure 6.3: Distribution of respondents' views on the trend of human-elephant conflict from 2002 to 2012.

### 6.5.2 Crop type, damage incidence and time of day

Rice was the most common crop grown (99.3% of the interviewed households), followed by maize (79.1%) and wheat (43.1%). More than half (55%) of the households, located predominantly to the south of the reserves, produced one crop of rice per year, while 45% of the households, situated mainly to the north of the reserves, produced two crops a year. Only one crop of wheat and maize were grown per annum throughout the buffer zones of both reserves.

Just over half of the respondents (51%) indicated that elephants raided rice, over more than a quarter of the respondents (34%) had witnessed elephants raiding maize regularly, and a further less than a quarter or 15% of respondents) reported that wheat was a regular food choice for raiding animals. The majority of the respondents reported that the crop damage by elephants occurred in the pre-monsoon and pre-winter seasons.

Forty-four percent of reports of human-elephant conflicts involving single bulls or two bull elephants were of crop raids, 48 % were of property damage 8% were human casualties (Fig 6.4A). Similarly, Family herds were found to raid crops (38.9%) and damage property (36%), but there were no records of a human casualty caused by a family herd (25%) (Fig 6.4B).

There was a significant correlation between the number of crop raiding/property damage incidents and human casualties ($r$ = 0.8, $p$ = <0.01). There was a significant difference in the number of incidents of human-elephant conflicts relative to the time of day, with almost 95% of all incidents occurring during the night (6 p.m. to 2 a.m.) ($\chi^2$ = 108.30, df = 3, $p$ = <0.001).

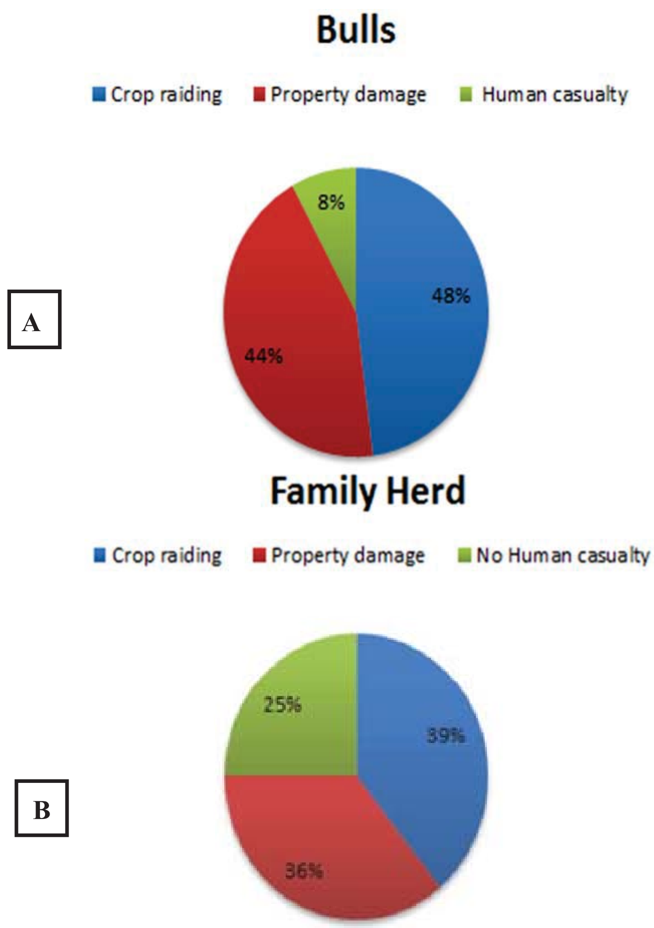


Figure 6. 4: Types and Trend of damage caused by bulls and family herd.

### 6.5.3 Plant parts preferred by elephants

Altogether 23% of interviewees described rice grain with husks as the food most preferred by Asian elephants, followed by whole rice plants without roots with 13% ($\chi^2$ = 181.79, df = 2, $p$ = <0.001). Similarly, 28% of the interviewees reported maize grain with husks was likely to be selected by crop-raiding elephants ($\chi^2$ = 274.89, df = 2, $p$ = <0.001). Eight percent of the respondents reported that whole wheat plants without roots were also favoured,, and 7% describe wheat grain with husks was also part of the raiding elephants' diet while 21% of the respondents could not answer on preference for all foods.

### 6.5.4 Conflict distribution by village

Overall, 54.6% of conflict incidents were centred in the south and south-western parts of the park buffer zones. Over half of the incidents (56%) occurred in the Chitwan National Park buffer zone, and 44% occurred in the Parsa Wildlife Reserve buffer zone. Ayodhyapuri Village in Chitwan reported the highest human-elephant conflict frequency (11.3%), followed by Gardi Village (10.9%). In the Parsa Wildlife Reserve buffer zone, Manahari Village suffered the highest rate of conflicts (9.78%), followed by Nirmal Basti (8.0%). There was a significant negative correlation between the distance of a village from park or reserve boundaries and the intensity of conflict ($r$ = –0.42, $p$ = 0.02) (Fig 6.5).

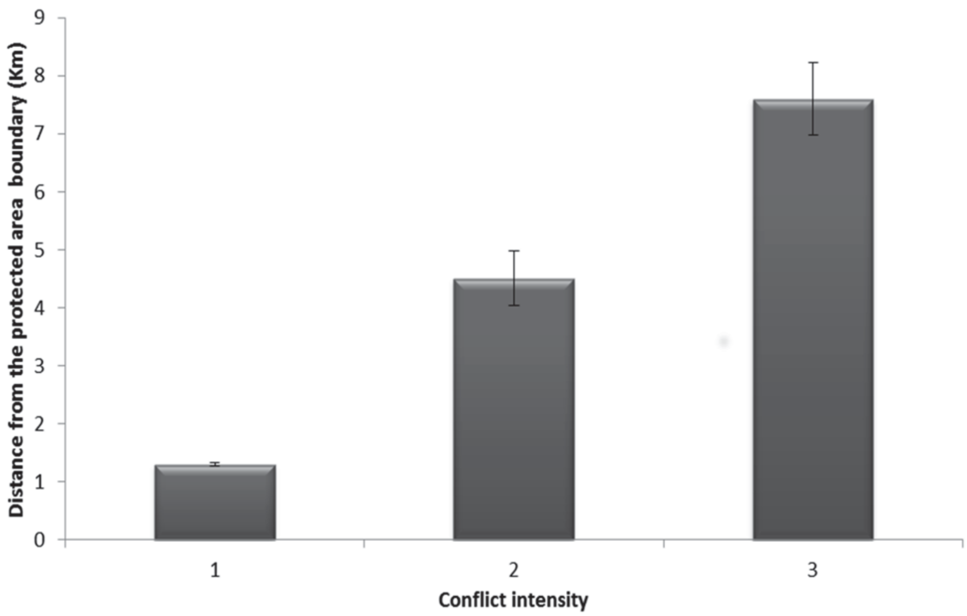


Figure 6. 5: Conflict intensity with increasing distance from the periphery of the parks.

### 6.5.5 Conflict intensity by region

In the easternmost region, conflict intensity per elephant was 1.74 (Fig 6.6), and the number of human and elephant casualties was with 5.75 per annum (4.45 human casualties and 1.3 and elephant casualties). Human and elephant casualties were high across all four known elephant distribution areas. However, the intensity of casualty per elephant was only 0.06 as the number of elephants in this region was the highest (Around 100 individuals) within the four elephant distribution regions in Nepal (Fig 6.6) at the time of this study.

In central Nepal (the Chitwan and Parsa areas, Fig 6.6), conflict intensity was 1.53. The casualty per elephant (0.17) was highest in this region (Fig 6.6). The elephant population was estimated at 25–30 individuals (Pradhan et al. 2011) and they are mostly residents.

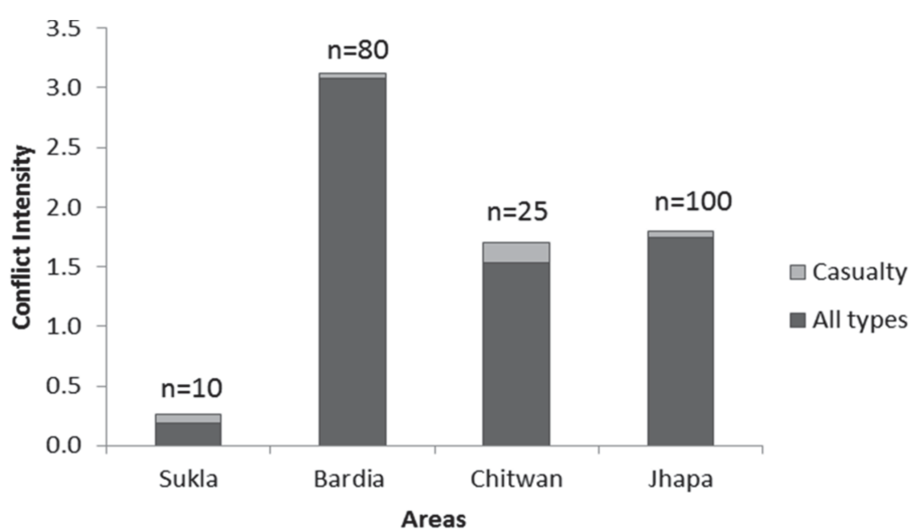


Figure 6. 6: Spatial distribution of elephant population represented by numbers with the intensity of all types of damage represented by black bars and the intensity of human and elephant casualty represented by grey bars.

Conflict intensity excluding casualties was highest in Bardia and Bankey National Parks in western Nepal (3.08). However, the rate of human and elephant casualties per elephant was the lowest among all regions of the country (0.04) (Fig 6.6).

In the far western region (Suklaphanta Wildlife Reserve and surrounding areas), the Asian elephant population was low at the time I conducted my research, with approximately 10 mixed migratory and resident individuals (Ten Velde 1997; Pradhan et al. 2011). Conflict intensity per capita (i.e., per elephant) was the lowest (0.19) among all the regions. Human casualties were low at the time of the present study.

### 6.5.6 Minimising conflict

Of the questionnaire respondents, 46.3% of questionnaire respondents reported a decrease in elephant abundance over the past 10 years, while just under half (53.7%) of the participants reported an increase. The half of respondents (50%) were of the view that the frequency of elephant visitations had been steady before five years, ranging from one to three visits per year. However, remaining 47% of respondents thought that the frequency had increased from only one to three to six visits per annum over the most recent 5-year period, while 3% of respondents could not answer on this question (Fig 6.7).

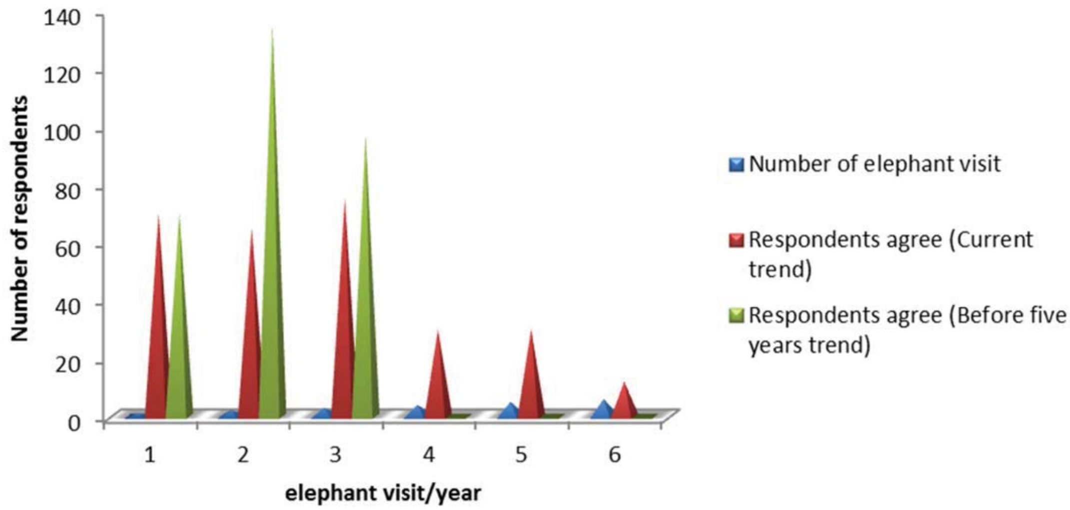


Figure 6. 7: Frequency of elephant visitation over time.

