UNIVERSIDADE DE LISBOA

Faculdade de Medicina Veterinária

DIETARY ASSESSMENT OF THE WESTERN LOWLAND GORILLA (*Gorilla gorilla gorilla*) GROUP IN ZOO BASEL, SWITZERLAND

SARA ANDREIA RODRIGUES ABREU

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DISSERTAÇÃO DE MESTRADO INTEGRADO EM MEDICINA VETERINÁRIA

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AVALIAÇÃO DIETÉTICA DO GRUPO DE GORILAS-OCIDENTAIS-DAS-TERRAS-BAIXAS (*Gorilla gorilla gorilla*) NO ZOO BASEL, SUÍÇA

Resumo

Enquanto a população de gorilas selvagens diminui, os que estão em cativeiro deparam-se com graves problemas de saúde como a obesidade e a doença cardíaca. Uma dieta adequada é essencial para manter estas populações saudáveis, mas em cativeiro é difícil oferecer dietas nutricionalmente e funcionalmente análogas às naturais.

Durante este estudo, no Jardim Zoológico da Basileia, foram avaliados dois gorilas machos, de dorso-prateado (16 anos) e de dorso-negro (12 anos), duas fêmeas em final de gestação (25 e 32 anos) e duas fêmeas geriátricas (47 e 55 anos). A adequação da dieta foi avaliada através da análise da sua composição, do consumo individual de nutrientes, do programa de enriquecimento ambiental, das características antropométricas e de registos clínicos prévios. No geral, a dieta fornecida foi completa e adequada às necessidades comportamentais e nutricionais dos gorilas. Foram observadas algumas diferenças significativas entre indivíduos, ligadas a opções de maneio, preferências individuais e requisitos específicos do estado fisiológico, idade ou hierarquia. Foi elaborada uma lista de recomendações e criada uma dieta-amostra para ajudar a corrigir os desequilíbrios identificados.

Uma análise dietética integrada e individual é particularmente importante numa espécie como o gorila, devido às suas complexas interações sociais e à necessidade de serem alimentados em grupo para manter níveis adequados de bem-estar.

Palavras-Chave: Gorila-Ocidental-das-Terras-Baixas, *Gorilla gorilla gorilla*, Dieta, Consumo nutricional, Enriquecimento ambiental

DIETARY ASSESSMENT OF THE WESTERN LOWLAND GORILLA (*Gorilla gorilla gorilla*) GROUP IN ZOO BASEL, SWITZERLAND

Abstract

While free-ranging gorilla populations are declining, captive gorillas face serious health issues such as obesity and heart disease. A proper dietary management is crucial to maintain healthy and thriving populations, but in captivity it can be difficult to provide diets that are both nutritionally and functionally equivalent to wild diets.

During this study in Zoo Basel were evaluated two male gorillas, one silverback (16 years) and one blackback (12 years), two late-stage pregnant females (25 and 32 years) and two geriatric females (47 and 55 years). Diet adequacy was assessed through the analysis of the diet composition, individual nutrient intake, dietary enrichment program, anthropometric features and previous clinical records.

Overall, the diet offered at Zoo Basel was complete and mostly adequate to the gorillas' behavioural and nutritional needs. Some significant differences were observed between individual diets, linked to management options, individual preferences and physiologic, age- or hierarchy-related specific requirements. A list of recommendations was compiled and a sample diet was created to help correct the identified nutrient imbalances.

An integrated individual analysis of diet adequacy is particularly important in a species like the gorilla, due to its complex social interactions and the need to group-feed to maintain proper levels of welfare.

Keywords: Western Lowland Gorilla, *Gorilla gorilla gorilla*, Diet, Nutrient Intake, Environmental enrichment

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Abbreviations

AA – Arachidonic acid
ADF – Acid Detergent Fibre
ALA – α-linolenic acid
AZA – (American) Association of Zoos and Aquariums
BID – twice a day
BMI – Body mass index
BMR – Basal metabolic rate
Ca – Calcium
ca. – circa
Cl – Chlorine
cm – centimetre
Co – Cobalt
Cr – Chromium
Cu – Copper
DE – Digestible energy
dl – decilitre
DM – Dry matter
EAZA – European Association of Zoos and Aquaria
EEP – European Endangered Species Programme
Fe – Iron
fl – fentilitre
g - gram
GE – Gross energy
HDL – High-density lipoprotein
I – Iodide
ISIS – International Species Inventory System
IU – International units
IUCN – International Union for Conservation of Nature
K – Potassium
kcal – kilocalories
kg – kilogram
l - litre
LA – Linoleic acid
LDL – Low-density lipoprotein
m – meter
ME – Metabolizable energy
Mg – Magnesium
mg – milligram
min - minutes
mmol – millimole
Mn – Manganese
N – Nitrogen
Na – Sodium
NAG – Nutrition Advisory Group
ng – nanogram
NDF – Neutral Detergent Fibre
NRC – National Research Council
Obs. – Observation
P – Phosphorus
pg – picogram
PMI – Primate mass index
PRPs – Proline rich proteins
PUFAs – Polyunsaturated fatty acids
R/R – Regurgitation and reingestion
SCFA – Short chain fatty acid
SD – Standard deviation
Se – Selenium
sp. - species
SSP – Species Survival Plan
µL – microliter
µmol – micromole
UVB – Ultraviolet B
VLDL – Very low-density lipoprotein
WSC – Water-soluble carbohydrates
Zn – Zinc

1. Externship Report

The curricular externship that originated this thesis took place in Zoo Basel, Switzerland, on the field of Zoo Animal Medicine, under the guidance of Dr. Stefan Hoby as my supervisor, with a duration of 585 hours, from the 16th of April until the 31st of July of 2015.

During this time, I had the opportunity to accompany Dr. Christian Wenker and Dr. Stefan Hoby, the two main veterinarians of Zoo Basel, on their daily work.

Zoo Basel is home to close to 6600 animals. The official count by the end of 2015 was as follows: 383 mammals (57 species), 689 birds (91 species), 239 reptiles (35 species), 43 amphibians (11 species), 3280 fish (272 species) and 1958 invertebrates (132 species). These animals are divided in 12 main areas that comprise each species enclosures: the Ape House, Afrika, the Antelope House, Australis, the Elephant Enclosure, Etosha and Gamgoas (referring to geographical areas located in Namibia), the Children Zoo, the Rhino Enclosure, the Sauter Garden, the Vivarium and the Birds House.

As such, the type and quantity of the daily veterinary work is quite diverse. As a student I was able to assist mainly in the daily diagnostic and prophylactic work, drug administration, induction, monitoring and maintenance of anaesthesia and assistance in the procedures that followed, such as diagnostic procedures, surgeries or re-location of the animal. I performed some diagnostic tests such as coprology, haematology, biochemistry and imaging (radiography, ultrasonography, endoscopy), necropsies, meat inspection of the surplus animals used as food for the carnivores and assisted in the management of the Blood and Serum Bank that Zoo Basel possesses.

I was also given the opportunity to participate in the Journal Club held by the veterinarians every two weeks and assist in the daily research that is required to handle such a varied population of species and health issues.

Finally, I was provided with the chance to do a more in-depth study on the feeding habits of the Western Lowland Gorilla (*Gorilla gorilla gorilla*) group, in collaboration with Dr. Christina Simon, from the animal feed company Provimi Kliba.

2. Literature Review

2.1 Nutritional Status and Diet Evaluation in Captivity

The (American) Association of Zoos and Aquariums (AZA) Nutrition Advisory Group (NAG) has defined objectives for a captive feeding program: providing a nutritionally balanced diet that the animal consumes consistently, that reasonably stimulates natural feeding behaviours and that is practical and economical to feed (Nutrition Advisory Group, 2002).

The purpose of a nutritional assessment is then to determine the adequacy of a diet so that optimal nutrition is achieved, reducing the risk of disease and increasing productivity, longevity and welfare in all stages of life of an individual and/or population (Crissey, Maslanka, & Ullrey, 2002; Fidgett & Plowman, 2009).

Several methods have been used to assess nutritional status (Crissey et al., 2002):

1. Determination of nutrient intake and evaluation of dietary husbandry;
2. Measurement of anthropometric features and scoring of the body condition;
3. Measurement of body fat as an estimate of energy reserves;
4. Biochemical analysis of body fluids and tissues;
5. Clinical evaluation and post-mortem examination.

After collecting the data, it is necessary to compare the values to previously established standard values of a healthy animal. To establish this, it would be preferable to have sufficient valid data already compiled from studies in the wild. However, in the absence of such, "standards can sometimes be developed from captive situations where the animals are healthy and breed well". Veterinarians can also resort, with caution, to well-studied domestic species that are taxonomically close to the target species, to serve as models (Fidgett & Plowman, 2009).

An essential tool to determine the adequacy of a diet is comparing it to the established nutrient intake requirements of the target species. However, "definition of the nutrient requirements of each of some 250 primate species is virtually impossible (…) Energy requirements of fewer than 20 species have been studied, and protein, mineral, and vitamin requirements of fewer than 10." (National Research Council, 2003).

To form reasonable estimations of nutrient requirements for the target species, different factors should be considered (Schmidt, 2004):

1. Existing information on diet composition and feeding behaviours in the wild;
2. Anatomy and physiology of the gastrointestinal tract;
3. Research information from similar species that can be extrapolated.

These different factors and the methods used to assess the nutritional status of Gorillas will be further addressed in this thesis.

2.2 The Gorilla

The Western Lowland Gorilla (*Gorilla gorilla gorilla*), the focus subspecies of this study, is part of the Primate order and Hominidae family, which includes Humans and Great Apes: gorillas, orangutans, chimpanzees and bonobos. Although unknown to science until 1847, the Gorilla genus has achieved considerable popularity amongst the human general population, mainly due to its impressive anatomy and close phylogenetic proximity to Humans – 97% to 99% genetic similarity, depending on the compared gene sequence (Chen & Li, 2001; Mittermeier, Rylands, & Wilson, 2013).

Currently two species of Gorillas are recognized: the Western Gorilla (*Gorilla gorilla*), divided in the subspecies Western Lowland Gorilla (*G. g. gorilla*) and Cross River Gorilla (*G. g. diehli*); and the Eastern Gorilla (*Gorilla beringei*) divided in the subspecies Mountain Gorilla (*G. b. beringei*) and Grauer's Gorilla or Eastern Lowland Gorilla (*G. b. graueri*) (Mittermeier et al., 2013; Taylor & Goldsmith, 2003).

As with all Great Apes, they are sexually dimorphic, large barrel-chested mammals that can distinguish colours and whose best developed senses are vision and hearing. With average heights of 109-152 cm for females and 138-196 cm for males, gorillas are the biggest and most powerful living primates. When they reach circa (ca.) 15 years old, dominant adult male gorillas usually develop a characteristic silver-coloured fur on their back (thus commonly called silverbacks) and a prominent sagittal crest. Each individual possesses a unique nose pattern and they are mostly terrestrial animals with a quadrupedal gait, although still quite capable of climbing (Medder, 2005; Mittermeier et al., 2013).

Some considerable differences occur in the social organization of the two species. About 40% of groups of Eastern Gorillas contain more than one silverback or mature males without silver-coloured fur, called blackbacks, along with the females and their infants, juveniles and sub-adult offspring. When a male becomes sexually mature he can sometimes be forced or choose to leave the group and become solitary. However, when it comes to Western Gorillas, multi-male groups are rarer. When a male reaches his sexual maturity he's usually forced out of the group by the dominant silverback and becomes solitary until he can challenge a dominant male or form his own group. All-male "bachelor groups" have occasionally been observed in Western Lowland Gorillas in the wild, but seem to be transient and with mostly immature males (Gatti, Levréro, Ménard, & Gautier-Hion, 2004; Mittermeier et al., 2013; Robbins et al., 2004; Taylor & Goldsmith, 2003).

To closely study gorillas in the wild a long process of human habituation is usually required. When a western gorilla silverback dies, its group frequently disperses and any human habituation that existed disappears. This and the fact that they live in dense forests difficult to journey account for the limited number of studies of this subspecies in the wild, compared with the studies in Mountain Gorillas which have a significantly reduced population (Doran & Mcneilage, 1998; Masi, Cipolletta, & Robbins, 2009; Ogden & Wharton, 1997).

Gorillas are distributed through Central and Western Equatorial Africa, living in very distinct habitats, specifically in terms of altitude (Figure 1). This translates into differences in temperature, rainfall and wind speed. As so, the quality, distribution, availability and seasonality of food sources varies considerably between each species' habitat, becoming particularly evident when we compare diet studies between lowland and mountain gorillas. (Doran & Mcneilage, 1998; Taylor & Goldsmith, 2003)

Figure 1: *Gorilla gorilla* and *Gorilla beringei* geographic range (United Nations Environment Programme - World Conservation Monitoring Centre & International Union for Conservation of Nature, 2008)

2.2.1 Conservation Status

The wild Gorilla population has suffered a drastic reduction in the last decades, with a tendency to keep decreasing. The reduction in Eastern Gorillas (*G. beringei*) over the time period of three generations (ca. 60 years, from 1970 to 2030) is suspected to exceed 50%, thus qualifying this species as "Endangered" according to the criteria of the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Robbins & Williamson, 2008).

As for the Western Gorilla (*G. gorilla*), the current tendency presents itself even grimmer. No accurate estimates of the Western Lowland Gorilla numbers are possible, as they inhabit some of Africa's densest and most remote rainforests, but the total population was thought to number around 100,000 to 125,000. However, it is estimated that the Western Gorilla abundance has declined over 60% in the last 25 to 30 years and as of 2007 they are listed as "Critically Endangered" in the IUCN Red List, only one step away from the "Extinct in the Wild" classification. The main direct threats to these Gorillas' survival are:

- Poaching and the commercial bushmeat trade;
- Diseases such as the recent Ebola outbreaks with very high mortality rates;
- Habitat loss and fragmentation due to logging, mining and industrial-scale agriculture.

Given that these threats are unlikely to dwindle in the near future, accompanied by the very low reproductive rates, a population decline of more than 80% over three generations (ca. 66 years, 1980-2046) is likely to occur (IUCN, 2014; Walsh et al., 2008; WWF, 2015).

2.3 Western Lowland Gorilla Diet in the Wild

From this point forward, unless stated otherwise, the word gorilla will always refer to the subspecies Western Lowland Gorilla (*G. g. gorilla*).

2.3.1 Habitat and Seasonality

Gorillas live in heterogeneous, low altitude tropical forests, with plants that provide fruits such as dicot trees, palms and lianas occurring at greater density and diversity than in montain altitudes. The main groups of herbaceous plants involved in the diet of gorillas are the monocotyledonous plants like the families Moraceae, Tiliaceae, Leguminosae and Marantaceae forests, but differences exist between sites. Temperatures are typical of tropical rainforests, not varying a lot from the 20ºC to 30ºC range (Doran et al., 2002; Doran-Sheehy, Mongo, Lodwick, & Conklin-Brittain, 2009; Remis, Dierenfeld, Mowry, & Carroll, 2001; Rogers et al., 2004; Taylor & Goldsmith, 2003).

Some habitats include hydromorphic clearings – swamp areas – with high density of herbaceous forest and water plants year round. This type of habitat may lead to a decrease in fruit availability, due to the type of dense forest plants (e.g. Marantaceae) that grow around it (Magliocca & Gautier-Hion, 2002).

As for seasonality, there's strong inter-annual and seasonal variations, most importantly regarding fruit availability, which generally increases in June/July, peaks in August/September and is at its lowest from November through March, depending also on rainfall (Deblauwe, 2009; Doran et al., 2002; Masi et al., 2009).

2.3.2 Foraging and Feeding Behaviour

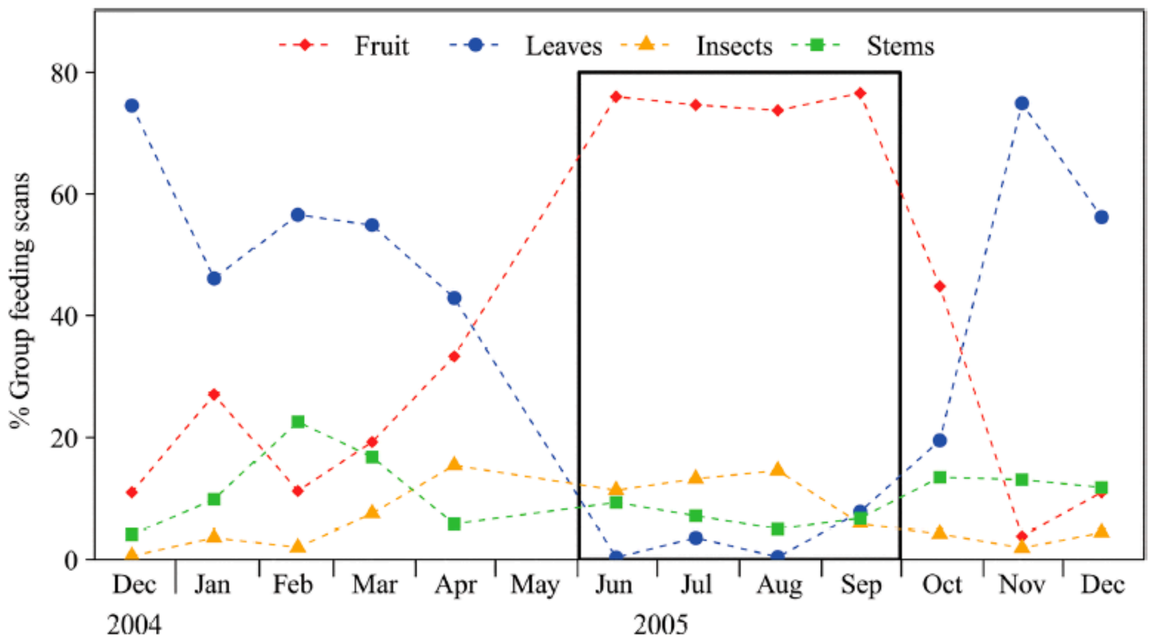
Several studies have pointed to a high variety of foods eaten by the gorilla, with over 230 different items and 180 species, the greatest diversity being among fruit species. Gorillas consume social insects regularly – ants and termites – and soil consumption has also been less frequently observed (Deblauwe, Dupain, Nguenang, Werdenich, & Elsacker, 2003; Doran et al., 2002; Popovich et al., 1997; Rogers et al., 2004; Rothman, Pell, Nkurunungi, & Dierenfeld, 2006).

The quality, relative proportion and diversity of food categories consumed shifts throughout the year depending on the fruit availability (Figure 2). Regardless, fruit is eaten almost every day, with studies showing ≥95% presence in faecal samples (Deblauwe, 2009; Doran et al., 2002; Magliocca & Gautier-Hion, 2002). This flexible dietary response to seasonal fruit availability lends the gorilla the classification of generalist frugivore-folivore or seasonal frugivore (Etiendem & Tagg, 2013; Magliocca & Gautier-Hion, 2002; Remis et al., 2001).

Gorillas reduce time spent feeding, but increase distances travelled daily during high frugivory seasons to consume particular fruit species, which are rarer and more dispersed, rather than subsisting on lower-quality forage. Percentage of fruit in their diet may vary from

50% to 90% at those times. As the fruit availability decreases, it is replaced by larger quantities of the less preferred fruits and the non-reproductive parts of trees and understory plants: leaves, herbs, shoots, stems, pith (inner core of the plant stem), roots and bark. Leaf flush occurs during these seasons, so gorillas can also consume high quality young leaves. According to Rogers et al. (2004) gorillas may adopt an energy saving strategy during low frugivory months to cope with the more fibrous lower quality vegetation. These foods, that provide nourishment and support them during this season, are called staple foods when they're consumed in considerable quantities all year, maybe due to its high protein content (e.g. certain leaves and water plants), or fallback foods when they seem to be consumed only when needed, due to their lower nutritional quality (e.g. bark). Plant species and parts can however shift between categories according to the habitat and seasonality, as gorillas are highly adaptable in their diet (Doran et al., 2002; Etiendem & Tagg, 2013; Fuh, 2013; Masi et al., 2015, 2009; Remis et al., 2001; Rogers et al., 2004; Rothman et al., 2006).

Figure 2: Seasonal variation in gorilla diet at Bai Hokou, Central African Republic, according to the time spent feeding on the most important food types – the bold box highlights the high-frugivory season (reprinted from Masi et al., 2015)



Gorillas have a highly selective feeding behaviour, selecting food parts that are the least fibrous and have more protein (e.g. certain leaves) or are more succulent and possess more energy and sugar and less antifeedants (e.g. ripe fruit) than the discarded parts (Doran-Sheehy et al., 2009; Rogers et al., 2004). They consume the fruits seeds, being considered a valuable seed disperser from a forest management point of view (Etiendem & Tagg, 2013; Petre et al., 2013; Remis et al., 2001).

Insect consumption also seems to be seasonal, with Doran-Sheehy et al. (2009) and Deblauwe (2009) reporting a termite feeding increase during the rainy months (starting in

March), presumably due to the increased availability. Another important factor may be the concurrent diet, with increased ingestion of termites during high-frugivory months/less fibrous food consumption. The exception to this being ant consumption, which is in greater quantity when gorillas are forced to forage more for herbs and terrestrial vegetation during very low frugivorous months, and winged-termites that are consumed when available (Deblauwe, 2009). A 6-month long study in the Central African Republic reported that 14% of the time dedicated to feeding activities was spent on insect consumption (Fuh, 2013), and another study in Southeast Cameroon reported it to represent less than 1% in the daily fresh weight ingested (Deblauwe & Janssens, 2008). Regardless, insects represent an important food item for gorillas, as they frequently and deliberately ingest them with faecal presence ranging from 20% to 70% depending on the studied site (Cipolletta et al., 2007).

In habitats characterized by swamp areas, water plant consumption is common, whether as staple or fallback foods, presumably due to their abundance, higher protein content and specially its mineral composition that compensates for the lack of important minerals in the abundant forest vegetation (Magliocca & Gautier-Hion, 2002; Rogers et al., 2004)

In spite of large body size differences, males and females seem to be remarkably similar in their diet composition and habits. In one study the male consistently fed more often and on a greater variety of leaves than the females, especially during fruit scarcity season, whilst in turn the females fed more often on fallback herbs. Remis (1997) reported that on high frugivory season males also ate more fruits, whilst females consumed more young leaves. Females also consumed more termites, a feeding activity that requires greater effort and time (Doran-Sheehy et al., 2009).

Different studies reported the daily activity budget of gorillas divided as follows: 40-70% feeding and foraging, 21-33% resting, 12-19% traveling and 0-11% dedicated to social behaviours or other undefined activities. These results come from observations in very different conditions (non habituated, semi-habituated, habituated or observation restricted to swamp clearings), and differences exist between seasons, gender and age. For example, immature individuals display substantially more social behaviour than adults and silverbacks seem to spend less time foraging and more time resting compared to adult females, perhaps due to the ability to displace lower ranking members from preferred food sites and therefore having better access to quality food. Other possible explanations for this difference, which also seems to occur in captivity, are the higher energy requirements for pregnant/lactating females and/or the need for dominant males to spend more time looking for predators or challenging rivals and monitoring and promoting group cohesion (Fuh, 2013; Magliocca & Gautier-Hion, 2002; Masi et al., 2009).

2.3.3 Diet Nutritional Composition

a. Energy, Protein, Fat and Fibre

Several nutritional analyses across different gorilla study sites have showed that mature and young leaves consumed contain, with some rare exceptions, more protein than stems and fruits. Fruits, on the other hand, are lower in fibre and higher in readily available energy due to the amount of easily digestible carbohydrates (soluble sugars). Even the less preferred fruits consumed during low frugivory season seem to have significant quantities of sugar, although they have a consistently higher fibre content. Pith, consumed in higher quantities during these times, is succulent and also possesses a considerable sugar content. Seeds and fruits chosen seem to be relatively low in fat compared with the discarded ones. Seeds are however a common source of proteins and lipids. Some barks contain considerable amounts of protein, which has been suggested as a reason for its increased consumption in the low frugivory season, when young leaves aren't available, and insects are also rich in protein, fat and essential amino acids (Doran-Sheehy et al., 2009; Head, Boesch, Makaga, & Robbins, 2011; Masi et al., 2015; Nishihara, 1995; Rogers, Maisels, Williamson, Fernandez, & Tutin, 1990; Rothman et al., 2006).

Fruit and foliage act then as complementary food sources, each providing different origins of energy and other nutrients, and the large diversity of plants consumed likely improves the overall dietary quality in terms of complementary amino acids as well as other nutrients (Milton, 1999; Remis et al., 2001).

An interesting study in Mountain Gorillas, by Masi et al. (2015) showed that throughout a whole year of fluctuating fruit availability the non-protein energy intake did not vary, whilst during periods of fruit scarcity the protein intake was substantially higher due to the leaves protein content. This suggests prioritization of non-protein energy and that to achieve this goal there can be over-ingestion of protein at certain times. Gorillas may be physiologically adapted to excrete the excessive nitrogen, as abnormally high levels of nitrites (compared to human standards) have been found in the urine of a study group (Masi et al., 2015; Rothman, Raubenheimer, & Chapman, 2011).

The fibre in plants is chemically complex, often including readily fermentable carbohydrates (e.g. pectin), partially fermentable structural carbohydrates (e.g. cellulose and hemicellulose) and polyphenolic compounds that are thought to be indigestible (e.g. lignin). In the detergent fibre method of analysis, the neutral detergent fibre (NDF) fraction represents the entire cell wall (other than pectin and some minor components) and the acid detergent fibre (ADF) fraction represents cellulose and lignin (Van Soest, Robertson, & Lewis, 1991). Both fractions can constitute a large proportion of primate foods, so measuring it and trying to calculate its digestibility is an essential step to assess the energy provided (Oftedal, 1991).

Table 1 presents the average macronutrient values of the foods eaten by the gorillas in four different study sites.

Table 1: Range of the mean nutrient contents of the foods eaten by gorillas in the wild, on a dry matter basis. Intervals represent the range between the different calculated means per type of food at each site and not the minimum and maximum nutrient values found for each category.

DM %	Crude Protein	WSC	Crude Fat	Fibre			Sources and Study Sites
				NDF	ADF	Lignin	
Fruit	5.7 - 8.4	34.8 - 38.6	1.7 - 3.2	44.3 - 78.7	23.9 - 65.4	13.4 - 26.9	Calvert, 1985 - Campo, Cameroon Doran-Sheehy et al., 2009 Mondika, Republic of Congo and Central African Republic Rogers et al., 1990 - Lopé, Gabon Rothman et al., 2006 - Cameroon, Gabon and Central African Republic
Leaves	16.6 - 18.9	3.9	2.6 - 4.5	46.1 - 64.2	30.1 - 47.7	17.6 - 25.2	
Stems, Barks	3.4 - 16.9	8.0	1.4 - 3.4	54.4 - 80.4	41.6 - 54.5	9.4 - 26.0	
Seeds	10.6	7.9	4.1	-	24.6	-	

DM = Dry Mater; WSC = Water Soluble Carbohydrates, NDF = Neutral Detergent Fibre, ADF = Acid Detergent Fibre

The fact that the most consumed foods during high frugivory season have a higher caloric content explains the reduction in feeding time as the gorilla's energy requirements are more quickly met. However, that strategy comes with a reduction in general nutrient intake (dry matter, fibre, fat, protein and micronutrients) and therefore reduction of the nutrient diversity. Studies also indicate that due to the lower caloric content of the leaves and fibrous foods consumed during low frugivory season, their strategy of increasing the time spent feeding and the dry matter intake allows them to extract the required energy from the protein, fibre and fat supplied in those lower quality foods (Masi et al., 2015).

b. Minerals, Vitamins and Essential Fatty Acids

Little information is available regarding the mineral, vitamin and fatty acid values of the wild Gorilla diet.

In a study conducted in Bai Hokou, in Central African Republic, sodium (Na) was the only mineral whose intake didn't vary across the year, suggesting that the consumption of this mineral in adequate quantities is prioritized in comparison with other micronutrients. The intake of zinc (Zn), copper (Cu), manganese (Mn), magnesium (Mg) and calcium (Ca) varied according to fruit availability, mostly decreasing when fruit consumption was higher (Masi et al., 2015). It has also been referred that the plants in Bai Hokou are relatively low in iron (Fe), and green leaves are an important source of Ca (Remis et al., 2001).

In another study in the Republic of Congo, which has since then been corroborated by the results in other locations, it is proposed that the main reason for the Gorillas to visit clearings where a swamp (or Bai) is present is to acquire micronutrient rich foods, especially in Na, Ca and potassium (K). Gorillas spend only a small amount of time there, and feed very selectively, presumably depending on the needs of their current physiological and reproductive status (Magliocca & Gautier-Hion, 2002; Sienne, Buchwald, & Wittemyer, 2014).

“Nutritional hypothesis supporting insectivory in wild primates includes the need for minerals, vitamins (B12), energy and protein” (Gomez, 2014). Although termites and ants consumed by gorillas present very high protein contents and could be consumed to make up for the lack of protein in fruits, its value may be more significant as a micronutrient source and antidiarrhoeal agent. Termites may supply them with a very significant Fe value and its contents of Na, Cu, phosphorus (P) and Zn are also high. The termite gut is a source for kaolinite as well, an anti-laxative compound, and some insects possess surfactant substances in their gastrointestinal tract that can interfere with the formation of tannin-protein complexes, mentioned below, thus allowing better protein assimilation (Deblauwe & Janssens, 2008; Deblauwe, 2009; Lambert, 1998).

Occasional observations of soil and decayed wood consumption have also been attributed to the need for its micronutrients, mainly Na, Ca and K (Rothman, Chapman, & Pell, 2008; Vlčková, 2010).

Although not directly related to gorillas, analysis of tropical forest leaves and fruits routinely consumed by wild primates have shown that these are good sources of minerals, essential fatty acids and vitamin C, which is particularly important as a lot of primates are unable to synthesize this vitamin. It is likely that these young leaves and fruits are also rich in vitamin E, pro-vitamin A, vitamin K and folic acid (Milton, 1999).

Table 2 presents the mean mineral values found in two studies in Bai Hokou, Central African Republic and Campo, Cameroon.

Table 2: Mean mineral contents of the foods eaten by wild gorillas on a dry matter basis

DM		Ca %	K %	Mg %	Na %	P %	Cu mg/kg	Fe mg/kg	Mn mg/kg	Zn mg/kg	Se mg/kg	Source
Fruit	Unripe	0.18	1.07	0.13	0.01	0.12	8.82	90.1	118.3	19.4	-	1
	Ripe	0.18	1.28	0.14	0.01	0.12	12.3	76	143.1	17.9	-	1
	-	0.35	1.81	0.16	0.01	0.17	12.4	206	140	52.3	0.04	2
Leaves		1.40	2.05	0.29	0.02	0.18	14.1	274	284	34.9	0.14	2
Stems		1.06	5.04	0.34	0.02	0.10	8.91	81.6	476	71.1	0.06	2
Shoots		0.40	3.02	0.26	0.02	0.22	14.0	93.4	552	48.0	0.08	2
Bark		1.23	1.65	0.12	0.01	0.07	6.0	106	155	10.5	0.10	2

1 - Remis et al., 2001, 2 - Calvert, 1985

Essential fatty acids are those which cannot be synthesised by the body, and for primates these include the n-3 and n-6 fatty acids, referring to the number of carbons from the methyl end of the fatty acyl chain to the first double bond. Also called omega-3 and omega-6 fatty acids, their main building blocks are, respectively, the α-linolenic acid (ALA) and the linoleic acid (LA) (National Research Council, 2003). Fatty acids are required to facilitate normal neural, retinal and brain growth, tissue development and normal cellular, cardiovascular and immune function (National Research Council, 2003; Reiner, Petzinger, Power, Hyeroba, & Rothman, 2014).

In Mountain Gorillas, although fruit accounts for a smaller percentage of the DM intake compared to the Western Lowland Gorillas, it provided a large portion of the fatty acid intake, and the majority of LA ingested. Leaves were low in fat, but they supplied most of the ALA consumed, due to the increased folivory. This study also noted that LA was the predominant fatty acid ingested, representing about 30% of the total fatty acids of the diet. It is very interesting to note that Mountain Gorillas milk has been reported to have a high proportion of arachidonic acid (AA), an n-6 fatty acid, but very low amounts were present in the diet analysed (Reiner et al., 2014). As dietary LA can be converted to AA after consumption, it is possible that the high AA levels in the milk result from the high LA intake (Milligan et al., 2008; Osthoff, Hugo, de Wit, Nguyen, & Seier, 2009; Reiner et al., 2014). However, no equivalent studies for Western Lowland Gorillas were found, and considering that fatty acid content in the diet can greatly affect its presence in the organism, comparisons and extrapolations can't really be made at this point.

c. Plant Secondary Compounds

Plant parts generally contain secondary compounds that can be toxic and/or impair digestibility such as tannins, other phenolics, alkaloids and terpenoids. Tannins, which are better studied and are granted a special focus in the literature about gorilla diets are defensive polyphenolic compounds that can bind with proteins and enzymes in the digestive tract and render proteins unavailable for absorption. They also decrease fibre digestibility in sheep, but not deer or marsupials, and their effect on gorillas is unknown. They can impart an astringent or bitter taste to fruit, reducing ingestion, but as fruit ripens it usually undergoes colour change and palatability increase, with tannins losing its astringency (Gomez, 2014; Lambert, 1998; Milton, 1999; Remis et al., 2001; Rogers et al., 1990; Smith, 2012).

Tannins can be divided into two main groups: hydrolysable (with weaker chemical bonds, breaking down into potentially harmful molecules) and condensed (presenting lesser health risks). Nonetheless, certain tannins, especially in the condensed category, and other polyphenols have been reported to improve health parameters in humans and mice, for example, by reducing blood pressure, inhibiting platelet aggregation and reducing lipid levels and low-density lipoprotein oxidation (Gomez et al., 2015; Smith, 2012). It's also been suggested that they can increase protein hydrolysis rate and not only help to control pathogenic microbes and therefore aid in maintaining a healthy gut microbial population but also assist in the control of the iron metabolism by binding to excess dietary iron. Interestingly, the fruits eaten by Gorillas in Bai Hokou that had high iron content also possessed high condensed tannin levels (Lambert, 1998; Remis et al., 2001).

Plant secondary metabolites measured in different gorilla study sites can reach very high concentrations, with condensed tannins averaging between 0.84% (stems) to 4.5% and 12% (leaves and fruits), on a dry matter basis (Remis et al., 2001; Rogers et al., 1990).

In general, gorillas across sites seem to avoid nitrogen-based alkaloids and may prefer to avoid foods or parts of these high in tannins and other antifeedants. However, a lot of the items consumed still possess them in high quantities, which suggests that gorillas can balance their intake and/or possess a physiological high tolerance for these compounds (Lambert, 1998; Masi et al., 2015; Remis et al., 2001; Rogers et al., 1990; Rothman et al., 2006).

Curiously, wild gorillas have also been observed consuming plants with pharmaceutical properties, such as nettles, and other common plants in their diets, for example from the *Aframomum sp*., which are thought to have anti-parasitical properties, suggesting some capacity for self-medication (Masi et al., 2012; McPherson, 2013).

2.3.4 Anatomy and Physiology

a. General Adaptations

A large body size can be a strategy to cope with a more generalized, lower-quality diet, as it allows the ingestion of greater quantities of food, as well as processing high-fibre and/or chemically defended plants without needing some of the gastrointestinal specializations of smaller primates (Doran et al., 2002; Remis, 2000). A few wild gorilla average weights and heights can be found in the literature, and they have been compiled in Table 3.

Table 3: Average adult wild born gorillas weight and height. When available, the maximum and minimum range, or the standard deviation (SD) are also presented.

Adults	Male	Female	References and Notes
Weight (kg)	140	-	Groves, 1970 (n=32)
	170 (132 – 218)	71.5 (68 – 74)	Jungers & Susman, 1984 (male n=14, female n=3)
	139 | 158	-	Meder, 1993 2 references (n=?)
	163	79	Leigh, 1994 (n=?)
	162	98	Smith & Jungers, 1997 (male n=5, female n=1)
Height (cm)	166.6	-	Groves, 1970 (n=32)
	166.4 (±10.5)	-	Jungers & Susman, 1984 (n=15)
	169	-	Meder, 1993 (n=?)

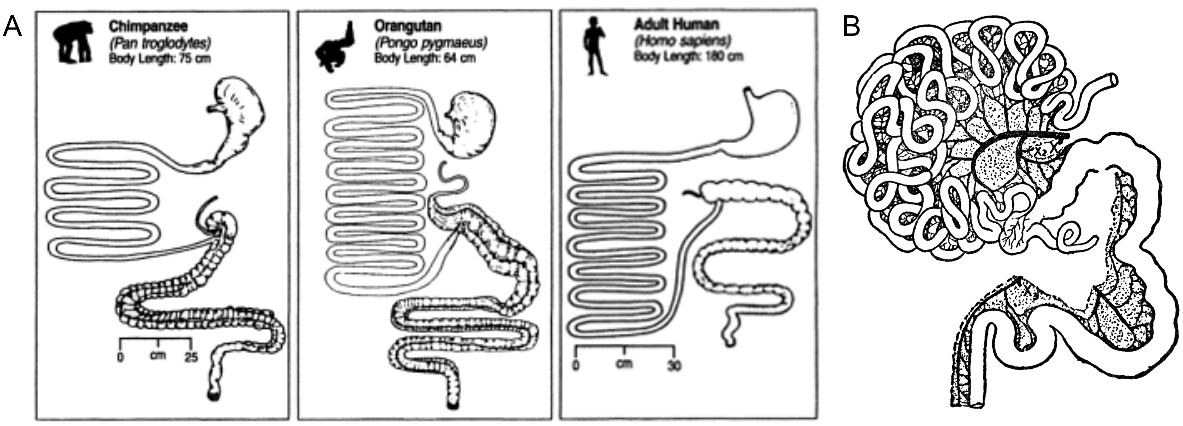
Gorillas possess powerful chewing musculature and dentition that enables them to eat dense fibrous items which most primates would most likely not be able to consume. Higher molarshearing blades and cusps are suited for breaking down plant material and the size of their incisors shows a higher adaptation to frugivory compared to Mountain Gorillas. Their dentition very much resembles the human's, except for the adult male large canines which are used for display and fighting, not eating (Calvert, 1985; Charmoy, Sullivan, & Miller, 2015; Medder, 2005).

A possible defence against the deleterious effects of tannins is the existence of proline rich proteins (PRPs), that have a high affinity for these compounds, in the saliva of humans (about 70% of its composition) and likely in the saliva of most primates, including gorillas (Milton, 1999).

b. Gastrointestinal Tract

The anatomy of the digestive system is directly correlated with the environment and the type of food that an animal eats, and the gorillas' gastrointestinal anatomy provides a large capacity for microbial fermentation, characterizing them as caeco-colic or hindgut fermenters (Smith, 2012). Gorillas have a globular stomach, an elongated small intestine and a large, pouched colon, that occupies over 50% of the relative gastrointestinal volume. Based on a male specimen, the colon is approximately 200 cm long with a maximum width of ca. 30 cm in the lower ascending colon, possessing teniae coli that facilitate the mixing of the intestinal contents and retention of digesta. The cecum is relatively small, with a volume of about 14% of the colon, typical of frugivores-folivores. The enlarged hindgut (cecum and colon) hosts large quantities of specialized microbial ciliates that aid in the breakdown of plant material. The digestive tract is quite plastic and able to, in a relatively short period of time, accommodate large amounts of ingested fibre (Chivers & Hladik, 1980; Milton, 1999; Remis & Dierenfeld, 2004; Rothman et al., 2006; Smith, 2012). As shown in Figure 3, the gastrointestinal tract of the gorilla is similar to the more frugivorous chimpanzee's, also presenting a cecum vermiform appendage, but with a longer small intestinal and a more voluminous hindgut (Stevens & Hume, 1995).

Figure 3: Comparative gastrointestinal anatomy of the Hominidae family: A - Genus Pan, Pongo and Homo (adapted from Stevens & Hume, 1995); B - Gorilla intestine (The Encyclopaedia Britannica: Volume 1, 1910).



As mentioned before, compared to the readily digestible ripe fruit, fallback and staple foods are quite rich in structural polysaccharides (fibre), indigestible by mammalian digestive enzymes. As such, the hindgut microbial metabolism provides a way for its host to harvest energy from these materials, by break down, fermentation and production of volatile or short-chain fatty acids (SCFA). As a by-product of the cellulolytic bacterial activity, the main SCFA produced are acetate, propionate and butyrate, which the host absorbs and uses as readily available energy in the bloodstream or ultimately as glucose storage in the liver (Lambert, 1998; Popovich et al., 1997; Schmidt, 2004; Stevens & Hume, 1995). SCFA help prevent the overgrowth of pathogenic bacteria, and are also believed to increase epithelial cell population and stop malignant cell growth, with butyrate playing an important role in mucosal immunity and tissue development (Gomez et al., 2015; Vlčková, 2010). The presence of fibre in the intestinal tract also enhances blood flow to the intestines, promoting tissue health and nutrient absorption (Schmidt, 2004).

Intestinal microflora is responsible for producing some vitamins (e.g. vitamin K and B12), which may be largely unavailable for hindgut fermenters, as these compounds are not absorbed in the colon and are therefore expelled in the faeces. Absorption of protein from microbial synthesis and degradation of bacterial cell walls may also be negligible, unlike what is seen in ruminants and foregut fermenters. However it is suggested that reclaiming these nutrients is one of the main reasons coprophagy is observed in gorillas (Gomez, 2014; Lambert, 1998; Vlčková, 2010).

In recent years there's been quite a few studies on the faecal microbiota and gut microbiome composition of the gorilla. A few of the most relevant results and conclusions of these studies further corroborate what has been said so far about their diet:

- Microbiome and degradation products indicate substantial fibre intake and fermentation (Gomez, 2014; McKenney, Ashwell, Lambert, & Fellner, 2014);
- There's presence of acetate and propionate yielding bacterial taxa also prevalent in the rumen and colon of cattle and other herbivores (Gomez et al., 2015; McKenney et al., 2014; Tsuchida & Ushida, 2015);
- More diverse metabolic products are present when the diet is higher in wild fruit, attesting to its higher quality and diversity as a food category (Gomez et al., 2015);
- Consumption of high levels of phenolics and other plant secondary compounds has been confirmed (Coupe, 2015; Gomez et al., 2015), as well as prioritization of non-protein energy (Gomez, 2014);
- Wild gorillas under higher anthropogenic pressure due to habitat encroaching exhibit particular microbiome profiles compared to gorillas on other locations. Captive gorillas also present adapted microbiomes that differ from what is found in the wild and even between different captive groups (Coupe, 2015; Gomez, 2014; Tsuchida & Ushida, 2015; Tsuchida, 2014).

2.4 Western Lowland Gorilla in Captivity

At the end of 2014 there were 861 Western Lowland Gorillas living in 145 institutions around the world and registered in the International Studbook (Wilms & Bender, 2015). Keeping gorillas in captivity presents its own set of challenges, a very important one being how to provide an adequate nutrition to all individuals of a group through a diet that promotes health and elicits natural feeding behaviours. It also presents a unique opportunity to study certain aspects of the gorilla physiology and biology in conditions usually unavailable in the wild.

2.4.1 Studies on Digestive Physiology

a. Digestibility

The digestibility of a food item determines the amount that is actually absorbed by the organism and therefore the availability of nutrients for maintenance, growth, reproduction and other body functions. It is affected by an animal's digestive system, body size, diet quality and physiological status. Most studies on this topic have been conducted in a captive setting, although some information comes from studies in the wild. The values next presented report on apparent digestibility, estimated by subtracting nutrients contained in the faeces from nutrients contained in the dietary intake. Therefore, it does not account for nutrients lost as methane gas or as metabolic waste products excreted in the faeces (International Livestock Centre for Africa, 1990; Rothman et al., 2008).

Crude protein digestibility is difficult to predict. Nitrogen (N) is an easily measurable component of the amino acids and crude protein is regularly estimated by multiplying its amount in a plant by 6.25, assuming a 16% N content. However, this method may not represent the actual available protein, for mainly three reasons: 1) some of the N is bound to the lignified cell wall, resistant to digestion; 2) a considerable part is bound to plant secondary compounds, such as tannins, also rendering it indigestible; 3) plant secondary compounds also contain significant amounts of non-protein nitrogen (Rothman et al., 2008). In a Mountain Gorilla study the portion of unavailable crude protein varied from 14.5% DM (herbaceous leaves) to 85.2% (decaying wood), totalling 15.1% of indigestible protein over one year's diet (Rothman et al., 2008). A study in captivity reached very similar values, from 14% to 16.5%, though analysis to differentiate N from microbial origin in the faeces wasn't conducted, which may confuse the estimations (Remis & Dierenfeld, 2004).