When asked which of the given determinant they think is the prime cause for the increased human-elephant conflict in this region, many village residents (78%) identified the ineffective and inadequate elephant deterrents such as trenches and electric fences as one of the causes of increased human-elephant conflict in the Chitwan–Parsa region. Half (50%) of the residents interviewed believed that a higher number of elephants was the primary cause of increased problems (Fig 6.8).

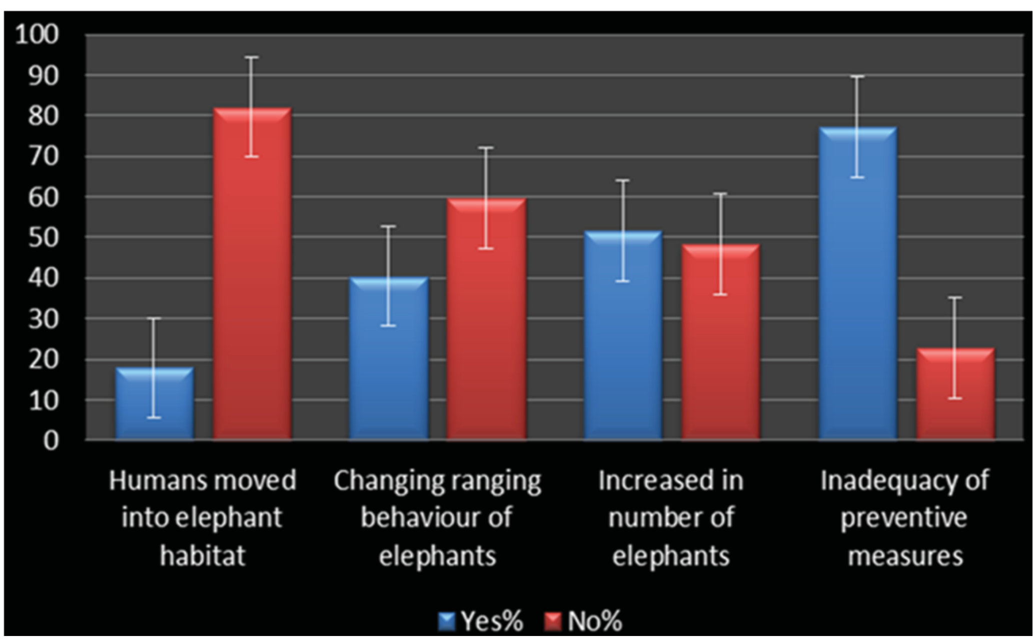

Figure 6. 8: Responses to the question as to what was the primary cause of the increased human-elephant conflict.

Fifty percent of respondents regarded the proximity of agricultural lands to forest fringes allowing easier access to elephants as being the primary reason for elephants moving into human-occupied areas. A total of 45% of respondents believed that depletion of natural wild foods in the forests resulted in elephants moving into human habitats. An additional 5.% of respondents felt that human disturbance of elephant habitats was the cause of elephants visiting villages in search of nutritive foods ($\chi^2$ = 244, df = 13, $p$ = <0.001, Fig 6.9)

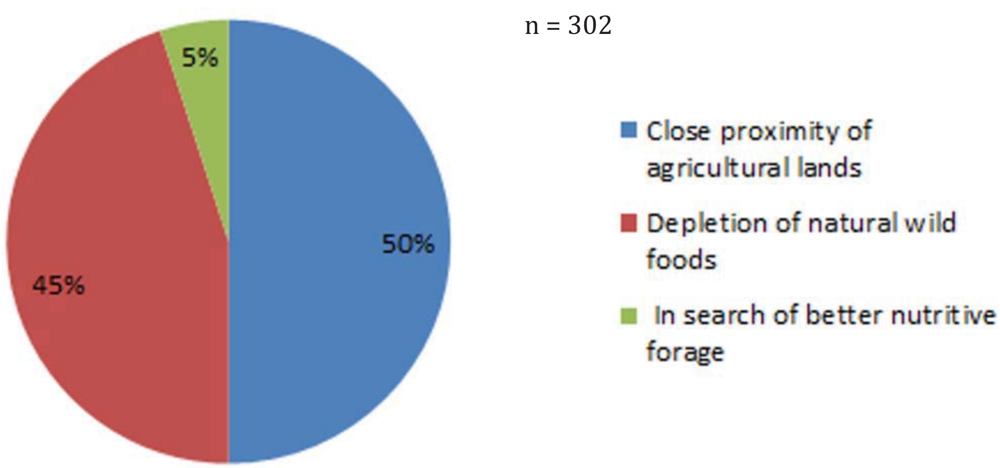


Figure 6. 9: Responses to the question as to what was on the primary cause elephant move to human habitation.

Many of the respondents thought that food supply should be a key focus in conflict mitigation. Over half (53%) felt that the regeneration of natural food plants in the forests would help reduce the frequency of elephant visitations to cropped fields, and

40% were in favour of growing alternative crops and pursuing other livelihoods. 6% of respondents favoured translocation of problematic elephants to remote areas, and 1% of participants suggested culling repeat offenders (Fig 7).

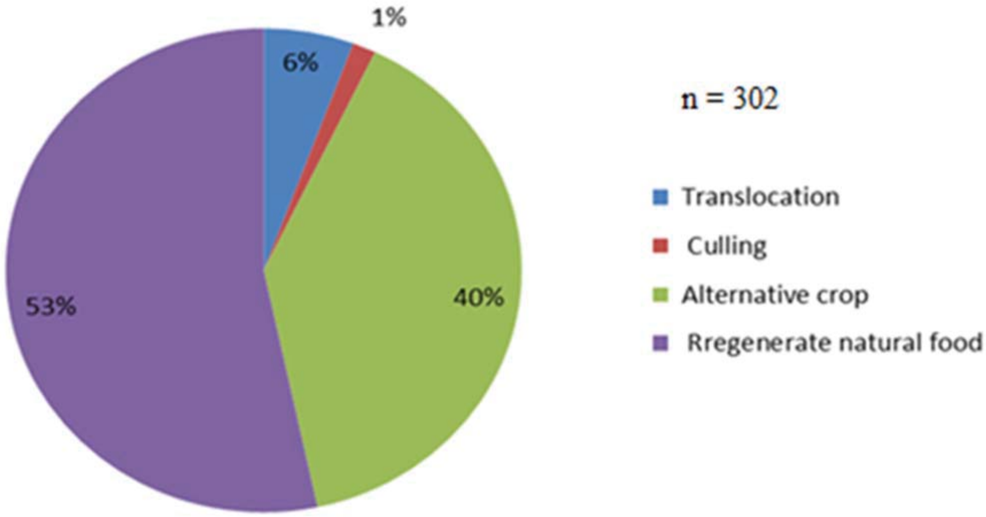


Figure 6. 10: Mitigation measures suggested by villagers during the questionnaire survey.

In response to questions about how elephants could be protected, 58.6% of the respondents were in favour of habitat management inside parks, 33.1% believed in raising people's awareness about elephant conservation, and 31.8% suggested introducing strong legal protection of elephants. A clear majority of respondents (87%) were positive about coexisting with elephants. In response to questions about how human-elephant coexistence could be sustained in the region, 73.8% of respondents favoured a compensation program to replace income lost to elephant damage. Over half of the participants (56%) suggested installing effective electric fences in all major cultivation areas in buffer zones as a way to reduce human-elephant conflict and enable peaceful coexistence.

## 6.6 Discussion

My data showed that the scale of human-elephant conflict differs according to the type of conflict. Crop damage was the most common type of conflict. Of the most heavily cultivated crops, rice was the most frequently raided. Crop raiding by elephants is a major issue in many parts of Asia and is caused by many factors, including elephant migration patterns, shifting water resources, habitat depletion and seasonally dependent nutritional requirements (Sukumar 1990). In my study area, rice was cultivated twice per annum and was the crop of choice for local farmers. The primary reason for elephants' preference for rice could be related to the proximity of rice fields to their seasonal migration routes. Also, my study has shown that the spatial distribution of crop-raiding activity was not uniform in either buffer zones of Chitwan or Parsa. Documented crop raids were mostly concentrated in the southern buffer zone regions of the park areas, especially in areas where cultivated crops were closer to park boundaries (Fig 6.1). Therefore, proximity plays a vital role in the crop-raiding activity.

Elephant raids of rice during the grain-laden season (pre-winter) occurred more frequently than raiding of other crop types. This raiding may be due to nutritional drivers. My unpublished data show higher protein content in the grains of cereal crops compared to wild grass species.

Elephants' preferences for certain grain crops can be explored further by identifying repeat raiders. Most crop raids were by a single or a few bull elephants identified by local villagers as repeat visitors that returned multiple times over a period of several years. This repeat crop-raiding behaviour could be correlated with adult bulls having higher nutritional requirements than other elephants because of their size and the high-energy behaviours associated with the male drive for reproductive success (Sukumar and Gadgil 1988).

My study also found that family herds ventured into agricultural fields and caused damage. This group behaviour could be predicted based on changed migration patterns and home ranges, as some of them have been found to visit new areas (Piple and Manahari VDC) in the northern parts of the Parsa Wildlife Reserve and Chitwan National Park where there had been no record of visitation by family herds in the past. Exploration of new areas is likely to be due to habitat shrinkage, water depletion and the increasing proximity of rice fields to elephant habitats. My results showed that elephant visitations have substantially increased in some areas during the last 5 years, especially in the non-traditional migration regions.

The spatial distribution of village households and their agricultural lands also played a crucial role in influencing the human-elephant conflict scenario. Houses in the forest fringe within <5 km of the periphery of national parks/reserves were more frequently affected than more distant villages. This was irrespective of their crop's stage of growth, what type of crop was cultivated or what type of property villagers held. A similar trend has been reported by Sukumar (1990) in southern India and by Pant and Hockings (2013) in Nepal.

Interviewees' perceptions of elephant conservation were found to be unilaterally positive in this study. People viewed natural food sources and habitat restoration as the main areas to be addressed to achieve conservation goals and to mitigate conflict. Existing mitigation measures such as electric fences and traditional herding techniques were seen to be least effective. The cultivation of elephant deterrent plants in villages in the forest fringe was deemed not to be practical by surveyed residents, as alternative income streams would be needed to replace the loss of income from crops displaced by non-edible deterrent flora. Villagers suggested that night patrols during peak crop-raiding times might not be feasible because of a lack of resources.

The spatial and temporal nature of conflicts and conflict intensity varied with region countrywide (Chapter 5, Koirala et al. 2015). My results indicated that eastern and western regions were conflicted hotspots, while medium and lower conflict intensities were typical in central and far western regions, respectively. The eastern region, which extends from Jhapa District in the far east through to Udaipur District in the far western portion of the eastern-most quarter of the Asian elephant's home range, was a critical conflict In this area, the elephant population was high at the time of my study, with as many as 100–115 individuals, mostly migratory (DNPWC 2008). In addition, conflict was high in this region in terms of elephant and human casualties, but the intensity of damage per elephant was less than in other regions because this region contained a higher number of migratory elephants. The higher number of casualties was attributed to the smaller area of forest-edge habitat (Nepal WWF 2007). Where there was a longer perimeter of cultivated habitat, there was also a higher probability of raids occurring (Sukumar 1990). People in this area grew a variety of crops. Some of these were high-profit cash crops, and frequent elephant raids of such valuable crops may have been intolerable to residents. As a result, retaliatory killings of elephants and human casualties had occurred. In contrast, in the western region (Bardia and Bankey areas), the Asian elephant population was estimated at ≤80 individuals at the time of the study, most of them migratory and with few permanent residents. Where elephants were fewer in number, human casualties were less.