As mentioned before, gorillas possess the digestive adaptations to ferment otherwise indigestible fibre. Smith (2012) completed a study in Oklahoma City Zoo where NDF digestibility in four different experimental diets was measured, and the indigestible portion varied between 39% to 47%, with the lowest values achieved when the gorillas were supplemented with psyllium fibre. Their diets were characterized by NDF values of 21-25%, considerably lower than the NDF values of foods commonly ingested in the wild (44-80%, Table 1 – page 9). In San Francisco Zoo, another digestibility study was performed with slightly higher fibre values, 30% of NDF for both experimental diets and 7% and 19% of ADF, on a DM basis. The other nutritional components varied very little between diets, except the whole DM intake, which also diminished from 32% to 22%. The resulting NDF indigestible portion was 30% and 55% and the indigestible DM fraction for the whole diet was 13.5% and 22.7%, respectively (Remis & Dierenfeld, 2004).

Although, as referred before, a large body size can facilitate fibre digestion, a study conducted in wild Mountain Gorillas showed no difference in food digestibility between the considerable larger silverback and the females. The DM indigestible fraction of their diet was 40.3 ± 2.8% in lower frugivory months and 58.9 ± 1.2% in high frugivory months. It's suggested that the unlikely difference was probably due to the higher bulk of indigestible fruit seeds (Rothman, Dierenfeld, Hintz, & Pell, 2008).

b. Mean Transit Time

"Dietary intake, the proportion of fibre in the diet of captive animals, feeding frequency, ambient temperature, pregnancy, activity level, age, and exposure to medications which could destroy natural gut fauna and flora all affect gut passage rates" (Remis, 2000).

The mean transit time or the mean retention time of faeces (MRT) in the digestive tract is calculated to determine digestive and colonic metabolism (Remis & Dierenfeld, 2004; Smith, 2012). A few studies in captivity have shown the MRT of gorillas to be higher than that of other primates, averaging approximately 50-55 h, although it depends on the diet composition (Remis, 2000; Remis & Dierenfeld, 2004). One study by Remis & Dierenfeld (2004) also presented slight variations between individuals, with the juvenile having a shorter MRT and the oldest, wild born female having the longest.

Longer retention times are correlated with a smaller relative DM intake ($g/kg^{0.75}/d$) and allow for better fermentation and absorption of fibrous food secondary components, namely SCFA (Clauss et al., 2008). This is an efficient digestive approach for a larger primate like the gorilla, that consumes predominantly leaves, and that has lower energy requirements per unit of body weight when compared to a smaller primate. In spite of needing more food in terms of absolute amounts, gorillas then eat relatively less quantities of food per kg of body mass, and process it more slowly. Therefore, they can more easily adapt to scarcity of high-quality food and ingestion of items with increased secondary compounds. It also allows nutrients to be delivered at a slower rate, stimulating an energy burning process instead of quick energy storage (Clauss et al., 2008; Lambert, 1998; Smith, 2012).

2.4.2 Feeding Behaviour and Dietary Enrichment

a. Undesirable Behaviours

A behaviour that occupies a disproportionate amount of time in a captive environment as compared to the activity budgets of wild populations is considered an undesirable behaviour, while a stereotypic behaviour is characterized as fixed in form, repetitive and without an obvious purpose (Lukas, 1999).

Regurgitation and reingestion (R/R), similar to the behaviour of rumination described in humans, is the voluntary retrograde movement of food and/or fluid from the oesophagus or stomach into the mouth, hands or substrate, followed by subsequent consumption of the regurgitate. It has never been reported in the wild, and theories suggest that it's performed as an adaptation to boredom, inadequate diet, stress, space restriction and/or lack of control in the captive environment. Food portions fed to gorillas in captivity are commonly low in fibre and energy dense, so smaller portions spread throughout the day are enough to satisfy their energy requirements. Because in the wild gorillas consume food in high quantities and with a high fibre content, which is constantly available to forage, it has been suggested that some captive diets are unable to provide a feeling of satiety, and subsequently supress the feeding motivation. R/R may provide a way of coping with that, and once the behaviour is established in their repertoire it could be elicited on other conditions (e.g. distress or boredom), as a stereotypic behaviour. Sweet pulpy fruits could also incite the R/R mechanism and other factors may induce or condition this behaviour, but the research completed so far hasn't been able to completely explain the reasons behind it, how to correct it, or the extent of its detrimental effect on the gorillas health (Cousins, 2015; Lukas, 1999).

Coprophagy, the ingestion of faeces, although rare, has been described in wild gorillas and it is much more common in Mountain Gorillas than in Western Lowland Gorillas. Proposed reasons for this behaviour in captivity include boredom or the re-uptake of lost nutrients, amongst others, and it may be vital in infant gorillas in order to establish proper intestinal flora. In a study looking to remove pelletized biscuits and decrease fruit and dietary starch from the gorillas' diet in several zoos, an increase in coprophagy was consistently observed. It is suggested that due to an initial weight loss in all individuals, the cited diet change was perceived as a food scarcity period and the gorillas resorted to coprophagy to compensate. The fact that a decrease of this behaviour was observed after weight stabilization further supports this theory (Cousins, 2015; Less, 2012; Ogden & Wharton, 1997; Rothman et al., 2006; Vlčková, 2010).

Removal of milk from the diet has led to a significant reduction of R/R in Zoo Atlanta, and in Cologne Zoo a case of extreme R/R was corrected by a radical change in the diet, replacing fruit, milk, eggs, meat, porridge, bread and sugar for a broad selection of vegetables, branches and leaves (Cousins, 2015; Lukas, Hamor, Bloomsmith, Horton, & Maple, 1999). Together with the removal of animal products and other processed food types, several studies have presented an increase in the fibre content as an important factor in the reduction of these behaviours, as well as achieving a satiation feeling and increasing foraging opportunities (Less, 2012; Remis & Dierenfeld, 2004).

Besides the reduction in undesirable behaviours, providing diets more similar to the wild ones presented other benefits, for example, an increase in faecal consistency and in the display of natural behaviours (Less, 2012; Remis & Dierenfeld, 2004; Smith, 2012).

b. Environmental Enrichment

"The maintenance of species-specific behaviours for animals in zoological institutions is of top priority, as this can help ensure high levels of animal welfare" (Charmoy et al., 2015). An enrichment program, which usually has as one of its main goals the encouragement of species appropriate foraging behaviour, must be based on a good understanding of the species natural history. Enrichment strategies are usually divided in categories like sensory, social, foraging, among others, and a complete program requires a well thought combination of these different types (Charmoy et al., 2015).

Gorillas in the wild can spend 40% to 70% of their day foraging and feeding, but conditions in captivity rarely promote that level of activity: gorillas housed in zoos spend around 43% to 76% of their time resting/inactive versus 21% to 33% reported in the wild, and only 20% to 29% of their daily activity budget is dedicated to foraging. Dominance behaviour, similar in the wild and in captivity, is also an issue as established hierarchies can restrict the access of all members of the group to the food. Limited space and/or clumped resources enables their monopolization by the silverback and other higher ranking members (Charmoy et al., 2015; Less, 2012; Masi et al., 2009; Smith, 2012).

A strict feeding protocol and schedule can make it more practical for animal keepers to manage all the daily tasks required, but can also significantly impact the natural foraging behaviour of the gorillas. As they become aware of the regular times food is being provided the foraging behaviour is reduced, increasing the time spent resting and decreasing overall activity levels (Charmoy et al., 2015).

Gorilla diets should be fed throughout the day in small portions, rather than one or two huge feedings, providing multiple interesting events (Cousins, 2015; Ogden & Wharton, 1997). Food preparation and placement is also very important. In the wild gorillas are required to seek out and manipulate food items to access the desired parts, but in captivity this process is often simplified, requiring only the immediate consumption of the food item. Methods to encourage this natural behaviour in zoos are plenty: concealing food in different containers (logs, cardboard, burlap bags, problem boxes), scattering of nuts, seeds or pellets through the enclosure and ice blocks with food and/or juice inside that act as time released treats are a few examples. Food items can be chopped in small pieces for spreading or given in its natural form, especially if manipulation is required to access the edible part. The use of artificial termite mounds or other ways to provide invertebrates are encouraged given the role insects have in the natural gorilla diet, previously described. Spreading the main diet and enrichment throughout the enclosure also increases foraging opportunities for individuals lower in the hierarchy, who will have a tendency to avoid foraging in enclosed areas without easy escape routes, whilst also allowing for individual preferences (Charmoy et al., 2015; Ogden & Wharton, 1997).

A study looking into the impact of different forms of environmental enrichment on foraging and activity levels concluded that automatic belt feeders, which deposited tubes containing dried treats in the enclosure throughout randomized times of the day, had the largest positive impact on the gorilla's behaviour. It is likely that the unpredictability of the enrichment increased the need to explore the environment, being previously suggested in this study that the timing of an enrichment can be as important as its type. Varying between types of food given and sometimes inserting novel items in the diet can also contribute to this unpredictability factor, and it can be as simple as using spices to change natural flavours. However, an institution must strive to achieve balance, as it seems complete unpredictability can provide as little stimulation as complete predictability (Charmoy et al., 2015).

"Browse refers to any sort of plant or plant part that is fed whole. For example, tree limbs, bush branches, flowers, herbs, whole plants – such as bamboo or cornstalks – and similar items would be categorized as browse" (Ogden & Wharton, 1997). Browse can greatly increase the amount of time spent eating and assist in reducing undesirable behaviours. Although previously considered an occasional enrichment item, in light of the information gathered in the wild, it's naturally higher fibre content and the favourable results of captivity studies, browse is now considered an essential diet component, and when not available hay or straw should be offered. Providing these materials can also encourage nest-making, creation of reaching tools and incite other expressions of social behaviour and group dynamics. Some institutions have adapted their outside enclosures to naturally provide browse sources, by covering it with different varieties of plants originated from the zoo's gardens, like Howletts Wild Animal Park in the United Kingdom. Other strategy consisting in planting and regularly replacing such food sources has been adopted by Melbourne Zoo in Australia, whose horticultural managers replace living plants on a daily basis (Cousins, 2015; Ogden & Wharton, 1997; Popovich & Dierenfeld, 1997).

Other studies in captivity have shown that gorillas prefer fruit over vegetables and foods high in non-starch sugars and sugar-to-fibre ratio and low in total dietary fibre and protein. They do not avoid commercial produce containing tannins, and the tolerance threshold for this antifeedant seems to increase with sugar content. If the option exists, gorillas will consume cooked food (Remis, 2002; Smith, 2012; Wobber, Hare, & Wrangham, 2008).

2.4.3 Dietary Management in Zoos

In 2004 a questionnaire regarding current feeding regimes was sent to all European Association of Zoos and Aquaria (EAZA) registered Gorilla European Endangered Species Programme (EEP) holdings. Forty-five of the fifty-seven holdings answered, and some of the more relevant results are summarized below (Alvarez, Aguirre, Eulenberger, & Dierenfeld, 2006):

- About 60% of the holdings feed their gorillas between three and five times daily, with the mean being 4.7;
- All institutions offer no less than 10 different food items daily, with 30% offering more than 20. Over the year more than 200 distinct food items are provided at every holding;
- Most institutions offer browse and vegetables (100%), fruit (93%), animal products (92%), commercial diets (64%) and liquids other than water (89%);
- 73% of the institutions provide browse on a daily basis and 13% on a weekly basis;
- The most common animal products offered are, in varied frequencies, meat (29% of all holdings), eggs (67%) and dairy products (76%). Of these yogurt, milk and cheese are the most common;
- 60% of the institutions supplement their diets with vitamins and/or minerals, at differing dosages and frequencies;
- Only 11% of institutions do not offer clean potable water *ad libitum*;
- 80% of the holdings report some seasonality in the diets provided;
- 91% of the holdings hand feeds certain items. The main reasons given for this are training, quantity control, visual health checks, reducing competition and administering medication;
- 27% of the institutions never separate the gorillas for feeding;
- At the time of the study 18% of the holdings considered all individuals in their care to be generally obese or overweight and an extra 13% considered individual gorillas to also suffer from this condition;
- 71% of the holdings reported R/R and could associate it to specific food items or situations, the most commonly identified being sweet fruits.

Most zoos stated that yogurt was given to improve gut flora. Although lactobacilli have been identified in the gorilla’s gut microbiome (Gomez et al., 2015), there is currently no published information to support that yogurt consumption is required in captivity or that it actually improves gut flora. It may also be unadvisable given the saturated fat contents of such animal products. However, if dairy products cannot be completely removed it is recommended that no-fat or low-fat products are used and only in small quantities (Alvarez et al., 2006).

As for supplementation, if an animal is already consuming a nutritionally composed diet, adding extra vitamins and minerals prophylactically could actually unbalance the intake. A study into the diet and serum concentration of several vitamins in different species of captive primates, including gorillas, didn't find nutritional differences between supplemented and non-supplemented animals, nor significant contributions of these multivitamins to the serum parameters tested (Crissey et al., 1999). Certain fat-soluble vitamins and minerals can be stored by the body and reach toxic levels, hence supplementation should only occur if there is a known nutrient deficiency (Alvarez et al., 2006; Schmidt, 2004).

When assessing diet adequacy, it's important to consider the nutritional composition differences between the food that grows in the gorilla's wild habitat and the domesticated produce that is cultivated in modern cities. The latter one has been modified over time to satisfy human tastes, with an increased concentration of simple sugars and a very decreased fibre content. Although nutritional analysis of food destined for human consumption usually measures dietary fibre instead of NDF and ADF, one study in Saint Louis Zoological Park analysed several local whole produce items they use to feed their primates and concluded that fruit averages 13.4% (± 5.6) of NDF, vegetables 18.8% (± 7.2) and leafy green vegetables 21.5% (± 7.5) on a DM basis. In this study, corn with kernel, cob and husk included, had the highest NDF at 44%, which was the only value similar to the NDF average concentrations in wild foods (44-80% - Table 1, page 9). Another study looking into the potential of produce as a way to increase NDF levels in ape diets was published 6 years before, by a few of the same authors, with the following values: 3-27% NDF for fruit, 8-31% for vegetables and 13-28% for leafy green vegetables. When evaluating these values, it is important to remember that the nutritional contents of a food item can vary depending on several factors, including sample, species, season and place of origin, so they are merely indicative and cannot be exactly applied to every situation (Schmidt, Kerley, Dempsey, & Porton, 1999; Schmidt, Kerley, Porter, & Dempsey, 2005).

Also in one of these studies, the concentrations for water-soluble carbohydrates (WSC), which comprises mono and disaccharides like glucose, fructose and sucrose, averaged 40.4% (± 16.6) for fruits, 25.4% (± 12.7) for vegetables and 20.8% (± 18.6) for leafy green vegetables, which is substantially high if we consider that wild fruits average 35-39% and almost all other wild foods consumed have an average WSC concentration of 8% or lower, as presented in Table 1, in page 9 (Schmidt et al., 2005).

Gorillas are physiologically prepared to obtain most of their energy through a low calorie, high fibre, high bulk diet. Therefore, although in the wild fruit plays an essential role, domesticated vegetables, and particularly leafy green vegetables, seem to be an economic and healthier alternative, with a nutrient composition closer to wild fruits. Over-consumption of fruit in captivity provides too much energy from simple sugars and inevitably leads to obesity and several other health issues, with a study in the Species Survival Plan (SSP)[1] gorilla population showing a correlation between amount of fruit consumed by females and all obesity biomarkers studied (Less, 2012).

When faced with severe dental health issues in their colobus monkeys (*Colobus guereza*), Paignton Zoo investigated the sugar levels in the food provided and eventually decided to completely remove fruit from the diet of several primate species they house, including gorillas. They observed a drastic decrease in dental health issues, gradual and sustained weight loss in overweight individuals and maintenance of healthy weights in the others, improved faecal consistency, lower incidences of diarrhoea and reduction of aggressive and self-directed behaviours across all primates. They argue that fruit possesses no nutritional benefits that cannot be acquired in other ingredients, and therefore when this highly palatable and valued resource is removed, the reasons for dominant individuals to display aggressive behaviours and consume more than they require is reduced (Plowman, 2015).

Another considerable difference between zoo and wild diets is the quantity of starch present. Polysaccharides can be divided in two categories: non-starch polysaccharides, composed by soluble fibre (e.g. pectins) and insoluble fibre (e.g. cellulose and hemicellulose), and starch and starch-like compounds, which are directly digestible by mammals. Starch itself is a glucose polymer that works as a plant energy reserve, consisting of amylose and amylopectin in various proportions. High amylose starch, found in legumes, seeds and unprocessed whole grains is more resistant to digestion and possesses a low glycaemic index, mimicking fibre in its function. High amylopectin starch, however, is found in items like bread, cereals, some root vegetables (e.g. potatoes) and commercial pellets or large extrudates (also known as biscuits or chow) that are offered to primates in zoos, often representing up to 35% of its composition on a DM basis. It has a high glycaemic index and fast digestion and absorption, leading to an increased demand for insulin secretion (Less et al., 2014; National Research Council, 2003).

Both a biscuit free diet and a diet with increased resistant starch were equally effective at reducing insulin and cholesterol levels in a study conducted in several North American zoos (Less et al., 2014). Browse contains very little starch, so its concentration in diets offered to captive primates is frequently higher than the one found in wild foods, and it is important to highlight that when high-starch diets are fed, excessively rapid fermentation can occur, causing abdominal discomfort and poor stool quality. Research also suggests that consumption of high amounts of starch by specialized hindgut fermenters can lead to a localized and systemic inflammatory response and recent studies, where institutions have excluded these biscuits from the gorillas' diet, yielded mostly positive results in correcting health and behavioural issues. Furthermore, since gorillas can quickly consume most of their

[1] The SSP is an initiative from the Association of Zoos and Aquariums (AZA), and it's the North American equivalent to EAZA's EEP.

day's calories through the ingestion of pellets or biscuits, this can eliminate the key element of their feeding ecology, which is the need to forage for long periods of time (Ball, Port, Harris, & Westfall, 2008; Less et al., 2010; Less, 2012; National Research Council, 2003; Saucedo-Rodríguez & Soto-Rendón, 2010).

However, these products are usually rich in nutrients that may be difficult to provide otherwise, and as knowledge of primate nutrition increases, healthier pellets with less starch and more fibre become available. They are also relatively inexpensive and as such become a very convenient way of providing a nutrient balanced diet. In some zoos pellets may be the main source of fibre and some vitamins and minerals, so precaution must be taken when reducing their quantity and adapting the diet (Less, 2012).

Increasing the volume of browse and tannins in the diet and decreasing calorically dense foods could positively impact the health of captive gorillas and approach their activity budgets to the ones recorded in the wild, especially since woody browses are one of the few food items available to zoos that closely mimic the nutrient composition of wild foods. Although it may be difficult for zoos to have access to browse all year round, particularly for institutions in northern climates, cooperation with local parks, horticultural associations or forest departments may yield positive results, with the possibility to use the fluctuations in local browse availability to provide a more seasonal diet. Mirroring the seasonal fluctuations that occur in the wild provides a more nutritionally rich diet and can be beneficial to the gorilla's health. Some studies also refer alfalfa hay as a suitable fibre source (Krebs & Kaummanns, 2005; Smith, Remis, & Dierenfeld, 2014; Smith, 2012).

"Gorilla diets and feeding regimes vary considerably amongst EEP zoos, and between AZA and EAZA facilities in general. In the wild diets vary with habitat; in captivity, diets differ amongst facilities (…) due, for the most part, to economics and geographical differences" (Alvarez et al., 2006). Although this is to be expected, and institutions need to adapt to their circumstances, a standard of care in nutritional quality and dietary enrichment must always be provided.

2.5 Nutrient Requirements and Recommendations

The daily requirements of animals are determined by a combination of physical and physiological factors. Although several studies have explored the nutritional composition of the foods gorillas consume in the wild, little information is available on quantities ingested and daily nutrient intakes. The determination of nutrient requirements, extremely valuable for captive management, would require the animals to go through long-term, controlled research, as it is usually done with domestic animals, and that is currently not possible with endangered species like the gorilla (Schmidt, 2004).

In 2003 the National Research Council (NRC) published the 2nd revised edition of the book Nutrient Requirements of Nonhuman Primates and to the knowledge of the author this is the most complete publication on the topic so far. It provides estimated adequate nutrient concentrations in diets intended for post-weaning nonhuman primates (Table 4), on which the remaining discussion in this chapter will be built.

Table 4: Estimated adequate nutrient concentrations (DM basis) in diets containing conventional feed ingredients intended for post-weaning nonhuman primates, accounting for potential differences in nutrient bioavailabilities and adverse nutrient interactions, but not for potential losses in feed processing and storage (adapted from National Research Council, 2003)

Nutrients	Concentration	Nutrients	Concentration
Crude Protein (%)	15 – 22	Se (mg/kg)	0.3
NDF (%)	10 – 30	Trivalent Cr (mg/kg)	0.2
ADF (%)	5 – 15	Vitamin A (IU/kg)	8000
Essential n-3 fatty acids (%)	0.5	Vitamin D_3 (IU/kg)	2500
Essential n-6 fatty acids (%)	2	Vitamin E (mg/kg)	100[a]
Ca (%)	0.8	Vitamin K (mg/kg)	0.5[b]
Total P (%)	0.6	Thiamine (mg/kg)	3
Mg (%)	0.08	Riboflavin (mg/kg)	4
K (%)	0.4	Pantothenic acid (mg/kg)	12
Na (%)	0.2	Available niacin (mg/kg)	25
Cl (%)	0.2	Vitamin B_6 (mg/kg)	4
Fe (mg/kg)	100	Biotin (mg/kg)	0.2
Cu (mg/kg)	20	Folacin (mg/kg)	4
Mn (mg/kg)	20	Vitamin B_{12} (mg/kg)	0.03
Zn (mg/kg)	100	Vitamin C (mg/kg)	200
I (mg/kg)	0.35	Choline	750

a. As all-rac-α-tocopheryl acetate
b. As phylloquinone

2.5.1 Energy

Primates have long gestation periods, long periods of nursing and high encephalization quotients, thus requiring large amounts of energy to function properly (Smith, 2012).

When organic substances are completely oxidized to carbon dioxide and water, the energy released is known as gross energy (GE). However, not all of it is available to the consuming animal. Apparent digestible energy (DE) is the one that's left after subtracting the value that is lost in faeces, and varies according to food composition, amount of food consumed per unit of time and the animal's digestive capacity. And if the energy that is lost through urine and combustible gases is further subtracted, the resulting value is called apparent metabolizable energy (ME), which aims to represent what is strictly available for the organism to perform its metabolic processes. One of the systems that has been most widely used involves the calculation of physiologically available energy, an approximation of apparent ME, which is obtained by adding the potential energy provided by the carbohydrates, protein and fat that compose the food item and that can be absorbed and utilised. Through digestibility trials the energy values each of these categories provides to an adult person was asserted, and most human nutrient databases express energy content in that way. However, this method usually disregards considerable energetic contributions from fibre, and so the values provided by these databases are likely to be underestimations of the energy gorillas are really obtaining from these foods (National Research Council, 2003). Popovich et al. (1997) has postulated that, given their digestive anatomy and physiology, gorillas can obtain almost 60% of their energy from colonic fermentation and SCFA, while humans obtain only 2-9%. One and a half kcal/g was selected as a conservative energy value for dietary fibre, and considering the gorillas wild diet, it was theorised that 100 g of DM would provide them with 194 kcal of ME.

A study in 1978, comparing different primate families in captivity, calculated daily ME intakes for Great Apes to be between 87.9-118 kcal/kg$^{0.75}$. This has led to the conclusion that daily energy requirements for captive species in this family can be roughly estimated with the equation 100 x (body mass in kg)$^{0.75}$, which for a 150 kg silverback, for example, would equal 4286 kcal. It's important to consider that activity level plays a fundamental role in energy requirements – the difference between captive and free-living animals can represent an increase up to 30% of energy expenditure, for example (National Research Council, 2003). Other way to assert the caloric needs of gorillas is presented in the 1997 SSP Management of Gorillas in Captivity Manual, by using the equation of Kleiber, a generic energetic equation for mammals, where basal metabolic rate (BMR) = 70 kcal x (body mass in kg)$^{0.75}$. The maintenance energy can then be estimated as 2 x BMR for adults and as 3 x BMR for growing animals. This would mean that a 150 kg silverback would require 6000 kcal/day (Popovich & Dierenfeld, 1997). However, Westbury et al. (2007) diet analysis of ten EEP zoos showed an average daily calorie intake of 5000 kcal for a 150 kg male gorilla and 2800

kcal for a 100 kg female, which is approximately 1.5 x BMR, and seems to indicate an overestimation of energy needs in the Kleiber equation.
In more recent years Rothman et al. (2008) estimated the nutrient intake in wild Mountain Gorillas by conducting focal observations and analysis of food and faeces over a 2-month period. By adapting the physiologically available energy method to incorporate NDF measured digestibility it was calculated that the two silverbacks (estimated weight of 200 kg) consumed 9203 ± 471 kcal/day, the females (four lactating, and two in a non-reproductive phase) 8178 ± 588 kcal/day and the juveniles 7124 ± 694 kcal/day. Even more recently, Masi et al. (2015) used observations from an habituated western gorilla group in 2004-05 and through a similar method estimated the mean daily energy intake to be 5038 ± 267 kcal for the group silverback, 9683 ± 225 kcal for each of the four lactating adult females and 8914 ± 589 kcal for a sub-adult male. Caution must be taken when comparing the two studies, as sample size is quite small and the equation used to calculate energy consumed isn't completely identical. The substantial difference in the silverback values may be due to subspecies differences (mountain gorillas are usually bigger) and/or due to some extrapolations of limited observation time.

2.5.2 Protein, Fibre and Essential Fatty Acids

The crude protein concentration recommended by the NRC is consistent with the percentage present in wild gorilla's food and apparent dietary intake – in mountain gorillas, even in higher frugivory season, protein intake was never below 15% of DM (Rothman et al., 2008). However, primates in general and gorillas in particular reach maturity late, have slow growth rates and small and relatively diluted milk yield, all factors suggestive of relatively low protein requirements. Given the findings that gorillas prioritize non-protein energy, probably over-eating protein on certain seasons as a result, and the possibility that these animals may be physiologically adapted to excrete excess nitrogen, it becomes plausible that consumption exceeds requirements (Masi et al., 2015; Oftedal, 1991; Rothman et al., 2008). Alopecia, anaemia and weight loss in a colony of captive gorillas over a 3-year period was ascribed to a dietary protein deficiency, when it's concentration in the diet was around 7% on a DM basis (Mundy, Ancrenaz, Wickings, & Lunn, 1998).
Studies in primates have shown that essential fatty acids are vital for brain development and maintenance of this organ and nervous functions, so a minimum of 0.5% of n-3 fatty acids and 2% of n-6 should be present in the diet, especially in pregnant females. Normal developments in several primates have been observed over a wide range of n-3:n-6 ratios and the upper limit of accepted concentrations appears to be quite high. However, a study on the role of diet and starches on inflammation has suggested that increasing n-3 fatty acids like ALA reduces the conversion of n-6 fatty acids like LA into inflammatory ones. Nonhuman-primate diets enriched in n-3 and n-6 polyunsaturated fatty acids appear to protect against coronary arterial atherosclerosis, whereas diets enriched in saturated and

monounsaturated fatty acids appear to promote the disease (Ball et al., 2008; National Research Council, 2003).

Although the recommended concentration of NDF varies between 10-30%, given the natural diet and digestive adaptations of the gorilla, a very minimum of 20% should be provided for this species. Besides all the health and behavioural risks, resulting from a lack of fibre, since captive diets are currently far from being able to mimic the high NDF concentrations of a natural diet, institutions should aim for an NDF value close to the maximum recommended value instead (National Research Council, 2003). Differences can even be seen on a physical level, by comparing the typical blown abdomens characteristic of high fermentation in free-ranging gorillas, with the usually flatter abdomens of captive gorillas (Figure 4) (Masi, 2011).

Figure 4: Comparison between blown and flat abdomens of free-ranging and captive gorillas, respectively. First Row – Free-ranging gorillas from Mbeli Bai, Congo (adapted from Mbeli Bai Study – The Gorillas. Retrieved May 4, 2016 from http://www.mbelibaistudy.org/#!gorilla/c1sr9). Second Row – Captive gorillas from Zoo Basel, Switzerland (adapted from Zoo News by Zoo Basel. Retrieved May 4, 2016 from http://zoobasel.ch/en/tiere/tiere/saeugetiere_tierbeschreibung.php?TiereID=99&ap3=1_3)

It should be noted, though, that the intestinal tract is extremely plastic, and some level of adaptation may exist in captive gorillas, for example, to lower volumes of fibrous foods. The blowing effect also varies throughout the day. Moreover, the gut microbiome is different between captive and free-ranging gorillas, which can also have an effect on the digestive process (Vlčková, 2010).

2.5.3 Essential Macrominerals

The essential macrominerals, which the mammal organism needs in larger amounts, include Ca, P, Mg, K, Na and chlorine (Cl).

The teeth and skeleton of mammals have a high relative body mass and density and contain over 98% of the body's Ca and 80% of the body's P. These two elements are also essential to cellular communications and modulation, which explains why they are required in superior quantities compared to other macrominerals. Green leaves like leafy vegetables are usually good sources of Ca and Mg, and seeds, nuts and invertebrates are good sources of P, although P intake is rarely a problem in primates. Since P can bind to Ca in the intestinal lumen and form calcium phosphate, which is unavailable for absorption, keeping a dietary Ca:P ratio between 1.1:1 and 2:1 has been emphasized. When the body senses low blood circulating values of Ca, due to reduced absorption, it activates safeguard mechanisms that will deplete bone Ca reserves. High protein and Na concentrations may also increase Ca requirements, due to greater urinary loss and decreased renal reabsorption. Although P associated with phytate is mostly unavailable for non-ruminants, causing P requirements to be higher than if only inorganic sources were considered, the ruminal microorganisms seem to render almost all of the phytate P available for absorption. Whether this is also true for the colonic microorganisms in the gorilla's digestive tract has yet to be confirmed, so recommended concentrations of non-phytate P in nonhuman primates is of 0.4% (National Research Council, 2003). It is unclear whether a 0.8% P intake is indeed necessary, as food concentrations in the wild range between averages of 0.1%-0.22% (Table 2), and when measured, P consumption by free-ranging mountain gorillas stayed below NRC recommendations (Rothman et al., 2008). The values recommended should then be more than sufficient to support adult maintenance, providing that appropriate vitamin D consumption and/or ultraviolet B (UVB) light exposure is met. This is important because calcitriol, the hormonally active metabolite of vitamin D, plays an essential role in Ca and P absorption (National Research Council, 2003).

Studies in rhesus monkeys (*Macaca mulatta*) seem to indicate that a 0.04% concentration would support maintenance requirements of Mg, but this occurs at low concentrations of Ca and P. Higher concentrations of these minerals appear to increase required Mg intake and given the relatively higher concentrations of Ca and P in natural primate diets, a value of 0.08% of Mg seems a more accurate dietary level, with 0.04% advised as a minimum (National Research Council, 2003).

K is usually found in high concentrations in plant tissue, with values over 3% of DM being common, so deficiencies are rare. Requirements appear to be lower in some primate species, but 0.4% reflects the higher concentrations reported to be adequate on different studies (National Research Council, 2003).

Na was the only nutrient consumed by wild mountain gorillas that didn't exceed human nutrient requirements, with a daily intake considerably below NRC recommendations even when there was deliberate wood consumption. In another study in western gorillas Na was the only mineral whose intake didn't vary across the year, highlighting that gorillas may balance and prioritise its intake more than other minerals (Masi et al., 2015; Rothman et al., 2008). Studies have concluded that diets with 0.25-0.65% of Na concentration appear to support maintenance of nonhuman primates, but are likely to exceed minimum needs. Captive gorillas have a propensity to heart disease, and given the influence of Na on blood pressure, it is advised to prevent any excess intake of this nutrient (National Research Council, 2003).

Based on studies in baboons and comparisons with other species, 0.2% of dietary Cl is expected to be sufficient (National Research Council, 2003).

2.5.4 Trace minerals

Minerals that are known to be required in trace quantities are Fe, Cu, Mn, Zn, iodine (I), selenium (Se), chromium (Cr) and cobalt (Co) as part of vitamin B12 (cobalamin). Fe requirements of nonhuman primates haven't been well established and if an animal presents a microcytic hypochromic anaemia, insufficient Fe intake should always be one of the explored differentials. However, Fe overload is currently a more recognised problem in primates. Haemosiderosis has been observed numerous times in several lemur species in captivity, presumably due to multiple reasons: high Fe content in the commercial diets, high ascorbic acid concentration, due to citrus fruits consumption, which enhance Fe absorption, and insufficient natural Fe absorption inhibitors such as tannins. Mineral requirements are often dependent on the intake of other minerals and substances. For example, excessive dietary Zn can lead to Cu deficiency and ascorbic acid may interfere with Cu absorption. The remaining trace mineral recommendations are based on extrapolations from other mammals and a few studies in primates, and should provide an appropriate nutrient value for maintenance of an adult gorilla. Ruminant animals have a dietary requirement for Co, which is incorporated into vitamin B12 during bacterial synthesis in the rumen, but a nutritional requirement for Co independent of vitamin B12 for nonhuman primates has not been demonstrated. Other trace elements like fluorine, molybdenum, silicon, boron, nickel and tin may be required, but very little research on needs of nonhuman primates for these elements has been conducted (National Research Council, 2003).

2.5.5 Fat Soluble Vitamins

Vitamin A (retinol) is found in foods of animal origin and some microorganisms. Most plants contain carotenoids, of which some can be converted, primarily in the gut mucosa, into this vitamin. It is mainly stored in the liver and it requires adequate zinc concentrations for maintenance of normal plasma levels. High plasma concentrations of carotenoids were found in orangutans (*Pongo pygmaeus*), and in gorillas the plasma retinol concentration seems to be higher than what is found in humans. The recommended daily intake of vitamin A in human adults is roughly 6000 IU/kg, already containing a safety factor, so 8000 IU/kg should meet or exceed the needs of nonhuman primates (National Research Council, 2003).

Vitamin D is necessary for the absorption of Ca and P, and although milk analysis from different primates indicates insufficient quantities of this vitamin, it is usually not a problem, as it can be synthesised in the skin in the presence of UVB radiation. Individuals who do not have access to natural, unfiltered sunlight may require sufficient vitamin D in the diet, especially nursing infants who need adequate concentrations of this vitamin to enhance appropriate bone growth and development. Differences in the biologic activity of vitamin D2 and D3 have been observed in many species so the estimated requirement is only given in terms of vitamin D3, which is usually better absorbed and more biologically active. For the species studied so far dietary vitamin D3 concentrations between 1000-3000 UI/kg seem to meet the requirements in the absence of UVB exposure. However, given the uncertainty on safe lower and upper limits of this vitamin, it would be prudent to provide some exposure to UVB radiation, either through open outside enclosures, selection of UVB-transparent windows or artificial UVB light sources (National Research Council, 2003; Schmidt, 2004).

Vitamin E is a collective term for the eight natural occurring compounds that possess varying levels of biological activity. It is found mostly in fatty foods like nuts and seeds and in some dark leafy vegetables like spinach. The NRC chooses to use the international unit (IU) where 1 IU = 1 mg of all-rac-α-tocopheryl acetate, considering the eight stereoisomers found in nature (National Research Council, 2003). However, as of 2000, α-tocopherol, in its synthetic and natural form, is the only recognized compound that meets human requirements. As 1 mg of α-tocopherol = 0.45 IU of the all-rac-α-tocopherol compound, the NRC recommended concentration of vitamin E as α-tocopherol is 45 mg/kg (United States Department of Agriculture, 2015a). Based on several published studies in primates, intake of 50 mg per kg of DM of α-tocopherol appears to be a reasonable estimate of the amount required. Vitamin E is mostly stored in fat droplets of adipose tissue. It functions as a potent anti-oxidant of biologic membranes and it stimulates optimal immune function. Its major biologic role is to protect polyunsaturated fatty acids (PUFAs) and other components of cell membranes and low-density lipoprotein (LDL) from oxidation by free radicals. Therefore, high dietary concentrations of fat and PUFAs, which include the essential fatty acids, will increase vitamin E requirements (National Research Council, 2003).

Vitamin K is found in higher quantities in green flower and leafy vegetables, it is essential for the blood coagulation process and it also plays a role in bone metabolism. Its principal active compound in the diet is phylloquinone, or vitamin K1, but menaquinone, or vitamin K2, can be produced by intestinal bacteria. The importance of the latter is uncertain, so setting minimal requirements for dietary phylloquinone is difficult. However, more attention should be given to the intake of this vitamin when the individual is receiving intestinally active antibiotics that can severely limit menaquinone gut synthesis (National Research Council, 2003).

2.5.6 Water Soluble Vitamins

Dietary requirements presented for most water soluble vitamins have been extrapolated from very few studies on primates, mainly from species typically used in laboratories like the rhesus monkey (*Macaca mulatta*) or the baboon (*Papio anubis*). Although it's hard to estimate accurate requirements, values presented should provide adequate levels for adult maintenance in normal circumstances. However, it's important to remember that interactions with other substances can frequently alter requirements. For example, niacin can be synthesized from a dietary excess of the amino acid tryptophan, but deficiencies on a number of other nutrients - vitamin B6, riboflavin, Fe, Cu – can inhibit this conversion. Substantial amounts of biotin can be synthesized by the gastrointestinal microbial flora, so antibacterial drugs like sulphonamides can prevent this production (National Research Council, 2003).

Vitamin C, or ascorbic acid, is a particularly important vitamin in diets for primates, as most of them, including humans, lack the enzyme required to synthesize it from glucose. It is required for a range of essential metabolic reactions and it is also regarded as a potent antioxidant. Wild mountain gorillas, ranging between 100 to 160 kg, seem to be consuming 2 to 4 g or more of ascorbate per day. The signs of deficiency are collectively called "scurvy" and some studies suggest that stressed animals may require higher vitamin C concentrations (Milton, 1999; National Research Council, 2003).

2.5.7 Life Stage and Gender Considerations

Biologic factors like gender, growth, age, health and reproductive status affect nutrient requirements (National Research Council, 2003).

Significant differences in energy intake between juveniles, females and silverbacks have already been presented before. In the previously referred studies in wild gorillas, lactating females had a higher intake of DM, energy and protein per kilogram of metabolic body mass than the silverbacks (Masi et al., 2009; Rothman et al., 2008). Energy requirements increase on the second trimester of pregnancy (about 300-350 kcal/day for humans) and after birth, lactation and the effort of carrying the baby make it the most energetically demanding life phase, possibly entailing a several-fold increase in food intake when compared to females in non-reproductive phases (National Research Council, 2003). Female western lowland gorillas also likely experience greater reproductive costs than other subspecies, as infants are weaned at a median age of 4.5 years, compared to 3.5 for mountain gorillas (Nowell & Fletcher, 2008). It is recommended to monitor the weight gain of pregnant females and assess if they need extra food to manage the increased requirements or, for example, if it may be best to let the individual use the excessive energy reserves gained during pregnancy to meet the increased energy needs during lactation (Schmidt, 2004). Folic acid plays an important role in erythrocyte production and the development of the foetus neural tube into brain and spinal cord. It is important to make sure that pregnant females and ones expected to become pregnant receive the recommended folic acid levels, maybe even raising it to 5-6mg/kg of DM if it all comes from natural sources, due to its reduced biologic availability. Lactating females should receive adequate concentrations of Ca, P and vitamin D for milk production and body maintenance needs (National Research Council, 2003). Iron requirements are known to increase in women who are lactating and resume their reproductive cycling. A captive gorilla female on a diet without commercial pellets was reported to present pallor, lethargy and poor mucus membrane colour when she reached this stage, and this clinical state was presumably corrected with iron supplements (Ball et al., 2008).

In terms of age, juveniles (around 4 to 10/11 years old) have greater nutritional needs per unit of body mass than non-reproducing adults, because fast growing animals must consume more nutrients to sustain body mass accumulation and since they're smaller they also have higher metabolic rates (National Research Council, 2003; Schmidt, 2004). This explains why wild juvenile gorillas also consumed more DM, energy, protein and minerals (Ca, P, Mg, K, Fe, Zn, Mn, Mo) per body mass unit than silverbacks (Rothman et al., 2008). At the other end of the spectrum, basal metabolic rate decreases with advancing age, due to a loss of lean body mass (non-fat parts of the body). Geriatric individuals also tend to become more sedentary which altogether considerably decreases energy expenditure and energy requirements. It becomes then important to monitor food intake and make sure the diet consumed is balanced and the individuals are not ingesting too many calories and accumulating excessive fat reserves (National Research Council, 2003; Schmidt, 2004). The correct diet adaptations for geriatric apes still needs to be further studied.

2.5.8 Recommendations

In order to work with nutrient concentrations, an appropriate quantity of food intake must be defined. Even when all the nutrient concentrations recommended are respected in a diet, if the animal eats in excessive or insufficient amounts it will result in unhealthy nutrient intakes. Animals housed in groups should receive enough food to meet their nutritional needs and limit aggressive encounters without allowing them to be overly selective (Schmidt, 2004). Popovich & Dierenfeld (1997) recommend feeding a gorilla no more than 4.5% of body mass on an as-fed basis, corresponding to approximately 1.25% in a DM basis. Based on the experience of Cologne Zoo, that offers large quantities of browse all year, the EEP Gorilla

Husbandry Guidelines admits the possibility of offering more than 4.5% of body mass to avoid competition and behavioural disturbances (Krebs & Kaummanns, 2005).

Other recommendations listed in the most recent draft of the Gorilla SSP Care Manual, in 2008, include minimal use of processed foods, complete absence of animal products, less reliance on primate biscuits and possible elimination of fruit, along with an increase in leafy green vegetables and browse. They propose a nutrient balanced diet that consists of 7% fruits, 57% leafy green vegetables, 4% root vegetables, 17% other vegetables and 15% high-fibre primate biscuits, on an as-fed basis. When a simulated diet is created using those proportions and the most common produce used by zoos in North America, it is characterized as having 20% of NDF, 21.5% of crude protein and 3025 kcal per day (Smith, 2012).

In the wild, gorillas obtain most of the water required through their foods, but have occasionally been observed drinking water from streams or extending their lower lip during rainfall. All facilities are advised to have clean potable water available at all times (Popovich & Dierenfeld, 1997; Rogers et al., 1990; Rothman et al., 2008)

A questionnaire distributed in 2006 looked into the nutritional adequacy of the diets in gorilla EEP facilities and data from 10 zoos (17 individual diets) were analysed. Dietary intake studies indicated that there was consumption of 93% to 100% of the diet offered, suggesting that analysis based on offered diets could offer a reasonably accurate estimation of the actual diet. Results showed that fibre content was considerably lower and fat content higher than what the current guidelines recommend. Energy provided per individual varied between 1900 to 9500 kcal/day, water soluble vitamins were excessive whereas macromineral concentrations were barely adequate. It is then recommended that institutions assess the adequacy of their diets and if necessary adapt them to the necessities of their gorilla group, striving to meet the most recent recommended nutrient concentrations (Westbury, Alvarez, & Dierenfeld, 2007).

2.6 Measurement of Anthropometric Features and Body Fat

The nutritional status of an animal can influence its physical dimensions and gross composition. Scoring systems based on body shape and prominence of skeletal features have been developed for several species and provide a non-invasive and systematic appraisal of an animal's nutritional condition, its evolution through time and the adequacy of its energy supplies (Crissey et al., 2002). However, gorillas show marked differences in body shape and composition, varying with age, gender and individual, and the creation of a standard scoring system hasn't been published so far.

Body composition was measured via post-mortem dissection in four adult wild-born captive gorillas, two males and two females, and for three of them the body mass was composed by 19.4-26.6% of fat, 10.2-13.4% of bone tissue and 36.1-38% of muscle. One of the females was considerably obese, with up to 44% of fatty tissue and only 16% of muscle (Zihlman & McFarland, 2000).