### 6.6.1 Expected outcomes

It was expected that this study would yield a detailed account of crop and property damage caused by elephants. Because the study period was short (just over 2 years), comparing long-term trends was not possible. I expected that I would find that different deterrents were used by locals in different regions and that evaluations of their effectiveness would lead to recommendations for novel damage mitigation measures. I further expected to obtain information about other mitigation measures from the literature and other parts of Nepal with similar human-elephant conflict problems.

Also, another of my goals was to understand local people's perception and attitudes towards the conservation of elephants, to shed light on the scale of the problem and what measures would be appropriate to introduce to reduce conflict in the future. Furthermore, information on the historic distribution and threat status of Asian elephants in Nepal would allow us to conclude how the situation has changed over the past 10 years, and which factors have contributed significantly to the current situation. Overall, results from this study were expected to provide some basis for planners and conservationists to design innovative approaches to reducing human-elephant conflict in Nepal because, at present, there is a dearth of information available, which makes conservation of the species extremely difficult.

In summary, my study shows that in central Nepal, the Asian elephant population is increasing, and animals are mostly resident, and the intensity of casualties was highest compared to other elephant population of the country. Crop raids by elephants were the primary cause of human-elephant conflicts. A combination of factors, including the depletion of natural food in the forests, the higher nutritional content of crops and the proximity of rice fields to elephant movement routes appeared to trigger crop raids, and ultimately, human-elephant conflict.

## 6.7 Recommendations

Based on my results, I have identified factors that need to be assessed further to realise Asian elephant conservation outcomes. I recommend the following measures in the form of an integrated approach to minimise conflict and to conserve these endangered animals and their habitat.

1. Identify elephant refugia and migration routes, and assess the year-round availability and nutritional content of preferred food plants in and around those areas.
2. Extension of effective electric fences in all major agricultural areas of the buffer zones, and considers digging elephant deterrent trenches along remote park boundaries.
3. Introduce fair and workable compensation schemes to address losses suffered from crop and property damage and to gain support from local communities.
4. Restore degraded lands with a full suite of food species preferred by elephants, including bamboo, banana and other palatable plants.

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# Chapter 7

## Conclusion

**Revegetating the migration route is an effective way to minimise human-elephant conflict.**

## 7.1 Summary, conclusion and management recommendation

Human-wildlife conflicts are an increasing problem in many regions of the world. The primary causes of conflict include increasing human populations, habitat loss and, in some regions, growing wildlife populations. Conflict can be particularly severe, where pastoral people live nearby the protected areas. Human-wildlife conflict attracts greatest attention when the wildlife species involved is endangered species. For example, the elephant is perceived as a serious threat to human livelihood in many areas within the elephant distribution. Understanding the fundamental drivers of human-wildlife conflicts is critical to the development of innovative solutions to this growing problem. In this thesis, I integrate investigations from two research themes, the wildlife nutritional ecology, and the status of human-elephant interactions and causes from a social science perspective to address the focal issue of human-elephant conflict and provide management recommendations.

I provide the first investigation into the nutritional ecology of the Asian elephant (Elephas maximus). A central aim of the thesis was to examine the diet and nutritional composition of the Asian elephant and its possible effects on human-elephant conflict. Diet and nutrition are important aspects of animal biology as they affect every aspect of an animal’s life (Simpson and Raubenheimer 2012). Understanding elephants’ nutritional requirements and how they solve food shortage problems is important in understanding the basis of human-elephant conflict and thus for conservation of elephant populations in the wild. My research has informed that habitat loss and nutritionally motivated crop raiding behaviour are the two primary causes of human-wildlife conflict. This information was further validated by my social survey results which suggest that crop raiding was the major type of conflict and paddy was the highest raided crop. The study has found that majority of the respondents believe that re-vegetating internal parklands and park boundaries with native elephant food plants are crucial for reducing human-elephant conflict.

Geometric analysis showed that elephants ingest a phenomenal amount of carbohydrates and that fibre is vital in regulating the balance of protein in the diets of captive elephants. For example, the pattern where animals regulate the % of protein-energy in the diet, and to do so use various sources of non-protein energy interchangeably, has been observed in humans (Raubenheimer et al. 2014), grizzly bears (Coogan et al. 2014) and dogs (Hewson-Hughes et al. 2012). These are all omnivores, but my study of elephants has shown, for the first time, the same trend in a herbivore, suggesting that the pattern is general. Furthermore, unlike the other studies which showed that fat and carbs to be regulated interchangeably, I have shown that fibre energy is also regulated as an interchangeable source of non-protein energy in the same way. This even further extends the pattern. Although not designed to advance the nutritional geometric models themselves, this study has expanded the range of animals that have been studied using these models and contributed towards a general understanding of macronutrient regulation in animals.

I suggest that it is critical not to ignore the energy impacts of digestible fibre when designing diets for captive elephants or when investigating the foraging ecology of wild elephants. Furthermore, I suggest that the supply of a variety of complementary foods (combined in such a way as to provide a balance of nutrients) with higher protein content can assist elephants to obtain a diet with consistent proportions of protein, non-protein and fibre energy, which is crucial for the management of obesity in captive elephants.

My results also suggest that the diet of domestic elephants in Nepal during the dry season is more varied than in other seasons, comprising a combination of both woody plants and grass species. Elephants foraged in both grassland and *Shorea robusta* mixed forests because in the dry season, grass biomass is less and so there is a decrease in the protein content obtained from grasses. To compensate for this low protein from grass, elephants fed upon browse species during dry months. Additionally, substantial amounts of browse were provisioned in the elephant camps, allowing them to obtain a balanced diet. However, during the other seasons (pre-monsoon, monsoon and winter), elephants mostly foraged in grassland habitats, acquiring their intake from available species of grasses. They were also provisioned largely with seasonal grasses in their camps. During the period of my study, in the pre-monsoon, monsoon and winter seasons, elephant keepers (mahouts) were found to be taking the elephants exclusively to grassland habitats for feeding, which normally had less protein and high neutral detergent fibre, NDF (an imbalanced diet) as the grasses were in their mid and late stages of growth. Additionally, because these elephants were foraging in this area for particularly long times, my results show that despite this food imbalance, the majority of the elephants maintained their recommended energy intake by consuming large amounts of food high in NDF rather than protein. Even though these elephants were able to meet the recommended energy from food with high NDF content, this feeding strategy can be improved to obtain recommended energy from a balanced diet. I suggest that year-round feeding grounds for these elephants should be chosen or designed that contain more diverse plant species, enabling elephants to select food plants that provide optimal nutrition. With a better selection, elephants may be able to achieve a balanced diet rather than resorting to suboptimal food selections based on non-complementary choices of fodder plants, which in turn leads to an imbalanced diet and potential health-related issues.

I recorded 57 plant species in 28 families in the wild in Chitwan National Park and Parsa Wildlife Reserve, Nepal, both parks of which have elephant feeding sites. In both these parks, elephants showed a preference for species such as *Spatholobus parviflorus*, *Saccharum spontaneum, Mallotus philippensis, Saccharum bengalensis, Phragmites karka* and *Phoenix humilis*. My results showed that there was a seasonal difference in the availability of food plants. There was a negative correlation between the availability of plants and preference by elephants, which shows that food selection by elephants, is not driven only by relative availability. The understanding of this relationship is vital for conservation management of elephants and their habitat (Chapman et al. 2003) and to minimise human-elephant conflict in the wild. Also, wild elephants were found to consume more browse in the dry season and almost an equal proportion of browse to grass species during the wet season. This pattern may be related to climate as in the dry season there was a reduction of grass biomass with lower protein contents while during the wet season there were a higher protein and fatty acids reported in browse compared to grass plant species (Dougall and Sheldrik 1964; Field 1971; Sukumar 1990). My review on diet, dispersal and ranging patterns of elephants showed that habitat fragmentation and degradation due to anthropogenic activities such as agricultural expansion, overexploitation of forest resources and infrastructure development have adversely impacted the availability of wild fodder plants. As a result, wild elephants have had to change their usual movements and ranging patterns for foraging. These changes to movements and range extension are believed to be the prime factors bringing elephants and agriculture into close contact. With the increasing demand for nutrition in these fragmented habitats, nutritional needs are believed to be the primary driver for crop-raiding behaviour, which is seen as one of the main reasons for escalating human-elephant conflict. This is especially true with large animals requiring large daily intakes (Sukumar 1989; Chiyo 2000). Thus, I suggest that human–elephant conflict could be minimised by re-vegetating elephant migratory routes with native elephant food plants. These food sources should be given particular attention as part of a habitat management strategy, especially during the lean season. At the same time, planting less-preferred food plants of elephants in the agricultural fields near the fringe areas is recommended.

## 7.2 Limitations

The conclusions that I made in **Chapter 2** were based on data from a single captive elephant and thus may not be very representative. Nevertheless, I believe the study to be valuable because even research on a single animal foraging can provide insights into nutritional ecology for that species (Johnson et al. 2013).

Due to logistical problems associated with estimating the dietary intakes of wild elephants, I estimated this using indirect evidence of signs of feeding and a relative utilisation percentage rather than the direct observation methodology that was used for the captive and domesticated elephants (see **Chapter 4**). This method provided limited information and made estimating the proportion of nutrient intake of individual elephants impossible.  However, the data was used to investigate the diet of the elephant population in general. Future studies of the nutritional ecology of wild elephants could focus on developing methods for understanding nutritional composition based on direct observation, which may give more reliable and consistent information about intake.

Direct quantification of the relative damage of crops in the different regions could not be carried out because of time and logistical constraints. Instead, I used information from a questionnaire survey and secondary data from published literature to examine human–elephant conflict. A direct quantification method would allow us to compare the intensity of crop damage with the availability of natural food plants in an area, thereby enabling us to correlate the temporal and spatial pattern of crop damage with the availability of natural food in an area.

Currently, in most parts of the world, elephant habitat is well protected, but recommendations from nutritional studies may be used for the development of better, long-term habitat management and elephant conservation strategies. Geo-spatial analyses of land-use cover and degree of forest fragmentation and edge habitats in potential and actual elephant habitat may inform conservationists in managing anthropomorphic impacts on elephant habitats and food supplies resulting from human encroachment into elephant home ranges. Climate change may also have serious impacts on food availability and elephant health, and nutritional research that can future-proof the species against human-elephant conflicts are a necessary part of any conservation strategy for Asian elephants.

The following critical areas of future research were identified in this thesis:

- Future studies should be conducted on other groups of captive elephants to validate the finding of protein regulation in dietary intakes.
- Further study is needed to develop methods to quantify the diet of wild elephants.
- Further investigation is needed into the nutritional composition of the intakes of migratory elephant populations' for validation of the differences in the

nutritional choice between resident herds, migratory herds and domestic populations. The pattern of nutrient choice is likely to differ between these groups because of a variation in nutrient demand reflecting the different levels of physical activities due to their different ranging behaviour.

- Finally, further research is required to assess dispersal patterns and local conflict in other areas that experience human-elephant conflict.