Compared to their counterparts in the wild, captive gorillas typically ingest a diet rich in calories and lower in fibre and polyphenols. Social dynamics during group feedings often don't allow for dietary portion control, and enclosure size and design frequently limits activity devoted to foraging, food collection and manipulation (Leahy & Lurz, 2010). Primates are evolutionarily adapted to store fat, so these differences can lead to obesity, which is defined as having an excess amount of adipose tissue in relation to lean body mass. The few reported body weights in captivity typically exceed wild weights, with females ranging an average of 85-110 kg and males of 144-207 kg (Less, 2012; Smith, 2012). However, weight alone may not be a good measure for body condition assessment and a normal weight range for gorillas has not been established yet. In humans the body mass index (BMI) = body weight (kg)/height^2 (cm) provides a more complete evaluation and is positively correlated with obesity, which allows for a quick non-invasive assessment and categorization of an individual as underweight, normal, overweight or obese.

A recent study by Less (2012) has looked into defining parameters for obesity and developing an adapted BMI for gorillas, validated by hormone indicators of adiposity. For other primates, researchers have calculated a non-human primate mass index (PMI) = weight (kg) / crown-rump length^2 (m), that excludes leg length from the measurements and makes it more practical to calculate in non-anaesthetised animals. It has been validated for a few primate species, but sometimes only for the males or the females.

In male gorillas, probably due to the gender dimorphic sagittal crest, which seems to be taller in gorillas with shorter torsos, no correlation was found between PMI and other indicators of body condition. A modified PMI was then calculated using back length instead of crown-rump, excluding the head measurement. In female gorillas, PMI also showed no correlation with any biomarkers, but other measurements, particularly hip width, and then shoulder width and widest point had significant relationships with leptin and triglycerides. This is probably due to gender differences in fat deposition, that also occur in humans (Zihlman & McFarland, 2000).

In conclusion, although no body composition measures were significantly related to all measured serum biomarkers, Less (2012) determined that males weighing more than 211kg or with a modified PMI > 358 and females weighing more than 86kg, with a hip width > 47cm, shoulder width > 56cm or widest point > 52cm are at risk and should have their blood serum assessed for obesity biomarkers. It is also concluded that males with a modified PMI > 377 and females with a PMI > 158 should be assessed for hyperglycaemia.

2.7 Biochemical Analysis of Body Fluids

The analysis of body fluids like blood, serum or urine is a central tool for veterinarians to assess the general well-being and identify and monitor specific health issues of the animals under their care. Almost no values for free-ranging gorillas exist in the literature, so Table 5 shows the current reference values for the most common blood and serum parameters analysed in captive gorillas.

Table 5: 2013 International Species Inventory System Physiological Reference Intervals and Means for Captive Western Gorillas (adapted from Miller & Fowler, 2015)

Haematology	Interval	Serum Biochemistry	Interval	Serum Biochemistry	Interval
Erythrocytes (× 10^6cells/µL)	4.61 (3.52 – 5.87)	Total Protein (g/l)	72 (57 – 87)	Uric Acid (µmol/l)	71.38 (11.9 – 148.71)
PCV (%)	38.9 (30 – 49.6)	Albumin (g/l)	38 (28 – 48)	Total Bilirubin (µmol/l)	8.55 (3.42 – 20.52)
Haemoglobin (g/dl)	12.4 (9.5 – 15.5)	Globulin (g/l)	34 (13 – 49)	Glucose (mmol/l)	4.38 (2.44 – 7.16)
MCV (fL)	83.5 (70.5 – 96.3)	Calcium (mmol/l)	2.35 (2.08 – 2.65)	LDH (IU/l)	586 (210 – 1644)
MCH (pg)	29.6 (22.8 – 30.8)	Magnesium (mmol/l)	0.74 (0.48 – 1.1)	Alkaline Phosphatase (IU/l)	389 (103 – 1147)
MCHC (g/dl)	32.3 (28.2 – 35.6)	Phosphorus (mmol/l)	1.36 (0.81 – 1.97)	GGT (IU/l)	25 (4 – 76)
Leucocytes (× 10^3/µL)	7.86 (3.44 – 16.49)	Sodium (mmol/l)	137 (130 – 145)	CK (IU/l)	269 (59 – 791)
Neutrophils (× 10^3/µL)	5.03 (1.13 – 12.37)	Potassium (mmol/l)	4.3 (3.3 – 5.7)	AST (IU/l)	31 (11 – 75)
Band Neutrophils (× 10^3/µL)	0.04 (0.01 – 0.12)	Chloride (mmol/l)	101 (94 – 108)	ALT (IU/l)	31 (7 – 72)
Lymphocytes (× 10^3/µL)	2.07 (0.59 – 4.84)	Iron (µmol/l)	16.5 (6.62 – 31.68)	Amylase (IU/l)	28 (6 – 68)
Eosinophils (cells/µL)	191 (38 – 571)	Creatinine (µmol/l)	97.24 (44.2 – 167.96)	Lipase (IU/l)	13 (0 – 58)
Monocytes (cells/µL)	401 (60 – 1048)	Urea Nitrogen (mmol/l)	3.57 (1.43 – 6.78)	Thyroxin (mg/dl)	6.3 (3.2 – 12.4)
Basophils (cells/µL)	75 (12 – 191)				
Platelets (× 10^3/µL)	190 (2 – 389)				
Reticulocytes (%)	0.2 (0 – 0.8)				

Triglycerides are fatty acids linked to glycerol, that function as an energy source and comprise the stored fat in adipocytes, while cholesterol is a lipid used as a precursor for cell membranes, bile salts and steroid hormones. Excessive levels of either element are associated with obesity, type II diabetes and heart disease in humans, and have more recently been used as markers for adiposity and obesity in gorillas. Cholesterol is constituted by four major lipoprotein groups: chylomicrons, very low-density lipoproteins (VLDL), low-density lipoproteins (LDL) and high-density lipoproteins (HDL). In humans the LDL fraction is considered very atherogenic, and low HDL and elevated triglyceride concentrations have been strongly correlated with increased risk of heart disease. The International Species Inventory System (ISIS), which provides its members in over 80 countries with a zoological data collection and sharing platform, reported in 2013 reference intervals in captive gorillas that are considerably higher than the values found in free-ranging gorillas, as shown in Table 6. There was no significant difference in the values between male wild western lowland gorillas and mountain gorillas, so those results are presented too. When evaluating the table, it is important to remember that, both in humans and gorillas, triglyceride values seem to increase with age, and that there is a considerable concentration increase of this biomarker when the individuals are not fasting. As this is frequently the case when samples are collected from free-ranging animals the difference between the levels of captive and free-ranging animals may be even greater (Less, 2012; Miller & Fowler, 2015; Schmidt, Ellersieck, Cranfield, & Karesh, 2006).

In humans, obesity will generally translate not only into higher levels of triglycerides and cholesterol but also of leptin, insulin and glucose, with subsequent low levels of adiponectin and glucose to insulin ration, so these represent other possible serum biomarkers of adiposity in gorillas. Bile acid secretion in the faeces can also be measured to determine cholesterol volume and synthesis in the body (Less, 2012).

Table 6: Adiposity serum biomarkers in captive and free-ranging gorillas (Means ± SEM)

<table>
<tr><th colspan="2">Biomarkers</th><th>Cholesterol
mg/dl</th><th>LDL
mg/dl</th><th>HDL
mg/dl</th><th>Triglycerides
mg/dl</th><th>Sources</th></tr>
<tr><td colspan="2">Free-Ranging Western Gorillas
(Males, n=4)</td><td>166.5 ± 18.5
(127 – 201)</td><td>69.5 ± 11.9
(46 – 88)</td><td>66.0 ± 7.6
(52 – 83)</td><td>85.3 ± 15.5
(60 – 100)</td><td rowspan="3">Schmidt et al.
(2006)</td></tr>
<tr><td rowspan="2">Free-Ranging Mountain Gorillas</td><td>Males
(n=3)</td><td>148.7 ± 21.3</td><td>58.3 ± 13.8</td><td>64.7 ± 8.8</td><td>47.3 ± 17.9</td></tr>
<tr><td>Females
(n=8)</td><td>179.4 ± 13</td><td>63.1 ± 8.4</td><td>71.9 ± 5.4</td><td>98.8 ± 10.9</td></tr>
<tr><td colspan="2">Captive Western Gorillas
(Males and Females, n=?)</td><td>256
(140 – 455)</td><td>106
(1 – 249)</td><td>91
(31 – 192)</td><td>116
(43 – 288)</td><td>Miller &
Fowler
(2015)</td></tr>
</table>

LDL – Low-density Lipoprotein, HDL – High-density Lipoprotein

Although not as commonly assessed, if nutrient imbalance is suspected or requires monitoring, it is possible to measure circulating levels of vitamins, its metabolites or other compounds. This may be used to evaluate the adequacy of dietary intake, but there are not a lot of published values for these measurements, so comparison with human references or taxonomically close species is frequently necessary. A few of the published results in gorillas are presented in Table 7.

Serum 25(OH)D is the major steady circulating form of vitamin D, being considered its most valuable indicator. 1,25(OH)2D is the biologically active form and may reflect immediate intake or sun exposure (Crissey et al., 1999).

Carotenoids are organic pigments found in photosynthetic organisms, of which some can be converted into vitamin A, and that upon consumption are stored in the body's fatty tissue. They are important in maintaining various immune functions and, in humans, circulatory levels of β-carotene have been used to assess malabsorption and nutritional status (Crissey et al., 1999).

Table 7: Vitamins and Carotenoids Serum Levels in Captive Gorillas (mean ± SEM) (Crissey et al., 1999)

Vitamins A and E	**Retinol (Vit A)** µg/dl	**Retinyl Palmitate (Vit A)** µg/dl	**α-tocopherol (Vit E)** µg/dl	**γ-tocopherol (Vit E)** µg/dl
n = 27	73.3 ± 8.88	11.2 ± 1.34	993.5 ± 65.2	41.9 ± 35.7

Vitamin D Metabolites	**25(OH)D** ng/ml	**$1.25(OH)_2D_3$** pg/ml
n = 25	16.7 ± 1.16	35.4 ± 4.17

Carotenoids	**Lutein + Zeaxanthin** µg/dl	**β-Crypto-xanthin** µg/dl	**Lycopene** µg/dl	**α-Carotene** µg/dl	**β-Carotene** µg/dl	**α-Crypto-xanthin** µg/dl
n = 27	36.9 ± 5.53	0.6 ± 0.15	0.7 ± 0.17	1 ± 0.21	0.8 ± 0.16	3 ± 0.49

2.8 Clinical Evaluation

A survey on the causes of mortality of the SSP gorilla population published in 1994 has stated that cardiovascular disease was a significant cause of death in 41% of adult captive gorillas (Meehan et al.,1994). In humans, obesity is associated with inflammation and insulin resistance, which are risk factors for the development of cardiac disease, hypertension and type II diabetes, for example. Heart disease in great apes is more frequently characterized by fibrosing cardiomyopathy, which differs from the atherosclerotic coronary lesions usually associated with caloric over-consumption and a sedentary lifestyle in humans. Therefore, although stabilizing lipid profiles is important for overall health, cholesterol does not seem to play a key role in most cardiac deaths reported. However, the pathological changes observed in these animals are suggestive of those seen in humans with uncontrolled hypertension, which can be aggravated by diets high in fat and Na. Research also suggests that hind-gut fermenters that consume too much starch can suffer from a localized and systemic inflammatory response, which has been linked to the development of fibrosing cardiomyopathy in humans. Great ape cardiac disease is currently the focus of intense research both at EAZA and AZA institutions, so new findings and conclusions are frequently being brought to light. Nevertheless, it remains possible that these high cardiac disease rates are associated to some degree with inadequate nutrition and the gorillas inability to manage low-fibre and low-polyphenol diets (Ball et al., 2008; Great Ape Heart Project, 2012; Less et al., 2010; Less, 2012; Smith, 2012).

Obesity, for which captive gorillas seem to have some propensity, is also linked to long-term health issues, like diabetes and arthritis, and apart from obesity and cardiovascular disease, nutritional imbalances can translate into a multitude of clinical signs. A few common clinical problems reported to have been solved through dietary changes are (Ball et al., 2008; Hatt & Liesegang, 2002; Mundy et al., 1998; National Research Council, 2003; Plowman, 2015):

- Diarrhoea and faeces of low consistency;
- Opportunistic gastrointestinal parasitical infections (*Entamoeba sp., Trichomonads sp., Balantidium sp., Ascaridia sp.);*
- Pallor and anaemia;
- Dermatological alterations;
- Skeleton mineralization defects;
- Dental disease
- Reduced fertility, neonate viability and milk yield.

Overall, a complete physical and clinical examination is essential in assessing if the individual and population is healthy and to determine the adequacy of a diet.

3. Materials and Methods

3.1 Study Purpose

The main objective of this study was to conduct a thorough analysis of the nutritional management and status of the gorilla group currently residing in Zoo Basel.

The literature review has detailed the several methods that can be combined and utilized to perform this evaluation, whilst describing the most relevant and recent findings regarding the target-species. It has also described the current situation, standards and challenges of maintaining a healthy gorilla population in EAZA and AZA institutions.

To complete a full dietary management analysis, the following goals were set:

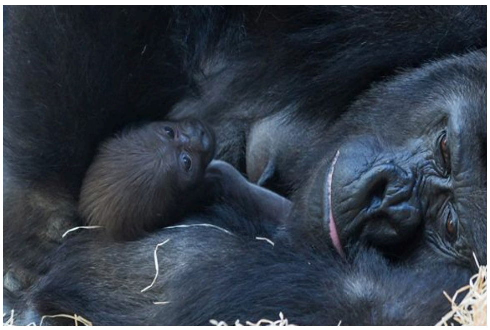
1. Determination of average individual and group nutrient intake and comparison with current recommendations;
2. Evaluation of the dietary and environmental enrichment program;
3. Measurement of anthropometric features and comparison with current recommendations;
4. Analysis of previous biochemical fluid analysis and clinical reports to identify any possible health issues that can be connected to the diet;
5. Development of a list of recommendations considering the results of the previous points and what is currently known regarding free-ranging and captive gorilla diets.

3.2 Subjects

At the start of this study, Zoo Basel kept a group of six gorillas: two males, M'Tongé, the silverback (16 years old) and Zungu, the blackback (12 years old), two late-stage pregnant females, Joas and Faddama (25 and 32 years old) and two geriatric females, Quarta and Goma (47 and 55 years old). During the data collection period (from 02/Jun/2015 to 01/Aug/2015) the two pregnant females gave birth and entered the lactation stage. Since the two new-born gorillas were completely dependent on their mothers and exclusively fed on their milk, they were left out of the individual data collection. Figure 5 details relevant medical and husbandry information for each individual.

Figure 5: Gorilla group kept at Zoo Basel during the duration of this study and relevant individual information (photos kindly provided by Zoo Basel)

Mobali
Born: 19 May 2015 - Male



Makala
Born: 16 July 2015 - Female

Figure 5 (continuation): Gorilla group kept at Zoo Basel during the duration of this study and relevant individual information (photos kindly provided by Zoo Basel)

M'Tongé
Born: 23 February 1999
Dominant male

Zungu
Born: 4 August 2002
Castrated due to unilateral cryptorchidism.
Diagnosed with Alveolar Echinococcosis in 2007, treated with Albendazol BID. Doesn't go outside, receives extra food by hand

Joas
Born: 6 July 1989
Gave birth: 19 May 2015, to Mobali
Rarely climbs to rooftop

Faddama
Born: 2 February 1983
Gave birth: 16 July 2015, to Makala

Quarta
Born: 17 July 1968
Diagnosed with Alveolar Echinococcosis in 2010, treated with Albendazol BID.
Doesn't climb to rooftop

Goma
Born: 23 September 1959
First gorilla born in a European zoo, was hand-raised. Doesn't climb to rooftop and doesn't go outside, receives extra food by hand

3.3 Study Site

The gorilla enclosure at Zoo Basel is divided into three main sections: an indoor area with wood-chips substrate (E1), another indoor area without substrate with two spaces divided by a wall (E2) and an outdoor area (E3), as can be seen in Figures 6 and 7. All sections have platforms at different heights, ropes and other climbing structures and several spaces hidden from public viewing. The indoor areas have windowed roofs, protected by nets, that can be opened to distribute food. Two problem boxes for environmental enrichment are installed in E2. The outdoor area possesses natural vegetation fully accessible to the gorillas. The movement between sections is made from E2 ↔ E1 ↔ E3, through grated tunnels and wall openings between E1 and E2. All passages can be closed to keep animals in a specific section. Furthermore, there is an extra quarantine area, accessed through E1, which is usually open to passage, but is rarely used by the gorillas. The quarantine area gives access to a scale, which was installed in the beginning of the study, and can be seen in Figure 10, on page 48.

Figure 6: Indoor Areas (E1 and E2) of the Gorilla Enclosure at Zoo Basel
(adapted from Enclosures and Pens – The Ape House, by Zoo Basel, 2012. Retrieved April 15, 2016, from http://zoobasel.ch/en/tiere/anlagen/anlage.php?AnlagenID=6)

Figure 7: Outdoor Area (E3) of the Gorilla Enclosure at Zoo Basel
(Adapted from Enclosures and Pens – The Ape House, by Zoo Basel, 2012. Retrieved April 15, 2016, from http://zoobasel.ch/en/tiere/anlagen/anlage.php?AnlagenID=6)

3.4 Assessment of Individual Nutrient Intake

3.4.1 Data Collection

In order to develop the observation schedules and select data collection tools, a preliminary two-day study was previously conducted. A daily schedule was created and four observation periods were established (Table 8).

Table 8: Zoo Basel gorillas daily feeding schedule and study observation plan

Hour	Section	Food	Obs.	Notes
7h	E1	Tea + Medicine + Fennel	-	In the last days fennel was replaced by some of the vegetables given at 16h10
8h30	E1	Pellets	-	-
8h40 – 9h	E3	Fruit + Vegetables	E3a	Usually just one or two types of food
10h20 – 11h	E2	Browse + Vegetables + Fruit (Problem Box)	E2	Vegetables were thrown from the roof, so a portion remained on the roof nets
11h30 – 12h	E1	Vegetables	E1	-
13h30	E1 + E2	Salad	-	Given by hand
14h – 14h20	E3	Fruit + Vegetables + Seeds or Nuts	E3b	Usually just one or two types of food
15h	E1 + E2	Tea	-	Veterinary Visit on Tuesdays - Extra snack (e.g. yogurt with fruit)
16h	E1 + E2	Medicine	-	-
16h10	E1 + E2	Egg + Vegetables + Fruit	-	Given by hand: egg + cucumber + bell pepper + tomatoes + 1-3 types of fruit
17h	E1 + E2	Salad	-	Thrown from roof and given by hand

On 14 randomly selected days over the course of two months (June and July) each food item was weighed and recorded. The records included which item was given by hand to which individual (Figure 8), and the feeding bout was observed in its entirety so items stolen by other gorillas could be accounted for in the records. Although not a pre-defined objective of the study, every time regurgitation or coprophagy were observed it was recorded. Food that was spread in the enclosures was weighed and if necessary, chopped into similar portions. The portion weight was estimated by calculating the average of several pieces, or by counting the final number of portions and dividing the item's complete weight by that number. Browse was weighed in its entirety before distribution, and the remains found in the following morning were collected and weighed as well.

Figure 8: Salad and afternoon meal for Zoo Basel's gorillas prepared for hand feeding

After distribution of the food items throughout the enclosures, focal observations were conducted. A calendar was previously established to get an even number of observations per individual per area (Table 9). After seven days it was confirmed that Zungu and Goma didn't go to E3, so those remaining time slots were distributed by the other gorillas.

Table 9: Calendar of focal observations for this study. Day 13 and 14 of observations were used to get extra measurements depending on difficulties of previous observations.

Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14
E3a	M	F	Z	G	J	Q	M	F	(Z) Q	(G) M	J	Q	F	J
E2	G	J	Q	Z	M	F	G	J	Q	Z	M	F	J	F
E1	Z	M	F	Q	G	J	Z	M	F	Q	G	J	Z	Q
E3b	Q	G	J	Z	F	M	Q	(G) J	J	F	(Z) Q	M	F	M

M – M'Tongé, Z – Zungu, J – Joas, F – Faddama, Q – Quarta, G - Goma

For E3a and E3b the observation periods began when the focus animal arrived at E3 and only finished when it left. For E1 and E2, the observation period started when the entrance to the respective section was opened and ended when the individual hadn't eaten for more than 5 minutes and was found resting. A piece of food was considered consumed when the animal would place it in his mouth or, in the case of big portions, consumed its majority. If the individual picked up a piece and then relocated to a hidden location, that piece was marked as consumed. When the gorillas moved out of sight, it was frequently easy to relocate and regain visibility, so the amount of time where observation wasn't possible was considered negligible to the final results. Browse consumption was measured by number of ingested leaves. To facilitate that measurement, it was considered that 1 unit was approximately 10 leaves.

On Tuesdays the gorillas were given an extra treat by the veterinarians, promoting the association between them and a positive stimulus, in order to make future veterinary interventions less stressful for the animals. On Saturdays, due to staff constraints, no time was spent outdoors in the afternoon, and the food reserved for that period was given earlier.

An example of data collected in a full day can be seen in the Annexes 1, 2 and 3.

3.4.2 Food Preparation

Zungu and Quarta's alveolar echinococcosis is thought to have resulted from ingesting food contaminated with faeces from a carnivore infected with the *Echinococcus multilocularis* tapeworm. These individuals received chemotherapy with Albendazol, 10 mg/kg, *per os* and twice daily, throughout all the study. Even though humans and apes are incidental hosts and can't further transmit the disease, measures were taken to avoid any future infection through food contamination. All tree branches that came from local woods, to use as browse, were freshly cut and placed straight into a protected surface, never contacting with the forest grounds. Grass from local farmers was eliminated from the diet plan. An experimental study into the in-vivo viability of *Echinococcus multilocularis* eggs after exposure to different combinations of temperature, humidity and duration was conducted (Federer, Armua-Fernandez, Hoby, Wenker, & Deplazes, 2015). Consequently, all the vegetables and fruit that came from locations where alveolar echinococcosis may be present went through a treatment of 30 minutes in 70ºC at 90% relative humidity. During this study, this comprised mainly the vegetables that were fed in E1 and E2 – onions, carrots, broccoli, celery, potatoes, beetroot and fennel. The eggs eaten daily were hard-boiled, and all the other fruits and vegetables were rinsed with running water before being fed. The water for the teas and medicine solutions was brought to a boiling point and then left cooling until luke warm.