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# Appendices

***"The elephant can survive, only if forests survive" quoted by Mark Shand***

**Appendix 1:** Plant foods eaten by Asian elephant in different regions in Asia.

| **Browse** | **Pradhan et al. 2008** | **Joshi & Singh 2008** | **Koirala et al. 2016** | **Steinheim 2005** | **Chen et al. 2006** | **Lihong et al. 2007** | **Samansiri & Weekaron 2007** | **Himmeslbach et al. 2006** | **Baskaran et al. 2010** |
|---|---|---|---|---|---|---|---|---|---|
| | Nepal | India | Nepal | Nepal | China | China | Sri Lanka | Myanmar | India |
| *Lagerstroemia parviflora* | √ | √ | √ | | | | | | |
| *Acacia arabica* | | √ | | | | | | | |
| *Acacia catechu* | √ | √ | √ | | | | | | |
| *Acacia chundra* | | | | | | | | | √ |
| *Acacia ferruginea* | | | | | | | | | √ |
| *Acacia intsia* | | | | | | | | | √ |
| *Acacia leucophloea* | | | | | | | √ | | √ |
| *Acacia megaladena* | | | | | √ | √ | | | |
| *Acacia pennata* | | | | | √ | | √ | | |
| *Acacia suma* | | | | | | | | | √ |
| *Arundo donax* | √ | | | √ | | | | | |
| *Bamboo* spp | | | √ | | √ | √ | | | |
| *Bombax ceiba* | √ | √ | √ | √ | | | | | |
| *Dalbergia lanceolaria* | | | | | | | √ | | |
| *Dalbergia latifolia* | | | | | | | | | √ |
| *Dalbergia sissoo* | √ | √ | | √ | | | | | √ |
| *Dalbergia volubilis* | | | | | | | | √ | |
| *Ficus. hirta* | | | | | | √ | | | |
| *Ficus nuobuo* | | | | | | √ | | | |
| *Ficus subincisa* | | | | | | √ | | | |
| *Ficus benghalensis* | √ | √ | | | | | √ | | √ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Ficus cyrtophylla* | | | | | | √ | | | |
| *Ficus glomerata* | | √ | | | | | | | |
| *Ficus hispida* | | | | | | √ | | | |
| *Ficus racemosa* | | | √ | | √ | √ | √ | | |
| *Ficus religiosa* | | | | | | | √ | | |
| *Ficus virens* | | | | | | | √ | | |
| ***Grass*** | | | | | | | | | |
| *Imperata cylindrica* - | √ | | √ | √ | | | | | |
| *Mallotus barbatus* | | | | | √ | | | | |
| *Mallotus philippensis* | √ | √ | √ | | | | | | |
| *Mallotus tetracvoccus* | | | | | | √ | | | |
| *Narenga porphyrocoma* | √ | | | | | | | | |
| *Phragmites karka* | √ | | √ | √ | | | | | |
| *Saccharum bengalensis* | √ | | √ | √ | | | | | |
| *Saccharum munja* | | √ | | | | | | | |
| *Saccharum spontaneum* | √ | √ | √ | √ | | | | | |

**Appendix 2:** Dates of observation sessions used to investigate Burma's foraging behaviour at Auckland Zoo; the days on which Burma had access to forest foods in addition to provisioned foods are indicated.

| **Observation session and day** | **Date** | **Forest or non-forest feeding** |
|---|---|---|
| *Session 1* | | |
| Day 1 | 26 November 2012 | Forest |
| Day 2 | 27 November 2012 | Forest |
| Day 3 | 28 November 2012 | Forest |
| *Session 2* | | |
| Day 4 | 6 March 2013 | Forest |
| Day 5 | 7 March 2013 | Non-forest |
| Day 6 | 8 March 2013 | Non-forest |
| *Session 3* | | |
| Day 7 | 18 March 2013 | Non-forest |
| Day 8 | 19 March 2013 | Non-forest |
| Day 9 | 20 March 2013 | Forest |
| *Session 4* | | |
| Day 10 | 27 March 2013 | Forest |
| Day 11 | 28 March 2013 | Non-forest |
| Day 12 | 29 March 2013 | Non-forest |

**Appendix 3:** Age, weight, sex, gross energy intake (GEI), digestible energy (DE) intakes of Asian elephants in two collections, one in Thailand (June) and the other in Auckland Zoo (Nov/ March).

Data sources: Thailand: Romani et al. 2014. Auckland Zoo: Koirala 2015 (Chapter 2)

| **Thailand Captive elephant** | **Age (years)** | **Weight (kg)** | **Sex** | **GEI (MJ per day)** | **DE (MJ per day)** | **Relative (DE) MJ per $kg^{0.75}$ per day** |
|---|---|---|---|---|---|---|
| 1 | 55 | 2575 | F | 593.4 | 313.4 | 0.9 |
| 2 | 55 | 2625 | F | 679.4 | 466 | 1.3 |
| 3 | 60 | 2725 | F | 701.2 | 358.2 | 0.9 |
| 4 | 45 | 2850 | M | 907.2 | 521.7 | 1.3 |
| 5 | 45 | 2905 | M | 763.2 | 457.3 | 1.2 |
| 6 | 50 | 3366 | M | 1039.7 | 607 | 1.4 |
| 7 | 10 | 1930 | F | 474.8 | 240.5 | 0.8 |
| 8 | 12 | 1993 | F | 495.7 | 298 | 1 |
| 9 | 26 | 3483 | F | 540.6 | 308.8 | 0.7 |
| 10 | 12 | 2697 | M | 497.6 | 208 | 0.6 |
| **Auckland Zoo elephant** | 33 | 3325 | F | 788.48 | 458.15 | 1.04 |

**Appendix 4:** ABCD. Age, weight, sex, gross (GEI), digestible (DE) and metabolised energy intakes of domestic Asian elephants in central Nepal. A, dry season (Mar/Apr); B, winter season (Nov/Dec); C, pre-monsoon season (May/Jun); D, monsoon season (Aug/Sep).

**A**

| Nepal domestic elephants | Age (years) | Weight (kg) | Sex | GEI (MJ per day) | DE (MJ per day) | Relative (DE) MJ per $kg^{0.75}$ per day |
|---|---|---|---|---|---|---|
| 1 | 26 | 2997 | F (non-lactating) | 907.95 | 355.44 | 0.88 |
| 2 | 13 | 2466 | F (lactating) | 1113.02 | 374.86 | 1.07 |
| 3 | 15 | 2643 | F (pregnant) | 817.50 | 370.72 | 1.01 |
| 4 | 16 | 2856 | F (pregnant) | 1447.00 | 279.81 | 0.72 |
| 5 | 12 | 1764 | M | 776.00 | 404.70 | 1.49 |
| 6 | 8 | 1600 | M | 747.00 | 341.00 | 1.35 |
| 7 | 58 | 3363 | M | 740.00 | 208.00 | 0.47 |
| 8 | 30 | 3200 | M | 985.52 | 378.61 | 0.89 |

**B**

| Nepal domestic elephants | Age (years) | Weight (kg) | Sex | GEI (MJ per day) | DE (MJ per day) | Relative (DE) MJ per kg$^{0.75}$ per day |
|---|---|---|---|---|---|---|
| 1 | 26 | 2997 | F (non-lactating) | 1195.31 | 428.45 | 1.06 |
| 2 | 13 | 2466 | F (lactating) | 1114 | 452 | 1.29 |
| 3 | 15 | 2643 | F (lactating) | 1164 | 451 | 1.23 |
| 5 | 12 | 1764 | M | 1257 | 392 | 1.44 |
| 7 | 58 | 3363 | M | 1213 | 523 | 1.19 |
| 9 | 27 | 2854 | M | 1211 | 412 | 0.87 |
| 10 | 46 | 4506 | M | 1494 | 426 | 0.78 |
| 11 | 46 | 2951 | M | 1083 | 426 | 1.07 |

**C**

| Nepal domestic elephants | Age (years) | Weight (kg) | Sex | GEI (MJ per day) | DE (MJ per day) | Relative (DE) MJ per $kg^{0.75}$ per day |
|---|---|---|---|---|---|---|
| 1 | 27 | 2997 | F (non-lactating) | 1049.00 | 410.00 | 1.01 |
| 2 | 14 | 2466 | F (lactating) | 1164.00 | 609.00 | 1.74 |
| 3 | 16 | 2643 | F (lactating) | 1038.00 | 491.00 | 1.33 |
| 7 | 59 | 3363 | M | 1090.00 | 315.00 | 0.71 |
| 12 | 69 | 3042 | F (non-lactating) | 1093.00 | 323.00 | 0.79 |
| 13 | 32 | 3330 | M | 1193.00 | 597.00 | 1.36 |
| 14 | 25 | 2869 | M | 1087.00 | 590.00 | 1.51 |
| 15 | 22 | 2840 | M | 1135.00 | 229.00 | 0.79 |

**D**

| **Nepal domestic elephants** | **Age (years)** | **Weight (kg)** | **Sex** | **GEI (MJ per day)** | **DE (MJ per day)** | **Relative (DE) MJ per kg$^{0.75}$ per day** |
|---|---|---|---|---|---|---|
| 1 | 27 | 2997 | F (non-lactating) | 1185 | 361 | 0.89 |
| 4 | 17 | 2856 | F (lactating) | 1127 | 174 | 0.45 |
| 7 | 59 | 3363 | M | 949 | 378 | 0.86 |
| 12 | 69 | 3042 | F (non-lactating | 1138 | 237 | 0.58 |
| 13 | 32 | 3330 | M | 947 | 311 | 0.71 |
| 14 | 25 | 2869 | M | 933 | 373 | 0.95 |
| 15 | 22 | 2840 | M | 951 | 440 | 1.13 |
| 16 | 43 | 3154 | F (non-lactating) | 1041 | 354 | 0.84 |

**Appendix 5:** Species, family, type of plant and plant parts consumed, and preference index for the majority of plants consumed by wild Asian elephants. A preference index score >1 indicates food that was utilised proportionately more than its occurrence in the environment, and food with a preference index score <1 was utilised proportionately less than its occurrence in the environment.

**Parsa Wet Season**

| Plant Species | Type | Family | Parts Eaten | IVI | Utilisation% | Preference |
|---|---|---|---|---|---|---|
| *Acacia catechu* | Tree | Mimosaceae | Leaves, twigs and bark | 16.38 | 2.8 | 0.17 |
| *Asparagus racemosus* | Under Shrub | Asparagaceae | Leaves, twigs and stem | 9.04 | 0.2 | 0.02 |
| *Bauhinia purpurea L.* | Tree | Fabaceae | Leaves and twigs | 5.13 | 0.1 | 0.02 |
| *Bamboosa sp.* | Grass | Poaceae | Leaves and twigs | 1.33 | 3.5 | 2.63 |
| *Bauhinia vahlii* | Climber | Fabaceae | Leaves and twigs | 5.47 | 0.1 | 0.02 |
| *Bombax ceiba* | Tree | Malvaceae | Leaves and bark | 2.74 | 2.85 | 1.04 |
| *Bridelia retusa* | Tree | Euphorbiaceae | Leaves and twigs | 2.30 | 0.2 | 0.09 |
| *Careya arborea* | Tree | Lecythidaceae | Leaves and twigs | NA | NA | NA |
| *Casearia elliptica* | Tree | Salicaceae | Leaves and twigs | 7.08 | 0.05 | 0.01 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Sida rhombifolia* | Shrub | Malvaceae | | 3.05 | 2.24 | 0.73 |
| *Cymbopogan sp.* | Grass | Poaceae | Stem with leaves | 51.35 | 0.2 | 0.00 |
| *Dalbergia sissoo* | Tree | Fabaceae | Leaves, twigs and bark | 1.11 | 0.7 | 0.63 |
| *Digitaria ciliaris* | Grass | Poaceae | Stem with leaves | 20.41 | 0.91 | 0.04 |
| *Dillenia pentagyna* | Tree | Dilleniaceae | Leaves and twig | 48.61 | 11.32 | 0.23 |
| *Duabanga sonneratioides* | Tree | Lythraceae | | 0.92 | 0.2 | 0.22 |
| *Equisetum debile* | Herb | Equisetaceae | Leaves and stem | 0.92 | 1.82 | 1.98 |
| *Ficus semicordata* | Tree | Moraceae | Leaves | 2.94 | 0.60 | 0.20 |
| *Garuga pinnata* | Tree | Burseraceae | Stem and bark | 11.59 | 17.59 | 1.52 |
| *Hemarthria compressa* | Grass | Poaceae | Stem with leaves | 38.87 | 0.10 | 0.002 |
| *Holarrhena pubescens* | Tree | Euphorbiaceae | Leaves and twig | 1.78 | 8.08 | 4.54 |
| *Hypericum uralum* | Shrub | Hypericaceae | | 2.02 | 2.39 | 1.18 |
| *Hypoxis aurea* | Grass | Poaceae | Stem with leaves | 3.89 | 7.28 | 1.87 |
| *Lagerstroemia parviflora* | Tree | Lythraceae | Leaves and bark | 22.55 | 0.80 | 0.04 |
| *Leea robusta* | Large shrub/Tree | Leeaceae | Leaves | 0.85 | 1.51 | 1.78 |
| *Litsea monopetala* | Tree | Lauraceae | Leaves | 1.80 | 0.40 | 0.22 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Mallotus philippensis* | Tree | Euphorbiaceae | Leaves | 10.36 | 1.61 | 0.16 |
| *Musa sp.* | Tree | Musaceae | Leaves and stem | 1.82 | 0.3 | 0.16 |
| *Osyris lanceolata/Wightiana* | Tree | Santalaceae | | 1.34 | 0.05 | 0.04 |
| *Desmodium oojeinense* | Tree | Fabaceae | Bark | 0.87 | 0.40 | 0.46 |
| *Paspalum sp.* | Grass | Poaceae | Stem with leaves | 2.31 | 3.00 | 1.30 |
| *Phoenix humilis* | Shrub | Palmae | Leaves, fruit and root | 2.61 | 0.30 | 0.11 |
| *Phragmites karka* | Grass | Poaceae | Stem with leaves | 3.35 | 1.51 | 0.45 |
| *Saccharum bengalensis* | Grass | Poaceae | Stem with leaves | 2.34 | 3.00 | 1.28 |
| *Saccharum spontaneum* | Grass | Poaceae | Stem with leaves | 36.92 | 0.40 | 0.01 |
| *Shorea robusta* | Tree | Dipterocarpaceae | Bark | 32.98 | 0.40 | 0.01 |
| *Spatholobus parviflorus* | Climber | Fabaceae | Leaves, bark and stem | 4.76 | 12.00 | 2.52 |
| *Sterculia villosa* | Tree | Malvaceae | Leaves and Bark | 6.11 | 4.50 | 0.74 |
| *Terminalia chebula* | Tree | Combretaceae | Bark | 1.14 | 0.10 | 0.09 |
| *Thysanolaena maxima* | Grass | Poaceae | Leaves and twigs | 1.32 | 7.28 | 5.52 |
| *Ziziphus mauritiana* | Tree | Rhamnaceae | Leaves and twigs | 2.73 | 0.11 | 0.04 |

**Chitwan Wet Season**

| Plant species | Type | Family | Parts Eaten | IVI | Utilisation % | Preference |
|---|---|---|---|---|---|---|
| *Artocarpus heterophyllus* | Tree | Moraceae | Leaves, fruits | NA | NA | NA |
| *Bauhinia purpurea L.* | Tree | Fabaceae | Leaves and twigs | NA | NA | NA |
| *Bamboosa sp.* | Grass | Poaceae | Stem, leaves and twigs | 6.46 | 5.95 | 0.92 |
| *Bridelia retusa* | Tree | Euphorbiaceae | Leaves and twigs | 1.03 | 1.48 | 1.44 |
| *Careya arborea* | Tree | Lecythidaceae | Leaves , twigs and bark | NA | NA | NA |
| *Sida rhombifolia* | Shrub | Malvaceae | | 1.22 | 0.12 | 0.10 |
| *Cleistocalyx operculata* | Tree | Myrtaceae | Leaves and twigs | 25.46 | 3.97 | 0.16 |
| *Cymbopogan sp.* | Grass | Poaceae | Stem with leaves | 1.14 | NA | NA |
| *Desmodium oojeinense* | tree | Fabaceae | | 2.23 | 0.49 | 0.22 |
| *Desmostachya bipinnata* | Grass | Poaceae | Stem with leaves | 3.56 | 3.56 | 1.00 |
| *Dillenia pentagyna* | Tree | Dilleniaceae | Leaves and twigs | 15.85 | 1.98 | 0.12 |
| *Duabanga sonneratioides* | Tree | Lythraceae | | 2.19 | 0.24 | 0.11 |
| *Ficus hispida* | Tree | Moraceae | Leaves and twigs | NA | NA | NA |
| *Ficus religiosa* | Tree | Moraceae | Leaves and twigs | NA | 4.76 | |
| *Hemarthria compressa* | Grass | Poaceae | Stem with leaves | 9.87 | 0.74 | 0.07 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Holarrhena pubescens* | Tree | Euphorbiaceae | Leaves and twig | 2.04 | 0.49 | 0.24 |
| *Imperata cylindrica* | Grass | Poaceae | Stem with leaves | 52.18 | 1.31 | 0.03 |
| *Leea macrophylla* | Shrub/Tree | Leeaceae | | 3.04 | 0.37 | 0.12 |
| *Litsea monopetala* | Tree | Lauraceae | Leaves | 17.17 | 12.4 | 0.72 |
| *Mallotus philippensis* | Tree | Euphorbiaceae | Leaves | 3.99 | 9.90 | 2.48 |
| *Murrya coenigii* | Tree | Rutaceae | Leaves and twigs | 4.92 | 0.49 | 0.10 |
| *Myrsine semiserrata* | Tree | Myrsinaceae | Bark | NA | NA | |
| *Phragmites karka* | Grass | Poaceae | Stem with leaves | 2.62 | 6.62 | 2.53 |
| *Premna integrifolia L.* | Tree | Verbenaceae | | 1.03 | 0.19 | 0.18 |
| *Saccharum bengalensis* | Grass | Poaceae | Stem with leaves | 3.86 | 0.37 | 0.10 |
| *Saccharum spontaneum* | Grass | Poaceae | Stem with leaves | 12.29 | 6.75 | 0.55 |
| *Shorea robusta* | Tree | Dipterocarpaceae | Bark | 131.73 | 23.44 | 0.18 |
| *Spatholobus parviflorus* | Climber | Fabaceae | Leaves, bark and stem | 4.08 | 14.00 | 3.43 |
| *Syzygium cumini* | Tree | Myrtaceae | Leaves, twigs and bark | 1.5 | 0.25 | 0.17 |

**Parsa Dry Season**

| Plant species | Type | Family | Parts Eaten | IVI | Utilisation % | Preference |
|---|---|---|---|---|---|---|
| *Acacia catechu* | Tree | Mimosaceae | Bark | 37.04 | 7.92 | 0.21 |
| *Cymbopogan sp* | Grass | Poaceae | Stem with leaves | 6.38 | 14.85 | 2.33 |
| *Duabanga sonneratioides* | Tree | Lythraceae | | 13.67 | 1.98 | 0.14 |
| *Lagerstroemia parviflora* | Tree | Lythraceae | Leaves and bark | 2.11 | 5.94 | 2.82 |
| *Litsea monopetala* | Tree | Lauraceae | Leaves | 1.80 | 1.98 | 1.10 |
| *Mallotus philippensis* | Tree | Euphorbiaceae | Leaves, bark | 20.37 | 11.88 | 0.58 |
| *Phoenix humilis* | Shrub | Palmae | Leaves, fruits and root | 3.40 | 9.90 | 2.91 |
| *Saccharum spontaneum* | Grass | Poaceae | Stem with leaves | 2.60 | 9.90 | 3.81 |
| *Shorea robusta* | Tree | Dipterocarpaceae | Bark | 40.00 | 1.98 | 0.05 |
| *Spatholobus parviflorus* | Climber | Fabaceae | Leaves, bark, and stem | 1.70 | 15.84 | 9.32 |

**Chitwan Dry Season**

| Plant species | Type | Family | Parts Eaten | IVI | Utilisation % | Preference |
|---|---|---|---|---|---|---|
| *Caesalpinia sp.* | Tree | Fabaceae | Leaves and flower | 3.36 | NA | NA |
| *Ficus hirta* | Tree | Moraceae | Leaves and twigs | 1.25 | NA | NA |
| *Ficus racemosa* | Tree | Moraceae | Bark | 1.26 | 11.63 | 9.23 |
| *Ficus semicordata* | Tree | Moraceae | Leaves and Bark | 7.9 | 7.75 | 0.98 |
| *Mallotus philippensis* | Tree | Euphorbiaceae | Bark | 1.26 | 9.30 | 7.38 |
| *Miliusa velutina* | Tree | Annonaceae | Leaves, bark | 4.22 | 6.20 | 1.47 |
| *Narenga porphyrocoma* | Grass | Poaceae | Stem with leaves | 5.8 | 1.55 | 0.27 |
| *Phoenix humilis* | Shrub | Palmae | Leaves, fruits and root | 1.25 | 1.55 | 1.24 |
| *Phragmites karka* | Grass | Poaceae | Stem with leaves | 3.09 | 3.10 | 1.00 |
| *Saccharum bengalensis* | Grass | Poaceae | Stem with leaves | 7.82 | 13.95 | 1.78 |
| *Saccharum spontaneum* | Grass | Poaceae | Stem with leaves | 37.3 | 12.40 | 0.33 |
| *Semecarpus anacardium* | Tree | Anacardiaceae | Leaves and bark | 1.39 | 9.30 | 6.69 |
| *Spatholobus parviflorus* | Climber | Fabaceae | Leaves, bark and stem | 6.96 | 10.85 | 1.56 |
| *Cleistocalyx operculata* | Tree | Myrtaceae | Leaves and twigs | 1.3 | 4.65 | 3.58 |

**Appendix 6:** Survey questionnaire to assess human-elephant interaction, focusing on crop raiding pattern in Parsa- Chitwan region, Nepal.

- Date:
- Questionnaire Number:
- Interviewer Name:

**Part One: Basic Information about the interviewee:**

1. Name----------------------; Age-----; Sex; Male ☐ Female . ☐

2. VDC/Municipality----------------Ward No-------- Village Name------------------------

3. GPS Location: (Way point) -----

**Part Two: Human-Elephant conflict:**

4. Since how long ago have you been living in this village? ……….. years

5. Have you or your family member experienced conflict with elephant over the last ten years:

   a) Yes      b) No

---

6. If yes you have experienced conflict, what type of conflict was it?

   1) Property damage   2) Crop raiding   3) Human casualty   4) Human injury   5) successfully chased without any damage

---

7. Did you or your fellow villagers injure or kill any wild elephants that attacked the villagers and raided crops?

   a) Injured   b) Killed   c) No

---

8. Of the problems 1-5 above caused by wild elephants, what are the most severe problems experienced by your village (in order of frequency and severity)?

---

9. Do you have crop fields?   a) Yes,      b) No

If Yes-- What are the different crops/ vegetables and fruits you grow?

Paddy, Wheat, Maize, Mustard, millet, Sugarcane, Banana --- others (tick or write)

---

10. What is the extent of different crops cultivated?

11. Which months do you cultivate these crops?

12. Which crops were perceived by the respondents to be the most raided (in order)?

Paddy, Wheat, Maize, Mustard, millet, Sugarcane, Banana --- others (tick or write)

13. Parts Eaten/ Trampling:

a) Whole plant b) the Whole plant without root, c) Only grain with husk d) Leaves e) stem

**Parts ate:** Paddy, ……….. Wheat,….. Maize, …… Mustard,….. Millet,……Sugarcane ………. Banana……… others….

**Parts trampled:** Paddy, ……….. Wheat,….. Maize, …… Mustard,….. Millet,……Sugarcane ………. Banana……… others….

14. Which growth stage?

a) Vegetative b) reproductive c) Heading d) Maturity

**Growth Stage:** Paddy, ……… Wheat,……. Maize, …… Mustard,….. millet,……Sugarcane,….. Banana,……Others…..

15. Which months of the year elephant damages occur?

a. Property damage b. Crop Raiding c. Human/ Elephant casualty

16. What is the frequency of elephant visit and crop raiding?

17. What is the time of the day the damage by elephant most likely occurred (early morning 2 am to 6 am; morning 6 am to 10 am; day 10 am to 2 pm; afternoon 2 pm to 6 pm; evening 6 pm to 10 pm; night 10 pm to 2 am)?

18. What is the trend of elephant damage over the last ten years?

I. Property damage (Mark)

a. Increased (…..)
b. Steady (…..)
c. Decreased (…..)

II. Crop raiding (Mark one)

a. Increased (…..)
b. Steady (…..)
c. Decreased (…..)

III. Human casualty (Mark one)

a. Increased (…..)
b. Steady (…..)
c. Decreased (…..)