3.4.3 Individual Intake Estimation

The focal observation results were used to calculate the percentage of food, as-fed, that was eaten by each individual, from the total dispersed in each section (Table 11 – page 49). Data from the preliminary study was also included when possible. To calculate percentages of browse consumption only leaf intake was measured (Table 12 – page 49). However, it was concluded that there was too much variability to register a trend, except for Goma who consistently consumed very little foliage. Conservatively, it was then deliberated that each individual consumed 18% of all browse, while Goma consumed only 10%. After analysis of these results, and considering the personal experience gained from observing the feeding habits of the whole group for the duration of the study, percentages used to calculate average individual intake per section or type of food were defined (Table 13 – page 49).

Pellets given at 8h30 were distributed by tossing hand-size portions in the direction of the individuals, at approximately the same time as the access to E3a was granted. Due to the difficulties in measuring pellet intake and the need to make full E3a observations, pellet consumption during this time period was considered equal between all individuals.

Three to four times a week a special enrichment item was prepared, frequently ice blocks with fruit and root vegetables. When those were placed in E2 and E1, due to the delayed release, it wasn't possible to monitor which individual consumed the items, so intake was considered balanced between the group members.

All the other items not belonging to a specific section, like rare items used for training or the veterinary visit were categorized as “Others” and were also distributed equally by every individual.

Finally, the afternoon salad meal was spread before the staff would leave for the day, so no observations were made of those feeding bouts. Given Joas initial reluctance to climb to the roof while holding her baby and the fact that Quarta and Goma were never seen climbing to that point, it was assumed that the salad given by hand was distributed equally amongst those three, and the remaining salad thrown in the roof was also allocated equally between M’Tongé, Zungu and Faddama (Table 13 – page 49).

Using the percentages defined it was then possible to estimate the daily individual intake of each food during dispersed feedings and add it to the known quantities given individually by hand.

3.4.4 Nutritional Composition of the Diet

The nutrient values of each food item offered during this study were obtained using food composition tables intended for human use. The main source utilized was the Swiss Food Composition Database (Swiss Federal Food Safety and Veterinary Office, 2015). However, if needed, parameters which were absent in this source or were presented in non-convertible units different from the NRC recommendations were then procured from the German or the American databases instead (Leibniz Institute German Research Centre for Food Chemistry, 2015; United States Department of Agriculture, 2015b).

Every value was converted from a fresh-basis to the adequate DM unit, to enable comparisons with the NRC recommendations. NDF and ADF are not utilized in human nutrition, so these values were obtained from the Zootrition® Dietary Management Software (version 2.6) and the NRC Food Composition Tables (National Research Council, 2003). The ME value for primates provided by Zootrition® was used for all foods except browse. Given the similarities in digestive anatomy and physiology, equations to calculate ME for horses were applied in this category (Kienzle & Zeyner, 2010). All the nutrient composition tables, divided by categories, can be seen in the Annexes 4 to 15.

Each food was placed in one of the following categories: animal products, leaf-eating primate pellets, mixed pellets, seeds and nuts, fruits, vegetables, browse and others. Due to the large amount and variability of vegetables in the diet, these were further divided according to their class and nutrient composition, into stem, flower, fruit, leafy, bulb, root and tuber vegetables (Table 10), so a more accurate nutritional assessment was achieved.

The data from individual food intake was also similarly categorized and converted to DM intake by using the average DM% of the corresponding category. Only on rare occasions, when a big quantity of leafy vegetables was offered, did the gorillas not consume all the food provided. Those exceptions were accounted for and, apart from browse, it was considered that 100% of the diet offered was consumed.

By multiplying the individual intake percentages of each category, converted to decimal values, by its average nutrient composition, it was then possible to determine the total nutrient concentration per individual by the sum of each category's contribution.

Metabolizable energy was estimated in kcal, by analysing the complete diet and calculating how much energy each food item provided.

Table 10: Nutrients supplied by different classes of vegetables (adapted from Lintas, 1992)

Class		**Vegetables**	**Nutrients**
Green Vegetables	Stem	Celery	V, M
	Flower	Broccoli, Cauliflower	DF, V, M
	Fruit	Tomato, Cucumber, Bell Pepper, Zucchini, Eggplant	
	Leaf	Chicory, Cabbage, Lettuces, Kohlrabi	
Root Vegetables	Bulb	Onion, Fennel, Leek, Chives	DF, V, M, CC
	Root	Carrot, Radish, Beetroot	
	Tuber	Potato, Sweet Potato	

DF – Dietary Fibre, V – Vitamins, M – Minerals, CC – Complex Carbohydrates

3.5 Measurement of Anthropometric Features

Crown-rump length and hip width were measured in the females, and back length was measured in the males, as specified in Figure 9. A minimum of two measurements per parameter per animal was sought, but it wasn't always possible. A scale was also installed, but due to the reluctance of the other gorillas in exploring locations without an easy escape-route, by the end of the study only M'Tongé had been weighed (Figure 10).

Figure 9: Gorilla anthropometric measurements as indicated by Less, 2012
A – Crown-rump length, B – Hip width, C – Back length

A – Measure from the bottom of the gorilla's back to the crown of the head	B – Measure from right above where the right leg meets the back to where the left leg meets the back when seated in this posture	C – Measure from the bottom of the gorilla's back to the bottom of the neck, even with the shoulder line

Figure 10: Zoo Basel's gorilla scale, outside the quarantine area, weighing M'Tongé

4. Results and Discussion

4.1 Individual Intake Results

The results obtained from the focal observations are presented in Tables 11 and 12. Table 13 specifies the final percentages used to calculate average intake during group feeding. The detailed results showing what each animal ate during the entire study, including during hand-feeding, can be seen in Annex 16.

Table 11: Percentages of total measurable spread food eaten per observation day by each gorilla in Zoo Basel. The afternoons when there was no E3b are highlighted in red.

%	M'Tongé	Zungu	Joas	Faddama	Quarta	Goma
E3a	48 / 42 / 70	-	27 / 0 / 0	31 / 0 / 8	0 / 7 / 2 / 4	-
E2	46 / 44	3 / 8	27 / 17	4 / 9 / 7	20 / 13	0 / 0
E1	34 / 38	0 / 0	8 / 6	37 / 18	7 / 13 / 12	7 / 5
E3b	43 / 96 / 88 / 40	-	17 / 27 / **0**	20 / 54 / **0**	2 / 1 / 0	-

Table 12: Approximate number of leaves consumed by Zoo Basel's gorillas during this study

Number of Leaves	M'Tongé	Zungu	Joas	Faddama	Quarta	Goma
Measured	20 / 190	180 / 250	120 / 370	1290 / 0 / 180 / 220	110 / 150	20 / 0
Mean	105	215	245	422	130	10
Percentage	10%	19%	22%	36%	12%	1%

Table 13: Percentages used to calculate individual intake of Zoo Basel's gorillas

%	M'Tongé	Zungu	Joas	Faddama	Quarta	Goma
E3a	45	0	25	25	5	0
E2	45	5	15	15	15	5
E1	45	5	15	15	15	5
E3b	45	0	25	25	5	0
Browse	18	18	18	18	18	10
Pellets/ Others	17	17	17	17	16	16
Roof Salad	33	33	0	33	0	0
Hand Salad	0	0	33	0	33	33

4.2 Diet Characterization

The average diet composition at Zoo Basel, the SSP recommended values and the average composition found in 10 surveyed EEP institutions is presented in Table 14. The amount of pellets consumed by the gorillas in this study is considerably reduced when compared to the SSP recommended concentration and this difference is directly compensated by an increased percentage of vegetables other than leafy and root vegetables (Smith et al., 2014). The average daily intake per gorilla during this study was 10.2 kg as-fed and 1.45 kg DM. The primate biscuits' nutritional composition is not detailed in the SSP recommendations, which would be needed to make direct comparisons. However, if we were to assume an equal dry matter value, in order to reach the SSP recommended percentages, an added individual consumption of 1.32kg of pellets would be needed, accompanied by a reduction of 14.8% in vegetables other than leafy and root vegetables.

Given the potential negative behavioural and physiological effects that can originate from high pellet and starch intake – abdominal discomfort, local and systemic inflammation, reduction of foraging behaviour, lack of satiation – it seems more adequate to try to mimic wild diets and keep pellet intake reduced to the minimum possible, while still providing the adequate nutrients (Ball et al., 2008; Less, 2012, National Research Council, 2003). A complete nutrient analysis is needed to assess what that minimum is, and it likely varies between institutions.

Table 14: Comparison of Zoo Basel diet composition with the 2008 SSP recommendations and the results of a 2007 dietary survey to 10 EEP institutions (adapted from Smith et al., 2014 and Westbury et al., 2007)

Food Category	Dry Matter (%)	As-fed (%)		
	Zoo Basel	Zoo Basel	SSP Recommendations	EEP Survey
Animal Products	1.38	0.96	0	6.58
Nuts, Seeds and Grains	1.35	0.2	0	3.25
Pellets / High fibre Primate Biscuits	10.78	1.71	15	2.42
Browse and Leafy Green Vegetables	47.91	50.73	57	23.66
Root Vegetables	3.50	4.95	4	45.13
Other Vegetables	23.05	31.82	17	
Fruit	3.77	9.12	7	18.95

Overall, the diet provided in this study seems to be more adequate than the average diet offered in EEP institutions about 10 years ago, with lower percentages of animal products, fruits, seeds, nuts and grains and higher percentages of natural high fibre foods like browse and leafy vegetables (Westbury et al., 2007). The pellet concentration is similarly low and the amount of non-leafy green vegetables is in the middle term between recommended and surveyed concentrations.

The total daily intake per body mass for all gorillas is described in Table 15. It is important to note that, apart from M'Tongé, these weights are an estimation derived from measurements in previous years and subjective observation, so they may not be completely accurate.

As mentioned before, browse consumption was measured by weighing the total amount given and subtracting the difference of the collected left overs in the next morning. However, although the largest, heaviest branches were easily collected, an uncertain amount of smaller branches would be mixed in the straw and substrate and become difficult to collect, which may have led to an overestimation of total browse consumption. It should also be noted that even though 10% of browse was chosen as a conservative value of what Goma may be consuming, this is likely still overestimated, and the same happens for the other geriatric female, Quarta, with the 18% concentration.

Considering these limitations, it is still possible to withdraw some conclusions and compare with the previously recommended intake values per body mass of 4.5% as-fed and 1.25% DM (Popovich & Dierenfeld, 1997).

Table 15: Average daily intakes relative to body weight (BW) in Zoo Basel's gorillas during this study

	M'Tongé	Zungu	Goma	Quarta	Faddama	Joas
Weight (kg)	189	115	60	75	140	100
As fed Intake (g)	15700	9713	7063	8491	10810	9158
As fed/BW %	8.3	8.4	11.8	11.3	7.7	9.2
DM Intake (g)	2112	1355	985	1229	1498	1388
DM/BW %	1.13	1.20	1.66	1.67	1.09	1.41

All gorillas had an intake of fresh matter high above the recommended. However, these recommendations were created considering that a substantial portion of the diet was composed by pellets, which provide a high nutrient concentration in a condensed and lighter form than the other natural foods. Given the previously described composition of the diet offered at Zoo Basel, greater quantities would be needed to supply the same nutrient concentrations, so this difference isn't completely unexpected.

The DM values offer a more accurate evaluation. M'Tongé, Zungu, Faddama and Joas intakes did not differ a lot from the recommended, although it is important to consider their current needs and if their current weight is healthy. For example, if Zungu is deemed underweight, even though he had the closest value to the recommended, he would actually require a higher intake percentage to reach an appropriate weight. Goma and Quarta had the highest values, with 1.66% and 1.67%. However, given their lower weights, this doesn't seem to translate into an excessive consumption, and it is more likely that this is a result of intake overestimations for the two geriatric females. Further analysis of other parameters, like anthropometric features and serum indicators, are required to make a proper assessment, as geriatric individuals are predisposed to accumulate fatty tissue, which leads to changes in body shape and may cause fat accumulation to become less obvious (National Research Council, 2003).

There were considerable differences between individuals in the amount of DM each category contributed to the whole diet (Table 16), the most relevant of which were:

- The percentage of fruit, the favoured type of food, was 6.3% higher in M'Tongé, the dominant male than in Zungu, one of the lowest individuals in the hierarchy;
- Browse percentages were noticeably lower in Goma, who indeed consumed less quantities and in M'Tongé, who consumed more of other preferred food categories, reducing the concentration of browse in his diet even though he may have eaten the same amount as the other gorillas;
- Food that was rarely offered by hand, like flower vegetables, seeds and nuts, contributed less to Goma and Zungu's diet, who had a decreased access to spread food. On the other hand, the extra food they received was largely composed by root vegetables, specifically for Goma, and tuber vegetables for both, which increased the contribution of the corresponding category well above the average for the other gorillas;
- Goma didn't like catalonia lettuce, so she's the only one who received none during hand feedings, while receiving extra leek. This decreased the amount of leafy vegetables she received. As it is very improbable she consumed the same quantities as Joas of the hand distributed salad at the end of the day, 12.9% of leafy vegetables is most likely still an overestimation. This may also apply to Quarta on a smaller level;
- If we consider the broad class of root vegetables, there was a big difference between Faddama, Joas and Quarta with a range of 16% - 17.8%, M'Tongé and Zungu with 20.6% - 23.3% and Goma with 30%, which can be explained by the quantity of root vegetables offered by hand to Zungu and Goma, and the greater bulk of food consumed by M'Tongé.

Table 16: Individual percentages each food category contributed to the whole diet of Zoo Basel's gorillas, with the average and difference between maximum and minimum value per category highlighted

%	AP	P	SN	F	Green Vegetables				Root Vegetables			Br
					VS	VFl	VFr	VL	VB	VR	VT	
M'Tongé	0.75	10.01	2.23	14.59	0.79	2.47	2.97	19.42	8.96	4.64	7.02	26.15
Zungu	1.37	8.88	0.62	8.40	0.14	0.43	3.71	19.97	10.78	1.39	11.17	33.16
Goma	2.05	11.58	0.83	12.46	0.54	0.59	4.47	12.71	14.43	7.53	7.92	24.89
Quarta	1.54	10.49	1.32	11.34	0.45	1.41	3.87	15.59	11.39	2.64	2.98	36.99
Faddama	1.31	10.55	1.44	11.55	0.37	1.16	3.73	20.16	9.22	2.17	4.63	33.71
Joas	1.16	11.38	1.55	12.63	0.40	1.25	3.49	14.38	10.33	2.34	5.10	35.99
Average	1.36	10.48	1.33	11.83	0.44	1.22	3.71	17.04	10.85	3.45	6.47	31.81
Max-Min	1.30	2.71	1.61	6.20	0.65	2.04	1.50	7.44	5.48	6.14	8.18	12.10

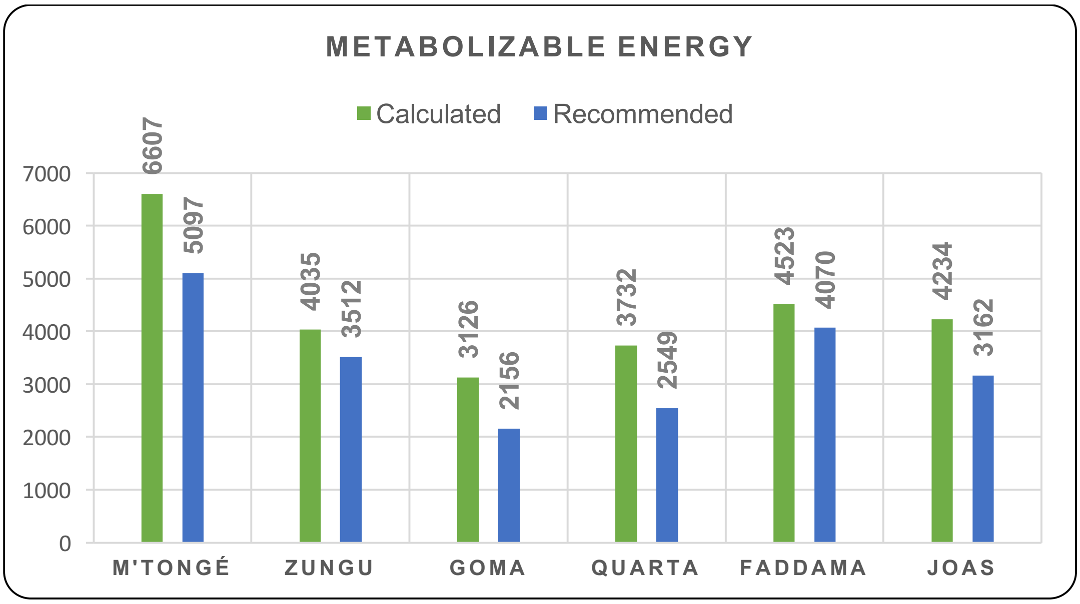
AP – Animal Products, P – Pellets, SN – Seeds and Nuts, F – Fruit, VS – Stem Vegetables, VFl – Flower Vegetables, VFr - Fruit Vegetables, VL - Leafy Vegetables, VB – Bulb Vegetables, VR – Root Vegetables, VT – Tuber Vegetables, Br - Browse

4.2.1 Energy

Annexes 17 and 18 detail each item's metabolizable energy and its contribution to the total caloric intake per gorilla. The final results can be analysed in Figure 11. Recommendations were calculated with the equation ME (kcal/day) = 100 x (body mass in kg)$^{0.75}$ (National Research Council, 2003). These are caloric recommendations for weight maintenance, and adaptations may be necessary to better fit the needs of over- or underweight individuals. Furthermore, these recommendations don't account for differences between age, gender, and reproductive status.

All gorillas seemed to be over-consuming calories, with differences to the recommended ranging between 453-1510 kcal.

Figure 11: Individual average Kcal/day intake in Zoo Basel's gorillas and comparison with NRC recommendations (National Research Council, 2003)



- M'Tongé presented the highest difference between recommended and calculated intake, which probably reflects his status as dominant male and the better access to more desirable and caloric food items.
- The arrival of M'Tongé to the group displaced Zungu from the top of the hierarchy to the bottom. As the other male in the group, a high-tension situation with the silverback developed, with Zungu generally doing his best to stay out of sight from M'Tongé. This led to a significantly decreased access to all spread food and higher amounts of stress, with his chronic disease potentially aggravating this situation. All these factors have probably resulted in weight loss and Zungu's calculated caloric intake likely reflected an attempt to consume enough energy to regain body mass.
- As mentioned before, Goma and Quarta's intake is likely overestimated. However, given their advanced age and reduced metabolism, their recommended energetic intake should also be overestimated (National Research Council, 2003). No

publications were found in the literature that study energy intake and the metabolism of geriatric females, so no comparisons are possible at the moment. Analysis of other parameters is needed to assess diet adequacy.

- Joas gave birth at the very beginning of the study, and Faddama's labour occurred between day 5 and 6 of data collection. Due to the augmented energy requirements of lactation, it is likely their caloric intake at the time of the study was more adequate than the recommended in Figure 11. Faddama is considerably heavier and fatter than Joas, so given those reserves, she wouldn't need to consume as much food to meet her increased energy requirements (National Research Council, 2003; Schmidt, 2004). Unlike what happened in the two studies that analysed kcal intake in wild gorillas, previously presented, the lactating females didn't ingest similar or more energy than the silverback (Masi et al., 2015; Rothman et al., 2008). This may indicate that M'Tongé was indeed consuming considerable more calories than what he would need for weight maintenance. The females may have also had less access to food than what would be expected in the wild, due to hierarchy dynamics, and were eating less than they would if there were no restrictions.

4.2.2 Nutritional Assessment

The results of the individual nutritional assessment have been summarized in Table 17, showing the differences between intake and the NRC recommendations already presented (National Research Council, 2003).

The full individual analysis is presented in the Annexes 19 – 24, where it is possible to evaluate the nutritional contribution of each food category to the individual's diet.

Care should be taken when analysing these results, as food nutritional composition can vary with growth, processing and storage conditions. Therefore, these are only approximate estimations.

Table 17: Differences between Zoo Basel's gorillas individual diet composition and NRC recommendations (National Research Council, 2003). Values in green are above recommended and values in red are below.

Differences from Recommended			M'Tongé	Zungu	Goma	Quarta	Faddama	Joas	Average
Crude protein	% DM	15.00	0.89	1.31	0.84	1.66	1.58	1.14	1.24
Crude fat	% DM	no value	5.67	4.75	5.17	5.54	5.48	5.57	5.36
Linoleic Acid	% DM	2.00	-0.50	-0.97	-0.84	-0.73	-0.69	-0.65	-0.73
Linolenic Acid	% DM	0.50	0.31	0.37	0.30	0.42	0.39	0.39	0.36
Crude ash	% DM	no value	8.56	9.13	8.52	8.87	9.01	8.59	8.78
NDF	% DM	10.00	16.22	19.33	15.86	20.88	19.67	20.51	18.74
ADF	% DM	5.00	12.30	13.92	11.79	15.31	14.52	14.88	13.79
Starch	% DM	no value	7.37	9.40	8.27	4.95	5.88	6.38	7.04

Table 17 (continuation): Differences between Zoo Basel's gorillas individual diet composition and NRC recommendations (National Research Council, 2003). Values in green are above recommended and values in red are below.