IV. Elephant casualty (Mark one)

a. Increased (…..)

b. Steady (…..)

c. Decreased (----)

**Part three: Causes of conflict**

19. What are the major causes of human-elephant conflict? (In order of priority)

a.______________ b.______________ c. ______________

20. Why do you think elephant move to human habitation (Circle one or more)?

a. In search of better nutritive forage
b. Easy access to agriculture field near elephant habitat
c. Depletion of natural food plants in the forests
d. Problem elephant
e. Traditional elephant range
f. Other (describe)______________

21. Which of the following do you think is the prime cause for the increased human-elephant conflict in this region (Circle one or more)?

a. Increase in number of elephants
b. Changing ranging behaviour
c. Human moved into elephant habitat
d. Inadequate preventive measures
e. Others (describe)_____________

---

22. What is the composition of the raiding group (Single male or Family herd) caused the most damage? (Rank 1-high damage, 2- medium damage, 3- lesser damage)

Single Male — Family herd

a. Property damage: ………… a. property damage: …………
b. Crop raiding: …………… b. Crop raiding: ……………
c. Human casualty: ………… .c. Human casualty:-------------
d. Human Injury ---------------- d. Human injury----------------

---

23. How do you know?
a. I've seen them.
b. Household member has seen them.

c. Have seen tracks
d. Have seen feeding sign
e. Have seen elephant dung
f. Have heard elephant sound
g. Have seen elephant damaged property
h. Have seen other signs

---

24. Do elephants move to your area from a specific route or different routes?

---

25. Can you show the elephant use area to the interviewer on a map or through participatory mapping? (Record the locations through GPS and mark on the map)

---

**Part four: Peoples Attitude towards elephant conservation:**

26. What do you think is the relative abundance of Elephants in your area?

a) Today: rare----- ( ) fairly common----- ( ) abundant ( ) (Tick one)
b) 10 years ago: rare---- ( ) fairly common------ ( ) abundant ( ) (Tick one)

---

27. Do you think elephants should be protected?

a) Yes b) No

If yes, how?

---

28. What should be done to minimize conflict between people and elephant in this area?

a. Translocation of problem elephant
b. Culling
c. Shift to alternative crop and livelihood option
d. Help regenerate natural food plants in the forests

---

29. Do you want human-elephant coexistence in this area? a). Yes b). No

---

30. If yes how?

a. _____________ b. _____________ c. _____________

---

31. If no what should be done?

   a. Culling of elephants

   b. Relocate elephants

   c. Relocate affected villages

   d. Others

Appendix 7

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BMC Ecology

RESEARCH ARTICLE

Open Access

# Feeding preferences of the Asian elephant (*Elephas maximus*) in Nepal

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## Abstract

**Background:** Nepal provides habitat for approximately 100–125 wild Asian elephants (*Elephas maximus*). Although a small proportion of the world population of this species, this group is important for maintaining the genetic diversity of elephants and conservation of biodiversity in this region. Knowledge of foraging patterns of these animals, which is important for understanding their habitat requirements and for assessing their habitat condition, is lacking for the main areas populated by elephants in Nepal. This study investigates the feeding preferences of the Asian elephant in Parsa Wildlife Reserve (PWR) and Chitwan National Park (CNP), Nepal.

**Result:** Fifty-seven species of plants in 28 families were found to be eaten by Asian elephants, including 13 species of grasses, five shrubs, two climbers, one herb and 36 species of trees. The species that contributed the greatest proportion of the elephant's diet were *Spatholobus parviflorus* (20.2%), *Saccharum spontaneum* (7.1%), *Shorea robusta* (6.3), *Mallotus philippensis* (5.7%), *Garuga pinnata* (4.3%). *Saccharum bengalensis* (4.2%), *Cymbopogan* spp (3.7%), *Litsea monopetala* (3.6) and *Phoenix humilis* (2.9%). The preference index (PI) showed that browsed species were preferred during the dry season, while browsed species and grasses were both important food sources during the rainy season. Elephants targeted leaves and twigs more than other parts of plants ($P < 0.05$).

**Conclusion:** This study presents useful information on foraging patterns and baseline data for elephant habitat management in the PWR and CNP in the south central region of Nepal.

**Keywords:** Browse. elephant habitat, Feeding sign, Food preferences, Micro-histological analysis

## Background

Elephants are among the internationally endangered large mammals [1]. The habitat of Asian elephants (*Elephas maximus)* has been decreasing throughout their range, due primarily to habitat destruction and fragmentation resulting from human land use practices [2, 3]. Even though elephant populations have decreased, in general, the local density of elephants has increased due to habitat loss [4]. This has caused resource competition among elephants [5], and increased human–elephant conflict [6]. Asian elephants are generalised herbivores utilising a variety of plant species [2, 7]. Large herbivores such as elephants require extensive home ranges to satisfy their high food demand [8]. Reduction in food availability due to loss of habitat has created challenges for elephant conservation in the many regions in Asia.

Although the dietary requirements of Asian elephants have been studied, the majority of these studies [2, 5, 9, 10] have dealt with the documentation of food plant species, the rate of consumption and seasonal comparative diet overlap between sympatric elephants and rhinos [11, 12]. However, details regarding food choice and seasonal diet composition remain unknown. Such information is important for Asian elephant conservation in terms of habitat management and human–elephant conflict mitigation.

Nepal provides important habitat for Asian elephants. Historically habitat in the Terai range was continuous. Currently, elephants are found only in four regions of the country, eastern, central, western and far-western. In central Nepal, Parsa Wildlife Reserve (PWR) is the main elephant habitat. However, elephants were found

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to migrate between PWR and Chitwan National Park (CNP) since the middle of the 1990s [13]. The migration of elephants between these sites was thought to be primarily due to the reduction of water availability in the Bara Forest near PWR resulting in reduced food availability and aggravated competition with livestock [13]. Currently, all the four isolated population of elephants in Nepal are in the lowland Terai region. These widespread and fragmentary distributed elephants strongly prefer floodplain communities, and there is a significant shift from browse to grass-dominated vegetation between seasons in Bardia National Park [12, 14]. However, the diet has not been studied for other elephant populations of the country.

This study aims to investigate the food preferences and seasonal changes in foraging patterns of the Asian elephant in the PWR, CNP and adjoining forests. We predict a climate-related reduction in grass productivity in the Parsa area will correspond with a reduction of grass in the elephant diet during the dry season. Information obtained from this study will aid elephant conservation in respect to the restoration of their habitats, and will thereby contribute towards minimising human–elephant conflict.

## Methods

The study was carried out at the Parsa Wildlife Reserve and part of adjoining reserve forest (Bara forest) in the north and Chitwan National Park and part of its buffer Zone forests. Permission for the study was acquired from the Department of National Park and Wildlife Conservation, the government of Nepal. Parsa Wildlife Reserve is the largest wildlife reserve in Nepal (Fig. 1), consisting of 499 $km^2$ sub-tropical forests in the south-central lowland Terai ecoregion of Nepal. The PWR is located in the Churia hills, the outermost foothills of the Himalayas [15], which are a part of the Bhabar District. The PWR is typically dry with average rainfall between 300 and 450 mm during the summer months [13, 16]. The typical vegetation of this reserve and the adjoining Bara forest is tropical and subtropical forest types with Sal (*Shorea robusta*) forest about 90% of the vegetation. Chirpine (*Pinus roxburghii*) grows in the Churia hills. Khair (*Acacia catechu*), Sisso (*Dalbergia sisso*) and Silk cotton (*Bombax ceiba*) trees occur along water channel. Sabai grass (*Eulaliopsis binata*) grows well on the southern face of the Churia Hills [17, 18]. Chitwan National Park was established in 1973 as the first national park in Nepal and was listed as a World Heritage Site in 1984. The CNP spans 932 $km^2$ and is situated in the sub-tropical lowlands of the Inner Terai, in the Chitwan district of south-central Nepal (Fig. 1). Elevation ranges from approximately 100 m in lowland river valleys to 815 m on Churia Hill ridgetops. In the north-west of this protected area, the Narayani and Rapti rivers separate the park from human settlements [19]. The buffer zone has mostly agriculture fields and human settlements along with community forests. The typical vegetation of CNP and its buffer zone forests is Himalayan subtropical broadleaf forests with primarily Sal (*Shorea robusta*) trees covering about 70% of the national park area. On northern slopes, Sal associated with smaller flowering tree and shrub species such as *Terminalia bellirica, Dalbergia sissoo, Dillenia indica, Garuga pinnata* and climbers such as *Bauhinia vahlii* and *Spatholobus parviflorus* [17, 18, 20].

Both the PWR and CNP are prime habitats for wild Asian elephants and both parks are adjacent to Valmiki tiger reserve in India (Fig. 1). These three trans-boundary, contiguous protected areas cover a 3549 $km^2$ mixed-habitat zone containing large tracts of grasslands and humid deciduous forests, which provide suitable habitat for a large number of megaherbivores and big cats such as Asian elephants, endangered tigers (*Panthera tigris*) and greater one-horned rhinos (*Rhinoceros unicornis*).

### Elephant feeding data collection

Opportunistic direct feeding observations and the observation of elephant feeding sign on food trails (elephant feeding routes) were the methods used in the present study to determine diet selection of elephants residing in different areas and travelling on different migration routes [9, 21]. The feeding routes observed to be taken by elephants were followed by field researchers, and all plant species showing signs of being eaten by elephants were recorded. Evidence of feeding sign included elephant footprints, fresh dung piles nearby to browsed foliage, and the identifying characteristics of plant damage caused by elephant browse, such as debarkation, branch breaking and uprooting. The following data were recorded to determine the feeding preferences of Asian elephants: (1) plant species browsed, (2) parts of the plant eaten (leaves, branches and/or bark), (3) habitat type and (4) global positioning system (GPS) coordinates of sample sites (Fig. 1). The relative frequency (percentage) of feeding sign was calculated to yield a feeding sign score. Feeding sign was ranked according to the intensity of browsing, the proportion of bark, stem and foliage removed and/or the area of grass eaten.

### Elephant dietary analysis from dung samples

Samples of elephant dung encountered during a total 24 days of field survey in the wet season (June–September

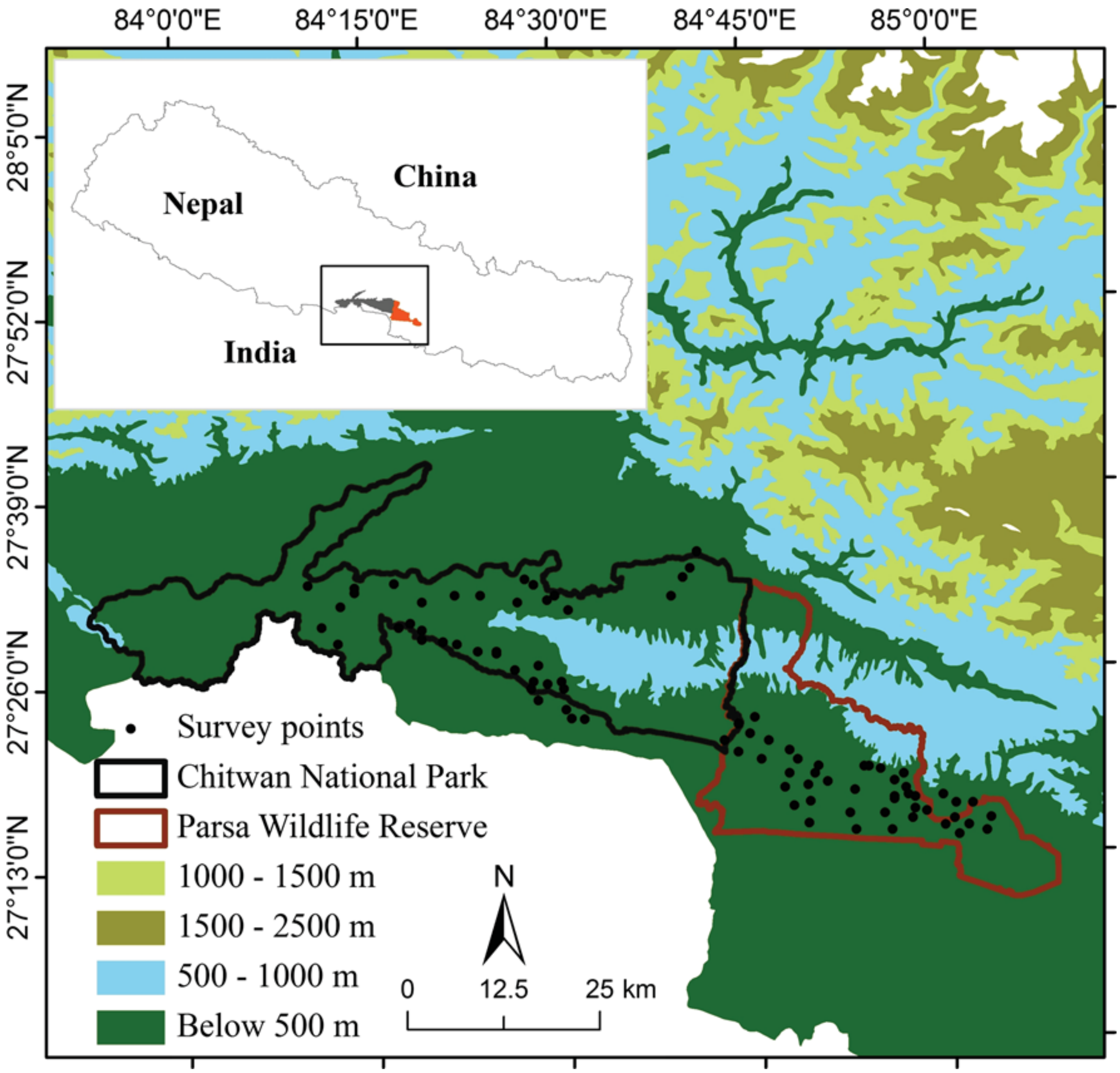


**Fig. 1** Map of the Parsa Wildlife Reserve (PWR) and Chitwan National Park (CNP) showing locations of plots used for vegetation and feeding sign surveys

2012) and the dry season (February–April 2013) were collected. Visual examination of deposited elephant dung piles was performed to identify the presence of macro plant fragments. Micro-plant fragments were identified through micro-histological analysis [22–24]. This dual methodology is widely used for estimating the diet composition of herbivores [25]. Fragments of probable food species were collected for the preparation of reference slides. The collection was made as per methods used in the previously published literature describing elephant food plants [11, 12]. A total of 20, non-overlapping random fragments were isolated on each dung slide and were compared with a reference slide for epidermal derivatives. Microphotographs were taken using a 100 × 4× lens and an Am Scope MT130 1.3 megapixel USB2.0 microscope eyepiece digital camera.

#### Food availability survey

To assess the food preferences of elephants, we carried out vegetation surveys using the point-centred quarter technique [26] to obtain data on the relative abundance of different plant species. A total of 30 transects of 2 km length each, one each per habitat type, were created for this survey. To compare the availability of food plants within and outside protected areas, 20 of these transects were placed in the protected areas, while the remaining ten transects were located in habitats outside national parks. Each transect was surveyed twice, once in the wet season (August/September) and once in the dry season (March/April). A total of 10 sample points were assigned to each transect at 200 m interval for the purpose of gathering data on potential forage trees. Also, 10 quadrats measuring 1 m × 1 m each were created near each sample points to collect data on density, frequency and visual estimation of cover % of dietary grass species. At each sample point, a cross was laid on the ground to divide the area into four quarters (Fig. 2). From each quarter, the closest tree from the centre was identified and the following data collected: (1) the species of the tree, (2) the distance from the tree to the centre of the quarter, (3) diameter at breast height (DBH) of the tree.

### Data analysis

Elephant feeding sign survey was conducted by scoring the different signs according to the intensity of damage. The definition of scores for bark was: $1 \leq 0.5$ m$^2$; $2 = 0.5$–$1$ m$^2$; $3 \geq 1$ m$^2$; for branch score: 1 = up to 5 cm diameter; 2 = 5–20; 3 > 20; while foliage score: $1 \leq 10\%$ of foliage eaten; 2 = 10–40%, $3 \geq 40\%$ and grass score of 1 = up to 1 m diameter; 2 = more than 2 m; 3 = more than 5 m. Total feeding score was calculated by multiplying the frequency of each plant species showing feeding signs with total feeding sign score of that species. Total feeding score of each species was multiplied by 100 and divided by the total feeding score of all species to calculate an index equivalent to utilisation percent. The importance value index (IVI) of a plant species in each habitat was calculated by adding the relative frequency, density and dominance (basal area) for trees. The relative frequency, density and cover for grass and herbaceous species was used as an index of availability of a species in the study area [21]. The density of browse was calculated using the distance from the tree to the centre of the quarter following Mitchell [27].

The preference index (PI) was calculated using the following equation [21, 28]:

$$\text{Preference index (PI)} = \frac{\text{Utilization percentage}}{\text{Percentage availability in the environment}} \qquad (1)$$

A PI score >1 indicates food that was utilised proportionately more than its occurrence in the environment,

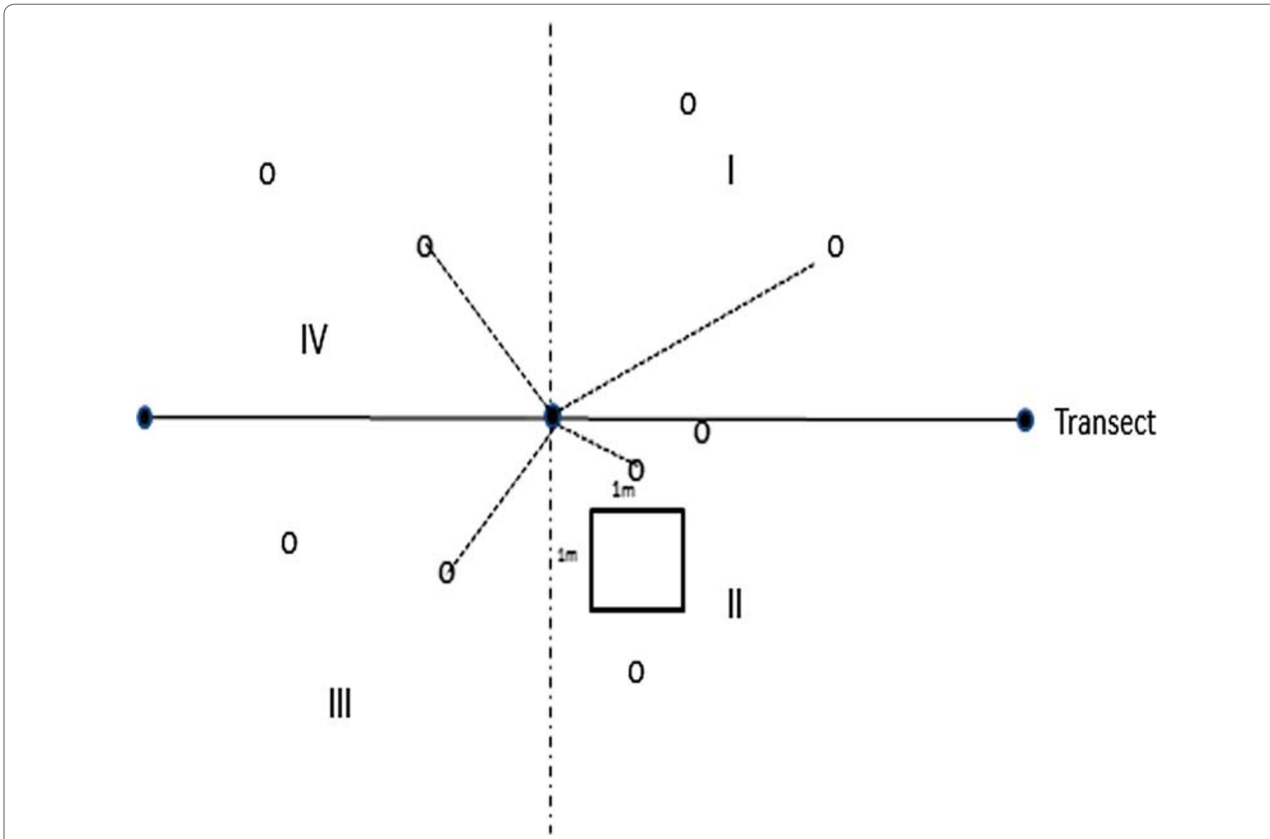


**Fig. 2** Sample points along a transect with the nearest trees in each quarter indicated by *dash lines* and a grass of 1 m × 1 m near each sample points

and a PI score <1 indicates a plant food that was used proportionately less than its presence in the environment.

The Chi-square test was used to test for differences in feeding preferences between plant parts, seasons and sites differences in vegetation density; Pearson correlation was used to determine the correlation between forage availability and preference. Simpson's diversity index was used to estimate the vegetation diversity, and the independent sample *t* test was applied to test for seasonal dietary intake differences in monocot and dicot plants. All tests were performed using Excel and IBM SPSS statistical version 22.

## Results

### Elephant foraging patterns

In total, 57 species of plants (13 grass, five shrubs, two climbers, one herb and 36 tree species) belonging to 28 taxonomic families were eaten by Asian elephants. In the Parsa area, 40 species (10 grass, four shrub, two climber, one herb and 23 tree species) were consumed, and in the Chitwan area 37 species (nine grass, three shrub, one climber and 24 tree species) were utilised; the utilisation pattern suggests that 76% of all identified food species were consumed during the wet season, with only 24% consumed during the dry season (Additional file 1: Appendix). The foliage (leaves and twigs) of both grasses and browsed trees were selected more than the stems, bark, roots and fruits during the wet season in both Parsa and Chitwan ($\chi^2 = 10.72$, df = 6, P < 0.05), whereas debarkation and uprooting were more common in the dry season ($\chi^2 = 5.24$, df = 4, P < 0.05).

### Dietary analysis from dung samples

Microscopic analysis of 36 dung samples collected during two seasons showed a higher dicot-to-monocot ratio in the dry season compared to the wet season. The average dicot-to-monocot ratio was 1:0.57 in the dry season, whereas the ratio was 1:1.11 in the rainy season. The observations from the feeding sign survey and the micro-histological analysis revealed that dicots were consumed more during the dry season (t = −4.27, df = 10, P = 0.002). There was no significant difference in the presence of dicot and monocot plants in elephant diet during the rainy season (t = 1.59, df = 58, P = 0.117).

### Regional food availability

There was no difference in the types of plants availability in and outside the two sites ($P \geq 0.05$). However, species diversity was slightly lower in CNP (Simpson's diversity index, D = 0.097) than in the PWR (D = 0.091). Similarly, in both study sites and seasons, food species densities and frequencies recorded were significantly different.

There was a significant relationship of grass and browse abundance in dry and wet season in Parsa and Chitwan, indicating an association between these factors ($\chi^2 = 8.92$, df = 1, P = 0.002). Higher densities of each browse species were recorded in the PWR (mean density, 25.00/ha) than in the CNP (mean density, 20.4/ha). Seasonally the wet season mean density of each browse species in Chitwan and Parsa were 23.2 and 15.4/ha respectively. In the dry season, the mean density of browse in Chitwan was 16.3 and in Parsa 20.0/ha. There was significant difference in the frequency of grasses (χ2 = 20, df = 1, P < 0.001) in the dry season in both parks with higher frequencies of grass species recorded in the dry season in CNP (mean frequency 3.45/q; mean density, 115.7/$m^2$) than in PWR (mean frequency, 1.57/q; mean density, 22.85/$m^2$). The mean grass frequency and density in the wet season in Chitwan was 4.5/q and 160 individuals/$m^2$, respectively. In Parsa, the mean grass frequency and density was 2.0/q and 131 individuals/$m^2$. There was a negative correlation between the availability of individual plant food species in the habitat and their utilisation by elephants (r = −0.244, P = 0.02).