Differences from Recommended			M'Tongé	Zungu	Goma	Quarta	Faddama	Joas	Average
Ca	% DM	1.00	-0.25	-0.15	-0.26	-0.08	-0.12	-0.11	-0.16
P	% DM	0.80	-0.47	-0.47	-0.47	-0.47	-0.47	-0.48	-0.47
Na	% DM	0.20	-0.07	-0.07	-0.05	-0.07	-0.07	-0.08	-0.07
Cl	% DM	0.20	0.13	0.12	0.15	0.10	0.12	0.08	0.12
K	% DM	0.40	1.85	1.84	1.84	1.79	1.82	1.72	1.81
Mg	% DM	0.08	0.11	0.12	0.11	0.13	0.12	0.12	0.12
Co	mg/kg DM	no value	0.73	0.49	0.63	0.61	0.62	0.66	0.62
Cu	mg/kg DM	20.00	-10.89	-10.44	-10.37	-10.01	-10.25	-10.15	-10.35
I	mg/kg DM	0.35	-0.028	-0.002	0.064	0.007	-0.009	-0.010	0.004
Fe	mg/kg DM	100.00	-11.86	-9.55	-14.24	-4.82	-6.08	-6.83	-8.90
Mn	mg/kg DM	20.00	51.45	57.21	48.97	66.66	60.67	64.27	58.20
Se	mg/kg DM	0.30	1.35	0.73	1.17	1.03	1.05	1.16	1.08
Zn	mg/kg DM	100.00	-59.89	-55.78	-55.45	-53.71	-55.63	-55.21	-55.95
Vitamin A	IU/kg DM	8000.00	14175.99	13969.91	16256.22	10342.70	12008.22	9808.05	12760.18
Beta Carotenes	mg/kg DM	no value	113.86	121.97	112.14	115.36	117.15	112.84	115.55
D (calciferol)	IU/kg DM	2500.00	-2348.62	-2279.84	-2206.55	-2263.30	-2294.45	-2284.70	-2279.58
E (α-tocopherol)	mg/kg DM	45.00	24.38	27.19	31.58	26.44	28.07	22.61	26.71
K (phylloquinone)	mg/kg DM	0.50	6.63	6.73	6.19	6.18	6.71	5.74	6.36
Biotin	mg/kg DM	0.20	0.37	0.23	0.35	0.29	0.30	0.31	0.31
Vitamin B1	mg/kg DM	3.00	5.18	6.34	8.06	6.40	5.93	5.93	6.31
Vitamin B2	mg/kg DM	4.00	2.30	2.91	3.90	2.89	2.75	2.49	2.87
Vitamin B6	mg/kg DM	4.00	4.66	5.04	6.40	4.50	4.35	4.25	4.87
Vitamin B12	mg/kg DM	0.03	0.11	0.22	0.34	0.25	0.21	0.18	0.22
Niacin	mg/kg DM	25.00	21.59	22.23	26.23	19.92	20.93	18.36	21.55
Pantothenic Acid	mg/kg DM	12.00	14.96	15.88	17.57	14.51	15.03	13.27	15.20
Folate	mg/kg DM	4.00	0.37	0.36	0.76	0.25	0.32	-0.04	0.334
Choline	mg/kg DM	750.00	192.57	155.22	232.00	145.82	176.04	99.27	166.82
Vitamin C	mg/kg DM	200.00	1368.90	1205.62	1265.52	1177.58	1228.45	1098.82	1224.15

4.2.3 Protein

Protein intake varied between 15.8% and 16.7%, which represents a very balanced consumption between all gorillas. The NRC recommends 15 - 20% of crude protein, which aligns with the averages of foods eaten in the wild, particularly for leaves, that have the highest average protein content, ranging between 16.6 - 18.9% DM (see Table 1, page 9). Recommended concentrations already take into account some reduced bioavailability, but even if we consider that, as mentioned before, 15% of total protein intake may be unavailable for digestion, implying a reduction of 2.4% between consumed and available protein, levels are still within very acceptable limits for what is consumed in the wild (National Research Council, 2003; Remis & Dierenfeld, 2004; Rothman et al., 2008). Since browse and leafy vegetable consumption contribute the most to protein levels, these values may be overestimated for Goma and on a lesser level for Quarta, but overall, intake seems to be appropriate.

4.2.4 Fat and Fatty Acids

The NRC doesn't provide a recommended value for crude fat, with Popovich & Dierenfeld (1997) recommending values below 8% and average values in the wild ranging between 1.4% to 4.5% (see Table 1, page 9). Fat consumption by Zoo Basel's gorillas was only slightly higher than that, averaging 5.4%, which is a positive remark. However, the situation changes when analysing specific n-3 and n-6 fatty acids. ALA was positively above proposed values, but the LA average falls 37% below the recommended, which enables a higher conversion of ALA into inflammatory fatty acids (Ball et al., 2008). An analysis of the diet indicates that LA concentration was mostly influenced by seeds, nuts and pellet concentrations in the diet, which explains why Zungu and Goma have the lowest LA concentrations. It is important to remember that adequate quantities of essential fatty acids are particularly important in pregnant females, to assure normal foetus brain development (National Research Council, 2003).

4.2.5 Starch and Fibre

Starch concentration in Zoo Basel's diet varied between 5% - 9.4%. Pellets offered had a relatively low starch content, and tuber vegetables, like potatoes, actually contributed more than the pellets to increase starch levels, particularly in Zungu and Goma. Given that natural diets provide very little starch, and the possible implications to gastrointestinal and overall gorilla health, it would be advised to keep these levels at a minimum by reducing offered quantities of this class of vegetables.

NDF and ADF in this study ranged between 25.9% - 30.9% and 16.8% - 20.3%, respectively. Although still far from the values seen in the wild, this is a very good concentration when compared to published values in other zoos. In the latest Gorilla SSP dietary survey, in 2010, only 1 out of 24 institutions reported to offer a diet with medium-high fibre levels, ranging from 25% to 30% NDF (Smith, 2012).

Browse was the category that offered most natural fibre, with an average of 55% NDF and 35% ADF. For the tree species offered, only leaf nutrient values were considered for this study, since they comprised most of the browse intake and no accurate way of measuring stem and bark consumption was found. However, the gorillas often fed on these plant parts too, so it is not possible to assess how much that intake may have increased fibre consumption. Leafy, flower and fruit vegetables were the natural foods that provided the next

highest fibre levels, averaging 17% NDF and 15% ADF. Pellets, particularly the ones designed for leaf eating primates, provided 33% NDF and 20% ADF.
Lowest and highest calculated fibre values correspond to Goma and Quarta, respectively, so in reality they might be slightly below what is presented. It seems that, given the high fibre levels consumed in the wild (averages of 44 – 80% NDF and 24 – 65% ADF – see Table 1, page 9), it would be more adequate to offer diets above 30% NDF and 20% ADF. For Zoo Basel's particular case, this would only be possible by increasing quantities of browse offered, implying a reduction in other types of foods, or replacing some of the browse species by very high fibre plants, like bamboo culms (Annex 15). If a portion of vegetables was replaced by pellets, like suggested by the SSP recommendations, fibre levels would also naturally increase.

4.2.6 Essential Macrominerals

K, Mg and Cl intake levels were appropriate. K values were considerably higher than recommended, but as this mineral is usually found in very high concentrations in natural diets, this is considered normal. Only Cl values were not found for this study's browse species, but Cl concentrations in leaves seem to be generally low, so this should not significantly influence the results (National Research Council, 2003).
Na intake varied between 0.12% to 0.15%, which is on average 35% lower than recommended. However, as mentioned before, the Na concentration in common foods eaten in the wild averages between 0.01% to 0.02% (see Table 2, page 10), with the exception of swamp plants whose Na average content may range between 0.2 - 0.6% DM (Sienne et al., 2014). Therefore, even if we consider the occasional swamp plant and decayed wood consumption to compensate for those small concentrations, it is still very unlikely that gorillas in the wild consume the NRC recommended concentrations, as shown in the study by Masi et al. (2015). Given the negative influence of this mineral in human high blood pressure and cardiac fibrosis, it is actually positive that Na consumption didn't reach the suggested values (Great Ape Heart Project, 2012).
Ca intake averaged 16% below recommended. M'Tongé and Goma were the most affected by this difference, as their intake of leafy vegetables and browse was in lower concentrations when compared to the other gorillas. P intake was considerably low, averaging 59% lower than recommended. Animal products presented the highest P concentrations, followed by flower vegetables, seeds and stem vegetables. Overall, the Ca:P ratio was 2.5:1. As referred before, it is unclear whether a 0.8% P intake is indeed necessary, as not only values in the wild are lower, but it is possible that the gorilla's intestinal microflora allows them to absorb phytate-P (National Research Council, 2003; Rothman et al., 2008). Given that concentrations of this mineral are the highest in foods that should be restricted, like nuts and animal products, it would be very challenging to increase P levels to the NRC

recommendations. Increasing Ca levels to suggested concentrations, P levels to 0.4% and allowing a 2.5:1 ratio seems to currently be the best possible solution without using P supplements.

4.2.7 Trace Minerals

There are no recommended quantities established for Co. Mn and Se consumption probably far exceed requirements, but for Mn, apart from its influence on Fe transport and absorption, no other negative side-effects from excessive intake have been found in the literature. For Se, the consumed quantities were still considerably below the values commonly reported to cause toxicity symptoms in primates (National Research Council, 2003).

I concentrations were very close to the NRC requirements, and given natural variations on food composition, minor differences above or below recommendations are not a cause for concern. Cu, Fe and Zn were all below recommended, by 52%, 9% and 56%, respectively. Fe slight deviation may be easily corrected with a small increase in browse consumption. Cu and Zn values in wild foods are far below from NRC recommendations (see Table 2, page 10), so although diet corrections can be attempted to increase intake of these minerals, not reaching these recommended levels doesn't seem to be a serious cause for concern. In wild foods, concentrations are highest for Cu in leaves and shoots, with 14 mg/kg, and stems have the highest concentration of Zn, with 71mg/kg, so these values may provide an approximate intake goal for Zoo Basel's gorillas (Calvert, 1985).

4.2.8 Fat Soluble Vitamins

Vitamins A, E and K were present in concentrations well above the NRC recommendations. No risk of toxicity is present, as quantities of vitamin A and E were still below levels proven to cause adverse symptoms, and phylloquinone is not toxic when consumed orally. In addition, observations on other animals indicate that vitamin E requirements for support of optimal immune function are higher than for prevention of deficiency clinical signs (National Research Council, 2003).

Vitamin D3 in this diet was only supplied by animal products and pellets, so concentrations were predictably very low when compared to recommendations. This shouldn't be a problem for Zoo Basel's gorilla population, as they have daily access to the outside enclosure, and in the specific time frame of this study there was no lack of direct sunlight exposure. However, it becomes a problem for Goma and Zungu, who refuse to go outside. Although the roof windows are built with special glass that allows the passage of some UVB radiation, given window size and enclosure structure, it is still very unlikely they are receiving enough radiation to reach adequate vitamin D production. Calcitriol is essential for adequate Ca and P metabolism, and chronic deficiency results in skeleton mineralization defects, so these individuals should be supplemented for vitamin D (National Research Council, 2003).

4.2.9 Water Soluble Vitamins

All water soluble vitamins appeared to be consumed in adequate concentrations. However, it should be noted that folate levels were barely above recommendations, falling very short of that value for Joas. As mentioned before, folic acid is essential for proper foetal development, and should be present in higher quantities in the early stages of pregnancy. Dietary intake should then probably reach 5-6 mg/kg of DM for females in reproductive age (National Research Council, 2003). Folate concentrations in the food items offered were highest in primate pellets and flower vegetables, followed by leafy vegetables and bulb vegetables, so relative increase of these food types should correct folic acid deficiencies.

4.2.10 Study Limitations

One of the goals of this study was to perform an accurate individual nutritional intake evaluation. However, a few different options would have allowed for better precision, and some other aspects couldn't be controlled but must be accounted for. As such, they are mentioned here for future reference and objective appraisal of this study's results:

- Ideally, there would be enough people performing the focal observations to allow for total food intake measurement per gorilla. With only one person conducting observational studies it was only possible to focus on one animal at a time.
- While 14 days of data collection seemed appropriate to calculate the average food quantities offered daily, it allowed for very few individual focal observations. A higher number of observations would have resulted in better assessments of individual consumption, without the likely overestimations for some individuals.
- The observations were restricted to summer months, and unusual high temperatures were registered on a few of the data collection days. This may have led to alterations in the gorillas' normal feeding behaviour, to cope with the unfamiliar conditions.
- As explained before, gorillas in the wild go through seasonal adaptations due to variations in food quality and quantity. In captivity, zoos also adapt their diets to what is available and less expensive, as seasonal produce sold in food stores changes and certain browse species are not available in the winter. As such, the results studied here reflect what is offered in the summer and not a whole year's diet.
- Some items could not be accurately measured, like leaf, stem, bark and pellet intake, and the daily browse leftovers. However, in the future, and maybe with more people involved in the data collection, methods could be devised to correct this gap.
- The human food composition tables only present values for edible portions, and this may not be the same for a gorilla. For example, gorillas consume the rind of the watermelon and don't peel the skin out of vegetables or fruits. Therefore, fibre intake may have been slightly underestimated.

- To provide safer produce, some of it went through thermal treatments. It is unknown how this affected nutrient composition and it should be noted that cooked produce, especially if high in starch, contains more readily available sugars than raw produce.
- Albendazol is known to cause gastrointestinal side-effects, like vomit, diarrhoea and nausea. Although this was not recorded during data collection, the effects on nutrient absorption in Quarta and Zungu are unknown.
- There is an overall lack of studies on the full nutritional composition of browse species. Almost no values for vitamins were found, and a few nutrient concentrations had to be extrapolated from similar species or from studies in different environments.
- Ideally, a complete nutritional analysis of the food items offered should have been performed, offering the most accurate evaluation.

4.3 Environmental Enrichment and Undesirable Behaviours

Compared with the answers collected from the survey on EEP populations in 2004 (Alvarez et al., 2006), Zoo Basel's gorilla dietary management is overall very positive:

- Gorillas were fed an average of 10 times a day, compared to the 4.7 EEP value;
- An average of 25 different food items was offered daily, ranging from 19 to 33, and a total of 66 different items were offered throughout the whole study;
- Browse was offered on a daily basis, in substantial quantities;
- Common animal products given were cooked eggs, daily, and yogurt, weekly;
- No dietary supplements were offered, only a special phytotherapeutical tea for lactating women was provided to Joas and Faddama;
- Potable water was available ad libitum;
- The animals were not separated for feeding, but certain items were frequently given by hand;
- R/R was seen in at least 3 individuals, and coprophagy was observed once in Zungu.

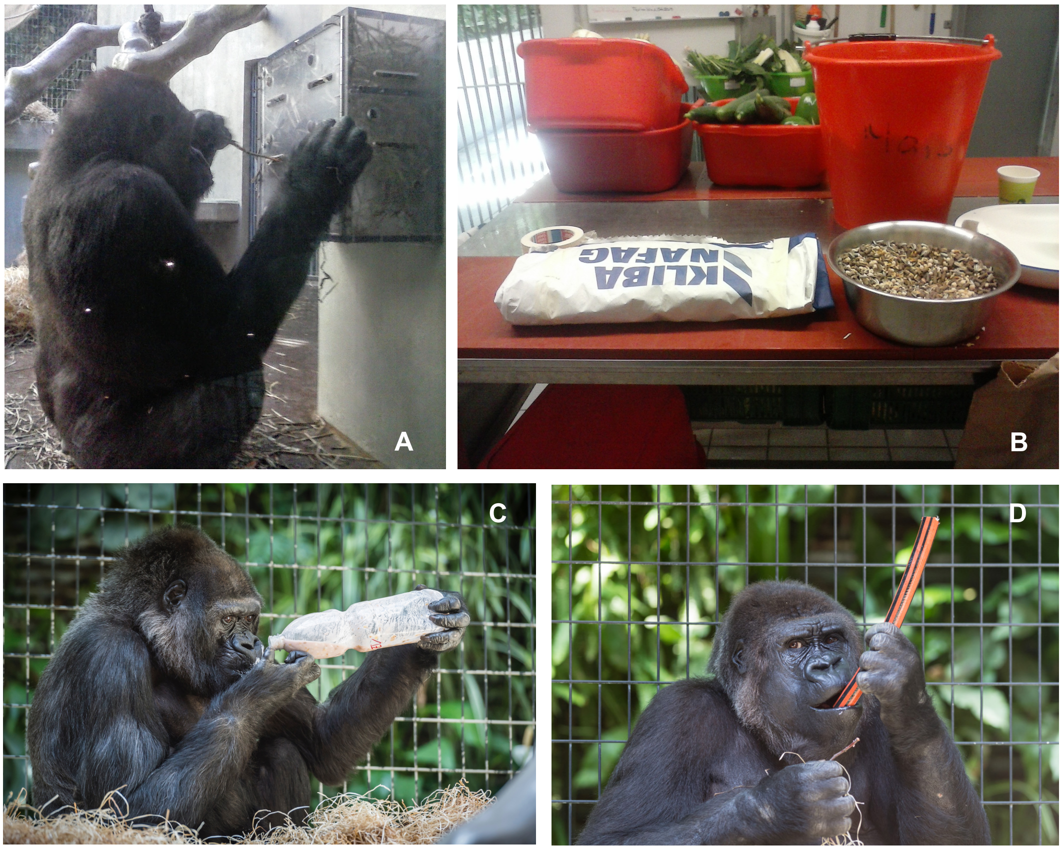
The activity budgets of Zoo Basel's gorilla population were not one of the aims of this study and were not determined. However, beginning and end time of focal observations were registered, so duration of each foraging period could be determined. Gorillas spent, on average, 15 min (5 – 25 min) on E3a, 34 min (12 – 50 min) on E2, 18 min (10 – 24 min) on E1 and 19 min (4 – 37 min) on E3b. This represents the average time it took gorillas to eat most of the food offered by spread, with the exception of the last salad distribution. E2 is clearly the enclosure gorillas spent more time foraging, easily explained by the fact that browse was always introduced there. Subjectively, little activity was observed other than the one occurring at feeding times, although the arrival of the baby gorillas probably decreased the respective mother's time spent resting/inactive.

The dominance hierarchy clearly played a role in the resources distribution. Although there was an attempt at balancing intake by hand-feeding more certain individuals, M'Tongé had better access to desirable items spread in the enclosures, and had an energy intake disproportionally increased when compared with estimated requirements. When spreading the food in the outside enclosure, for example, it was difficult to achieve a balance between offering larger pieces, more easily accessed, of which M'Tongé would take a very big portion, if not all sometimes, or cutting the food in small portions, hiding them and making the access difficult, but having the gorillas leave the enclosure without finding part of the items.

The number of feeding events was positively high, with a balanced portion distribution throughout the day. There was considerable diversity in food types offered, which likely improved the quality of the overall diet. Food placement also posed a positive challenge to the gorillas, either by distributing food on the roof, which promoted physical fitness and varied locomotion postures, spreading smaller items like nuts and pellets, or by placing food in the problem box and a variety of other containers that required different methods to open

(Figure 12). These enrichment stimuli were varied and frequent, purposefully making every day slightly different. It was interesting to note that some individuals, like Quarta, were more prone to forage on the small items, than, for example, M'Tongé, who preferred larger, easy to collect items and was also rarely seen at the problem box. Although probably a consequence of hierarchy and intake requirements, the possibility of choice was a positive characteristic of this diet (Charmoy et al., 2015; Ogden & Wharton, 1997).

Figure 12: Examples of gorilla dietary enrichment in Zoo Basel. A - Zungu collecting food from the problem box. B – Mixed pellets prepared as an enrichment item, inside a folded paper bag. C – Goma drinking yogurt during the veterinary visit. D – Joas consuming a frozen yogurt treat, prepared inside a hose section



An aspect of Zoo Basel's dietary management that could be improved is the strict feeding protocol (Charmoy et al., 2015). Not only was there very little variation in the time schedule, but the classes of food offered at each given time were quite regular too. This meant that Zungu and Goma had a constant decreased intake of specific spread items and consumed probably too much root and tuber vegetables, for example. While the strict feeding protocol did facilitate the keeper's tasks, the animals seemed quite aware of their schedule, which likely lead to decreased time spent foraging. Although harder to change, the closing and opening of doors worked as a queue sign to when and where food was available, reducing the need to forage to actually find the food's location.

In terms of animal products, the eggs were offered as a protein source of high biological quality, a small beef portion was offered once, and not all individuals consumed it, and yogurt was usually offered once a week per occasion of the veterinary visit. However, besides termites and ants, gorillas in the wild consume no animal products (Popovich & Dierenfeld, 1997). It would be ideal to replace these types of foods for an artificial termite mound or find another interesting way to provide invertebrates. That being said, although it wasn't observed, it is possible some of the gorillas already have access and consume invertebrates in the outdoor enclosure.

Diverse quality browse was offered daily, in considerable quantities. The outdoor enclosure also possessed plants which were occasionally fed upon, particularly the grass. It is not clear if this was done in order to ingest specific nutrients or for self-medicating reasons, for example, but it is positive that the gorillas have the option to use the resources of their environment and exhibit natural behaviours.

Measuring the frequency of undesirable behaviours wasn't one of this study's goals, but every time any of these behaviours was observed it was documented. Undesirable behaviours were observed in 4 out of the 14 data collection days. Goma, Quarta and Faddama were seen performing R/R, always after the afternoon meal or after banana consumption. Although there's not enough data to draw solid conclusions, R/R in Zoo Basel's gorillas was apparently associated with the consumption of pulpy fruits like pear and banana, as noted by other studies (Cousins, 2015; Lukas, 1999). It is also very possible that this behaviour occurred more frequently than observed, as it becomes difficult to identify when the bolus is brought to the mouth and then immediately swallowed again.

Coprophagy was observed once, in Zungu. Considering that this behaviour possibly serves as a way to ingest nutrients usually lost in faeces, and that an increase in coprophagy was seen in gorillas going through weight loss, this may be an added indication that Zungu's nutrient intake was below his requirements, which were probably increased due to stress and chronic illness, and that he may have been losing body mass (Less, 2012).

4.4 Anthropometric Measurements

All clinical records referring to the gorillas since 2010 were collected, and all measured weights and the latest estimations can be seen in Figure 13.

The remaining anthropometric measurements and calculations are presented in Table 18. As described by Less (2012), for females PMI = weight (kg) / crown-rump length^2 (m), and for males PMI = weight (kg) / back length^2 (m). Although it might seem a simple task, these measurements required the gorillas to have their back against the enclosure grid wall in the right position, and also required for them to allow the measurement. This was not always the case, so averages from several measures had to be made, and values might not be completely accurate. An individual analysis and discussion of these measurements, already considering the results from the nutritional assessment, is presented in the next chapters.