### Plant species preferences

Elephants showed a positive PI score for 26 out of the 57 utilised plant species (Fig. 3). Elephant browse that had relatively high PI scores ranged from 1.04 (*Bombax ceiba*) to 9.2 (*Ficus racemosa*). Similarly, vine PI scores ranged from 0.02 (*Bauhinia vahlii*) to 9.32 (*Spatholobus parviflorus*). Shrubs that had relatively high PI scores were *Hypericum uralum* (1.18) and the palm *Phoenix humilis* (2.91). Grass PI scores ranged from 1.28 (*Saccharum bengalensis)* to 5.51 (*Thysanolaena maxima*). Species that were highly abundant, which may have led to lower PI scores, included *Shorea robusta, Dillenia pentagyna, Hemarthria compressa, Imperata cylindrica* and *Cymbopogon* spp.

Overall, in both sites, elephants showed the strongest preferences for common species such as *Spatholobus parviflorus, Saccharum spontaneum, Phoenix humilis, Saccharum bengalensis, Mallotus philippensis,* and *Phragmites karka*. In addition to these species, elephants in the Chitwan area showed a strong preference for *Cleistocalyx operculata* and *Bridelia retusa*, while Parsa area elephants showed a strong preference for *Litsea monopetala*, *Thysanolaena maxima*, *Sterculia villosa, Equisetum debile, Bambusa* spp. and *Hypericum uralum*. The availability of these species in the two parks varies. Amongst these 26 most preferred species, 17 species were preferred more by elephants in Parsa, while the remainder (nine species) were preferred relatively more by Chitwan elephants (Fig. 3).

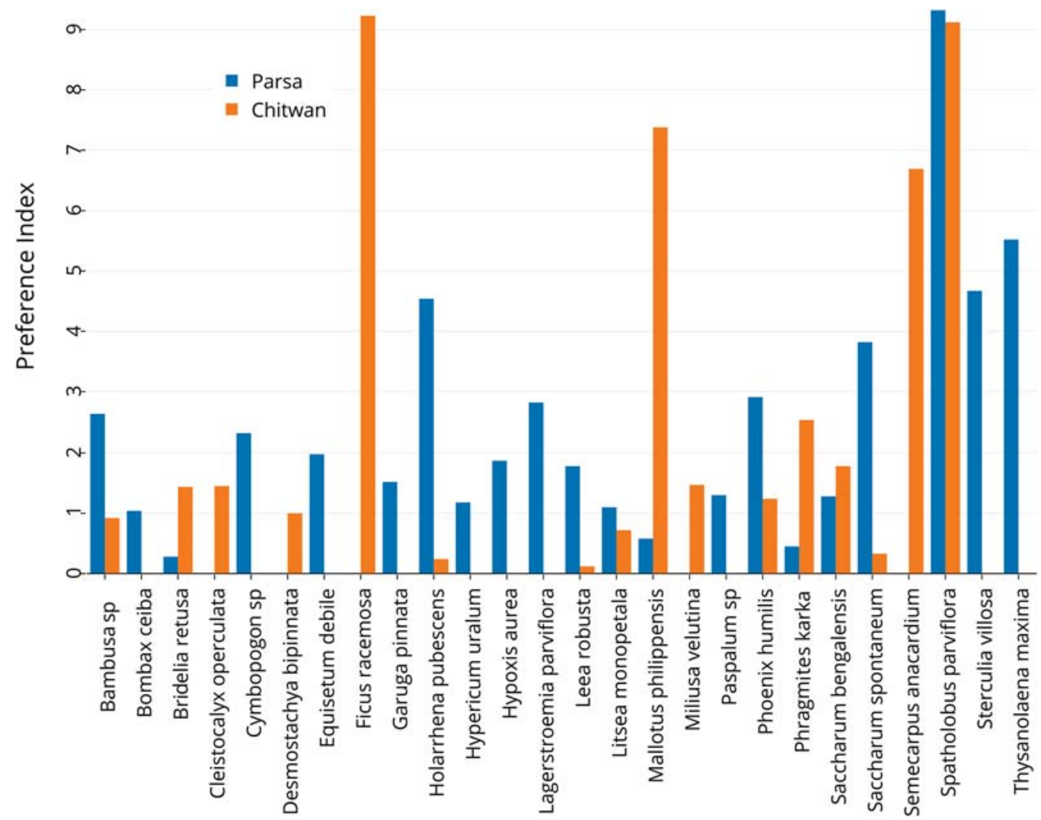


**Fig. 3** Preference indices (PI) for the most prevalent plant species found in the diet of wild Asian elephants in the Chitwan National Park (CNP) and the Parsa Wildlife Reserve (PWR) in both the rainy and dry seasons

## Discussion

Nepal has lost over 80% of its elephant habitat to human settlement [5]. As a result, the resident elephant population, estimated to number between 109 and 142 individuals, is presently restricted to four isolated areas [29]. Available diet and nutritional preference are the two most important factors that drive elephant movements, and that generate conflict with humans, especially when available elephant habitat is shrinking [30]. Reduction in grass, especially in the dry seasons may result in elephant migration. Human–elephant conflicts may arise mainly due to elephant migration [31]. Thus, knowledge of elephant foraging patterns and seasonal food availability is important for mitigation of human–elephant conflict. The management of grass species in the dry season is crucial. In areas like Parsa where there is an environmental constraint in retaining surface water, some potential habitats could be irrigated during the dry season to maintain grass productivity.

The present study recorded 57 plant species within 28 families that were foraged by Asian elephants in the PWR and CNP. In a similar study, Sukumar [2] reported 112 species of plants in the elephant's diet in southern India, and Chen et al. [9] reported 106 plant species in the diets of elephants in Shangyong National Natural Reserve in Xishuangbanna, the People's Republic of China were catalogued. The wide range of results between studies may be due to differences in the number and diversity of plant species available. Divergent results may also be partly due to differences in sampling methods; variances in forest condition (disturbed versus undisturbed), composition, and sampling area could also have contributed to divergent results.

Elephants are mixed feeders, and there is seasonal variation in their food selection [8]. In the present study, we found that browse flora and grasses were both eaten by elephants during the wet season, while browse vegetation dominated the dry season diet. Indeed, it seems that the proportion of dicot and monocot species in the diet of elephants varies across different home ranges. In southern India, elephants are known to rely heavily on graminoids (grasses, sedges and rushes) in the wet season and almost exclusively on woody plants during the dry season [32]. Similar patterns of seasonal variation in feeding have been reported by Pradhan et al. [12] in Bardia National Park in Nepal, and also for African elephant in Uganda [33]. In Nilgiri Biosphere Reserve, southern India, grasses dominate the elephant diet in all seasons, while browse flora forms an important portion of their diet only during the dry season [10]. Likewise, in the foothills of the Himalayas, browse forms the majority of the diet in dry seasons [34]. In similar studies, browse dominated the diet of elephants all year in the rainforests of Malaysia [35], north-eastern India [36] and in the state of Bihar, Central India [37].

Results of the present study are comparable to the data obtained in the above-mentioned studies in terms of dry-season diet. This browse-dominated dry season diet could be due to the lower average grass biomass available when the dry season causes a reduction in grass cover. It could also be due to the need to meet specific nutrient requirements, for example, the high levels of essential minerals in the hard wood of browse plants [12]. However, our study revealed a slightly different trend in the wet season, when a similar proportion of grass and browse were found in the elephant diets. This could be due to the migration patterns of elephants in Nepal: at the onset of the rainy monsoon season, elephants move from Chitwan to Parsa and towards upper slopes [13]. As the monsoon develops, elephants migrate from grass-rich lower elevations south to the foothills of the Churia range for occasional resting. In the Churia foothills, elephants have more opportunities to eat foods other than grasses, as these foothills are rich in preferred woody species.

In the present study, we noted a difference in feeding preference for stems, leaves and twigs, bark and other parts of woody plant species. Foliage (leaves and twigs) of both grass and browse flora were eaten more than other parts of plants in the wet season, while bark dominated the dry season diet. The use of bark from various tree species by elephants might relate to macronutrient balancing [38], and for gaining moisture and mineral supplements [39] that would otherwise have been unavailable during the dry season. The current study aligns with the findings of Pradhan et al. [12] in Bardia National Park, Nepal, where bark consumption dominated the diet of elephants in the dry season. Differences in forest structure, methodologies used and spatial and temporal availability of different groups of plants could explain the variance in PI between the two studies, which are both based on elephant populations in Nepal.

Spatially and temporally, PI can vary between species. In the present study, widely abundant foods such as *Shorea robusta, Mallotus philippensis, Imperata cylindrica* and *Saccharum bengalensis* were avoided by elephants in some seasons and locations, despite their high availability (Additional file 1: Appendix). Therefore, it is important to examine independently the PI scores of species that are of high availability (or rare) to determine whether the score could be due to the methodological limitations of this index alone [40], or could involve other factors. The PI scores derived from Parsa and Chitwan could be obtained from multiple rather than single factors [41]. Factors such as seasonal availability [42], palatability [43], nutritive value and plant tissue toxicity are all important influences on the selection of food plants by elephants [35].

Although in both the PWR and the CNP, elephants prefer common plants such as *Spatholobus parviflorus,* in fact *Saccarum spontaneum, Phoenix humilis, Saccharum bengalensis*, *Mallotus philippensis* and *Phragmites karka*, there are some less common species such as *Acacia catechu, Bombax ceiba, Bamboosa* spp and *Ficus* spp that are important food for elephants. In the present study, feeding patterns observed in both areas revealed that Parsa elephants ate a more diverse, species-rich diet than did Chitwan's Asian elephant population. The Parsa area has a higher number of elephants, possibly suggesting that nutrition is superior in PWR due to greater dietary diversity. However, further study on habitat preference in all seasons is needed to further investigate this. In addition, the present study has also yielded new data supporting previously unrecorded Asian elephant preferences for *Thysanolaena maxima, Sterculia villosa, Equisetum debile, Semecarpus anacardium* and *Hypericum uralum.*

## Conclusion

Asian elephants have a diverse diet including monocot and dicot plants. Their diet in the dry season (February–April) contained a higher proportion of dicots compared to that of the wet season (June–September). There was a negative correlation between availability of plants and preference by elephants, suggesting food selection by elephants is not passively driven by relative availability, but related to specific preferences [44]. Further studies are needed to understand this feeding selectivity and its implications for the elephants. The current study provides baseline information about different types of natural food available in the Parsa and Chitwan regions of Nepal, and their relative importance in the diets of elephants in and around the PWR and CNP. This information is important for realising successful outcomes for the conservation of Asian elephants and improved seasonal management for the long-term protection of this endangered species and its shrinking habitat.

## Additional file

**Additional file 1: Appendix** Species, family, type of plant and plant parts consumed, and preference index for the majority of plants consumed by wild Asian elephants. A preference index score >1 indicates a food that was utilised proportionately more than its occurrence in the environment, and food with a preference index score <1 was utilised proportionately less than its occurrence in the environment.

**Authors' contributions**

RKK, DR, and WJ designed the study; RKK, MP collected the data; RKK, AA analysed the data. RKK wrote the manuscript, and all authors contributed to the final version of the paper. All authors read and approved the final manuscript.

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**Competing interests**

The authors declare that they have no competing interests.

**Availability of data and materials**

Nearly all data are available in the manuscript itself.

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DRC 16

Appendix 8

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

## STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

**Name of Candidate:** Raj Kumar Koirala

**Name/Title of Principal Supervisor:** Weihong Ji, Senior Lecturer

**Name of Published Research Output and full reference:**

Koirala RK, Raubenheimer D, Aryal A, Pathak ML, Ji W.2016. Feeding preferences of the Asian elephant (Elephas maximus) in Nepal. BMC ecology. 16:54.

Koirala RK, Ji W, Aryal A, Rothman J, Raubenheimer D. 2015. Dispersal and ranging patterns of the Asian Elephant (Elephas maximus) in relation to their interactions with humans in Nepal. Ethol Ecol Evol 28: 221-31.

**In which Chapter is the Published Work:** Chapter 4 and 5

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate:

  and / or

- Describe the contribution that the candidate has made to the Published Work:

  Contributed in the designing of the projects. Collected, analysed the data and interpreted the results. Prepared the prliminary draft of the manuscripts.

Candidate's Signature

19/06/2017
Date

Principal Supervisor's signature

26/06/2017
Date

GRS Version 3– 16 September 2011