Figure 13: Recorded weights of Zoo Basel's gorilla population since April, 2010

Boxed values are estimations and not objective measurements

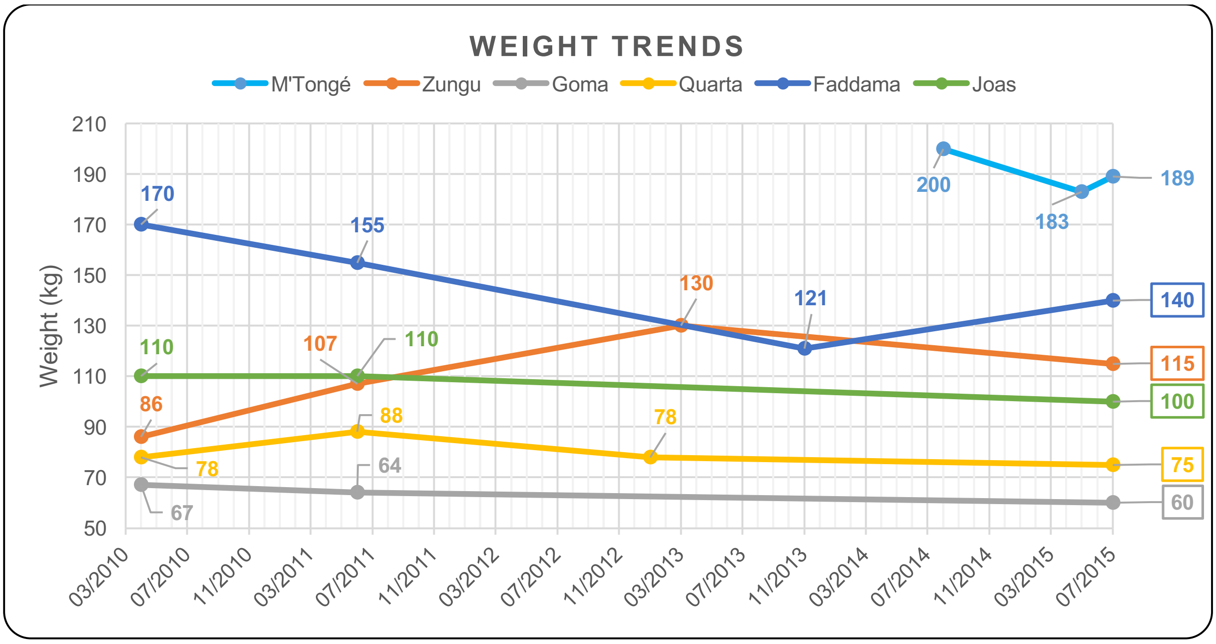


Table 18: Anthropometric measurements of Zoo Basel's gorilla group

cm		M'Tongé	Zungu	Goma	Quarta	Faddama	Joas
Back Length	**Measurements**	66	59, 57, 62, 60				
	Average	66	59.5				
Crown Rump Length	**Measurements**			61, 59	70	75, 79, 79	66, 71, 68, 70
	Average			60	70	77.7	68.8
Hip Width	**Measurements**			34, 32, 32	36	44, 39, 40	38, 37
	Average			32.7	36	41	37.5
PMI (kg/m^2)		433,9	324,8	166,7	153,1	232,1	211,6

4.4.1 M'Tongé

The silverback gorilla only arrived at Zoo Basel in August 2014. He weighed 200kg at the time, and clearly went through an adaptation phase where he lost maybe more than 20kg. By the time the scale was installed, in May 2015, and this study started, he was well adapted, had established his position as the dominant male and leader of the group, and weighed 183kg. In two months he gained 6kg, which is consistent with the results indicating that he was consuming considerably more kcal than the required for his weight. However, it is possible that he was still trying to recuperate the initial body mass he lost, and upon that goal could reach a balanced intake and stable weight.

Although 200kg is still in the range for male gorillas in captivity, it is above the average weights reported in the wild of 140 – 170kg (see Table 3, page 12). With 189kg, he also had a PMI well above the 358 limit established by Less (2012), which means he could be at risk for hyperglycaemia and elevated serum obesity biomarkers. If he were to reach 200kg again, his required daily caloric intake would increase from 5097kcal to 5318kcal, which is still 1289kcal below what he was consuming during this study.

It becomes then important to monitor his weight, and it would be advised to start implementing a more calorie restricted diet, as it doesn't seem necessary for M'Tongé to reach weights in the order of the 200's again, and it might even lead to health problems in the future. As he consumes a considerable amount of fruit, root and tuber vegetables, these would be the indicated foods to try to partially remove from his diet, not only decreasing total kcal but also starch and simple sugars that may be prejudicial to his health (Less, 2012; Plowman, 2015).

If possible, it would also be useful to collect blood samples and analyse the serum for the previously referred obesity indicators (Less, 2012).

4.4.2 Zungu

The first weight recording of Zungu, in April of 2010, occurred when he was 7 years old, which means he was a juvenile and hadn't reached his full adult weight. By March 2013, at the age of 10, he had gained 44kg and was probably starting to approach his adequate weight as an adult blackback male. Although no measurements were available to prove this, it is likely his weight loss process started only when M'Tongé arrived at the group and displaced Zungu from the top of the hierarchy. It is unclear how this weight loss may have been influenced by his chronic progressive alveolar echinococcosis.

As expected, Zungu's weight is below the ranges found for wild and captive males (see Table 3, page 12) and his PMI is below the established limit of 358 (Less, 2012). It seems then prudent to adjust his diet and increase caloric intake. An easy way to do this would be to provide more pellets during the times the other gorillas are outside, particularly the ones intended for leaf-eating primates, which are already nutritionally balanced. It would also be positive if items given by hand are diversified so he can have a more adjusted diet when compared with the other gorillas. Ideally there would be a way to reduce contact between the two males, therefore reducing the hierarchical pressure, stress and decreased access to food. However, given the conditions available in Zoo Basel, and the fact that gorillas are complex social animals, there was no way to do that without further decreasing Zungu's welfare.

In captivity, male gorillas are reported to weight 144kg – 207kg (Smith, 2012). Therefore, 144kg should be established as an initial weight goal for Zungu. Physiological healthy gorillas with this weight are advised to consume 4157 kcal per day in order to maintain body condition, which is 122 kcal above Zungu's estimated intake during this study, so a significant increase in calorie consumption would be needed to reach this goal.

4.4.3 Goma

Goma's weight has been decreasing slowly since 2010, which was to be expected for a geriatric gorilla (National Research Council, 2003). She is already way past the normal age span of wild gorillas, so there aren't any valid weight references for this case. Although her hip width is below the established limit by Less (2012) of 47cm, her PMI is actually slightly above the limit of 158, indicating a possible hyperglycaemia. It would be interesting to evaluate her current serum levels, and it would probably benefit her to consume a more balanced diet, without so many bulb and root vegetables. However, Goma's age and especially her dental status do not allow her to easily consume all foods anymore and the vegetables given to her by hand were usually cooked to facilitate mastication.

Goma is one of the oldest gorillas known to live in captivity, and the main goal should be for her to keep eating enough quantities and kcal to maintain a stable weight, as it's been the case in the last years. Big changes in her diet at this point would likely cause her some difficulties in adjusting and end up being detrimental to her health.

4.4.4 Quarta

Quarta's case has some similarities with Goma, as she is also a geriatric gorilla. She gained 10 kg between 2010 and 2011, but lost them again in the following two years, and appears to have remained at a steady weight ever since. Her PMI and hip width fall below the limits established by Less (2012) and show no cause for concern. Her current weight is also very close to the averages found in free-ranging gorillas (see Table 3, page 12), so, overall she appears to be a healthy individual with an adequate caloric intake. An uncertainty concerning her general metabolism and physiological status remains, due to her chronic infection with alveolar echinococcosis.

4.4.5 Faddama

Faddama's weight measurements indicate that she was extremely overweight in 2010, having lost 49 kg in three and a half years. It is difficult to evaluate how much of her current estimated weight was gained during pregnancy, as she had probably been regaining body mass in the year before that. Faddama is anatomically bigger than the other females, not just in waist perimeter, but also in height and overall figure, even presenting some characteristics usually attributed to males, like a sagittal crest more prominent than what is usually seen in females. This possible physiological deviation from normal values and her recent pregnancy make it harder to evaluate her nutrition status at the time of this study. Her anthropometric values also don't coincide, with a hip width below the limit established by Less (2012), but a PMI and weight well above what is considered a risk for obesity and hyperglycaemia.

In any case, she has been approximately 20 kg lighter than what she was at the time of the study, and observation and comparison with other gorillas, while a subjective method, still seems to clearly indicate an excessive accumulation of fatty tissue, particularly on the waist (Figure 14).

Figure 14: Faddama approximately nine months after parturition (Zoo News by Zoo Basel, 2016. Retrieved April 21, 2016, from http://zoobasel.ch/en/aktuell/detail.php?NEWSID=970)

Therefore, although obesity serum biomarkers would provide a more accurate assessment, it remains very likely that Faddama is considerably overweight and should also reduce her caloric intake. As she's currently lactating, which is a very energy demanding time period, this reduction should not be drastic, but perhaps incrementally, so her excessive energy reserves can compensate for the reduced intake (Schmidt, 2004). In order to do this safely, however, close monitoring of her weight, and the health status of mother and baby would be essential.

4.4.6 Joas

Joas weight seems to have remained stable since 2010, only slightly decreasing, and she was actually estimated to be lighter at the end of her pregnancy than in 2011. Her hip width is also below the established limit, while her weight and PMI are above, although not as intensely as Faddama. It remains possible that the limits established by Less (2012) are simply not valid for pregnant females or females who have given birth recently.

Joas is currently lactating, her weight is on the upper threshold of what is reported to be normal in the wild (Table 3, page 12) and it has remained stable in the last years. Therefore, it would probably be advisable to maintain her current diet, monitor weight trends, and re-evaluate after a few months if the anthropometric measurements remain high and if some caloric restriction should be implemented.

4.5 Clinical Evaluation

A full clinical evaluation of a wild animal like the gorilla is difficult to accomplish without sedation or anaesthesia, which was not warranted for the duration of this study. However, careful observation and analysis of clinical records can still provide essential information regarding the health status of an individual and the adequacy of its dietary management.

Besides the aforementioned chronic alveolar echinococcosis in Zungu and Quarta, the other individuals have had no relevant health issues in their recent past. The fact that the two females at reproductive age have carried through successful pregnancies, and the babies remain healthy and growing at a steady rate is also a positive indicator of the gorillas' overall management. None of the common clinical problems mentioned before were observed during this study, or are stated in recent clinical records, except for Goma's dental status, which probably originates mainly from her very old age. Routine coprology search for parasites every three months didn't reveal any infection and all individuals eliminated well-formed faecal pellets.

Regarding biochemical analysis of body fluids, it is important to note that blood samples were obtained sparingly and always under anaesthesia, after fasting the animals for at least 12 hours. Almost all haematological values were within the reference limits. On 2010 all gorillas were anaesthetised and moved to a temporary enclosure while a new enclosure was built. At the time, Goma presented a slight anaemia and hypohaemoglobinaemia, with a small degree of anisocytosis and poikilocytosis. The cause was unclear and it is possible it was related to malnutrition, but in 2011, when all gorillas were transported back to the new enclosure, her blood analyses were normalised. Zungu presented a slight anaemia and leucocytosis on different occasions, that can be attributed to his chronic disease.

The serum parameters more closely linked to nutrition status were gathered from the Zoo's clinical records, starting in 2009, and are analysed in more detail in Table 19. Although some values are indeed surpassing the reference limits, mineral concentrations in serum don't depend solely on dietary intake. For example, Na and K concentrations are more closely related to water and electrolyte imbalances, and Ca is also homeostatically regulated and remains constant over a wide range of Ca intake (Crissey et al., 2002). Hypoproteinaemia and hypoalbuminaemia can be linked to diet deficiencies, but the values highlighted are show a hyperproteinaemia in Zungu and Quarta, accompanied by a hypoalbuminaemia in Quarta in the 2010 analysis. It is likely that was a consequence of their chronic disease, due to organ dysfunction and/or an inflammatory process. M'Tongé also presented hyperalbuminaemia immediately after his arrival at Zoo Basel. A possible explanation for this is that the stress from travel may have led to a temporary dehydration, malnutrition and homeostatic imbalance. P was low for Quarta and Faddama on one of measurements, which may indicate that a dietary imbalance was occurring at the time, with either insufficient P or vitamin D, or excessive Ca consumption (Crissey et al., 2002).

More relevant to the scope of this study are the glucose, cholesterol and triglycerides concentrations. Joas and Faddama presented relatively high glucose concentrations in their serum analysis, sometimes surpassing reference limits. This is consistent with the previous observations that suggest both of them may be overweight. Fructosamine could make a better biomarker, as it reflects a longer term glucose status, but no standard range values for gorillas have been found in the literature. Although temporary hyperglycaemia is often benign and asymptomatic, chronic hyperglycaemia, even at levels slightly above normal can produce a very wide variety of adverse health complications. Diabetes is characterized by insulin resistance and is the most common cause for chronic hyperglycaemia. Its most frequent symptoms can be difficult to identify – hunger, fatigue, polyuria, polydipsia, dehydration and blurred vision – and although it's unlikely that any of Zoo Basel's gorillas suffer from this condition, it has been suggested that captive gorillas can have some degree of insulin resistance and it would be valuable to make a current assessment of the situation (Less, 2012).

Cholesterol and triglycerides of all individuals were within reference limits for captive animals (Miller & Fowler, 2015). However, they were frequently above what is normally found in male free-ranging gorillas, specifically for cholesterol in Zungu, Quarta, Goma and Faddama, and for triglycerides in Quarta, Faddama and Joas. It is possible the values for triglycerides in free-ranging females are physiologically higher than for males, like it has been shown in mountain gorillas, but no studies can attest to that so far (Schmidt et al., 2006). Even though cholesterol doesn't seem to play a fundamental part in gorillas' cardiac problems, it is still an indicator of obesity and/or lack of fibre in the diet, while triglycerides are associated in humans with obesity and type II diabetes (Less, 2012). Therefore, it would also be important to have a more recent evaluation of these serum parameters, especially in Joas and Faddama, as it may better indicate if and how overweight they are. M'Tongé has not yet been evaluated for these obesity biomarkers, and given his recent weight gain and high anthropometric measurements, a current cholesterol and triglyceride evaluation would also be important.

As the standards of care of captive animals evolve, so does the knowledge and techniques that allow for a better health assessment with reduced stress and negative impacts on the animal's wellbeing. Figure 15 shows a few examples of what some institutions are currently able to do without requiring anaesthesia or sedation. This is done by training the gorillas to voluntarily perform the necessary behaviours, usually by receiving a desirable food item as a reward (positive reinforcement training). Although these behaviours take a long time to train, and require a lot of patience and dedication from the keepers, the benefits are plenty in terms of research, preventive medicine, diagnostics, therapeutics and disease management. Implementing some of these in Zoo Basel's gorillas could significantly improve their health assessments.

Figure 15: Procedures performed in voluntary gorillas in several institutions using positive reinforcement techniques in protected contact

A - Heart Ultrasound (Retrieved April 22, 2016 from http://zoonooz.sandiegozoo.org/zoonooz/big-hearts/)

B - Blood pressure (Retrieved April 22, 2016 from https://greatapeheartproject.org/projects/blood-pressure/)

C – Blood draw (Retrieved April 22, 2016 from https://www.youtube.com/watch?v=D5RIXlSqL9c)

Table 19: Serum biochemistry analysis of Zoo Basel's gorilla population since 2009. Values that surpass the reference limits are highlighted in red, values that are very close to the reference limits are highlighted in yellow and values that are within reference limits for captive animals but not for free-ranging animals are highlighted in blue.

Date		Na	K	Ca	Mg	Cl	P	Fe	Gluc	Fruct	TP	Alb	Glob	Urea	Uric Ac	Creat	Chol	Trig
		mmol/l	mmol/l	mmol/l	mmol/l	mmol/l	mmol/l	µmol/l	mmol/l	mmol/l	g/l	g/l	g/l	mmol/l	µmol/l	µmol/l	mg/dl	mmol/l
M	08/14	135	4.2	2.18	0.84	-	1.25	10.4	6.78	-	80	55	25	2.14	-	115	-	-
Z	06/09	140	5.5	2.23	0.77	105	1.53	17.2	6.1	245	76	35	-	4.7	-	84	263	80
	04/10	143	5.2	2.33	0.62	100	1.65	20.8	4.4	232	81	35	-	4	130	103	305	89
	06/11	144	4.3	2.38	0.59	102	1.24	12.7	5.7	246	88	36	-	4.3	118	119	274	89
	03/13	144	4.8	2.18	0.7	100	1.43	9.9	-	-	93	30	-	4.4	142	119	154	71
G	06/11	142	4.5	2.26	0.91	101	1.32	11	4.2	230	73	35	-	2.7	39	83	216	62
Q	04/10	145	5.5	2.04	0.6	102	1.14	6.9	3.7	219	108	20	-	2.6	93	81	216	115
	06/11	145	3.9	2.14	0.62	102	0.71	14.2	5.5	228	84	35	-	3.7	44	95	209	133
F	04/10	148	4.2	2.32	0.7	104	1.08	9.9	7.2	240	84	36	-	2.8	90	104	278	177
	06/11	147	3.5	2.2	0.69	102	1.08	10.4	6.6	240	83	34	-	2.3	82	108	220	115
	11/13	145	4.4	2.33	0.74	102	0.74	14.4	8.3	252	75	36	-	2.5	67	100	239	142
J	04/10	143	4.4	2.43	0.67	100	1.03	13.9	6.7	262	78	38	-	2.3	60	82	197	142
	06/11	141	4.3	2.37	0.71	97	1.28	15.9	7.6	260	73	36	-	2.5	52	104	185	124
Captive Reference Intervals[1]		137 130-145	4.3 3.3-5.7	2.35 2.08-2.65	0.74 0.48-1.1	101 94-108	1.36 0.81-1.97	16.5 6.6-31.7	4.38 2.4-7.2	-	72 57-87	38 28-48	34 13-49	3.57 1.4-6.8	71.38 12- 149	97.24 44-168	256 140-455	116 43-288
Free Ranging[2]		-	-	-	-	-	-	-	-	-	-	-	Male Western Gorillas (not fasting) →				167 127-201	85 60-100

M – M'Tongé, Z – Zungu, G – Goma, Q – Quarta, F – Faddama, J – Joas

Gluc – Glucose, Fruct – Fructosamine, TP – Total Protein, Alb – Albumin, Glob – Globulin, Bilir – Total Bilirubin, Uric Ac – Uric Acid, Creat – Creatinine, Chol – Cholesterol, Trig – Triglycerides

1 - Miller & Fowler (2015), 2 - Schmidt et al. (2006).

4.6 Recommendations

Based on the study results and discussion, this chapter aims to present a set of recommendations intended to improve the dietary management of Zoo Basel's specific gorilla population.

4.6.1 Diet

- In accordance to diets in the wild, the only animal products offered should be in the form of invertebrates, like termites, ants and other insects. This may be easily achievable since many different insect species are bred in Zoo Basel. If this is not possible, eggs supply a good protein source and could be maintained in the diet, although the need for daily consumption is undefined. Yogurt and meat should be excluded.
- Due to its high concentration of WSC, the amount of fruit offered should be reduced (Plowman, 2015; Schmidt et al., 2005). Using it sparingly for enrichment or as a training treat seems more adequate than current quantities. Since fruits and pellets are the most calorie dense items, feeding these items mostly by hand can help control caloric intake, especially for overweight individuals like Faddama.
- The pellets for leaf-eating primates supply a nutritionally complete and balanced food source, are high in fibre and have a relatively low starch content. As there are nutrients difficult to offer in proper amounts with only the natural foods available, pellet concentration should be increased. However, given the negative behavioural and physiological effects of diets high in pellets or biscuits, reaching the high amount suggested by the SSP does not seem necessary (Ball et al., 2008; Less, 2012, National Research Council, 2003). If initially the consumption is lower than intended, it is possible to increase acceptance by offering the pellets in the morning, when the gorillas are hungry. The mixed pellets, which are not nutritionally balanced (Annex 5), should only be used in low quantities and sparingly, for enrichment.
- Root vegetables, which include the smaller classes of bulb, tuber and root vegetables currently compose 16% to 30% of the gorillas' diet and this amount should be substantially reduced. They provide a considerable amount of starch that is not present in wild diets, entailing the same physiological negative effects as diets high in pellets and biscuits (Less, 2012; National Research Council, 2003). Cooked root vegetables, in their broader sense, can still be given to Goma, but below quantities currently offered and more balanced with all types of vegetables and other types of food.
- Flower vegetables are relatively rich in linolenic acid, P and some trace minerals found to be lacking, with considerably less starch than root vegetables, so increasing its concentration in the diet is recommended.

- Due to the similarities with food consumed in the wild, browse should still compose the bulk of the diet, with leafy vegetables complementing this category. Increasing the proportion of fibrous, less calorie-dense items seems to be the most secure way of increasing the feeling of satiation, maintaining desirable body weights, decreasing unwanted behaviours and increasing overall health (Less, 2012; Lukas, 1999; Remis & Dierenfeld, 2004; Smith, 2012)

Using the nutrient composition averages calculated from each food category, a new sample diet was created, aiming to reduce all imbalances previously identified in the current diet (Table 20). The main focus was promoting adequate levels of satiation with browse, while still providing a more nutritionally complete intake with pellets and adapted quantities of other food types. The current diet offered the whole gorilla group 8.7 kg of DM, so to account for a reduction in intake for at least M'Tongé and Faddama, the calculations for the sample diet were based on a total of 8.3 kg of DM. For animal products, only the nutritional composition of eggs was considered, and the percentage provided accounts for one egg per individual per day. The resulting nutrient composition of this diet and comparison with the results previously presented can be analysed in Table 21.

Table 20: Sample diet composition and daily quantities for the gorilla group in Zoo Basel (n=6, 2 males and 4 females) and comparison with current diet.

Diet Composition	As Fed				Dry Matter			
	Current (%)	Current (g)	Sample (%)	Sample (g)	Current (%)	Current (g)	Sample (%)	Sample (g)
Animal Products	0,96	544	0.87	367.1	1,36	111	1.15	95
Pellets	1,41	820	6.74	2829.5	8,64	722	30.00	2490
Mixed Pellets	0,30	209	0.00	0.0	1,84	184	0.00	0
Seeds and Nuts	0,20	133	0.69	291.4	1,33	125	3.30	274
Fruit	9,12	5635	1.56	655.3	11,83	1049	1.50	125
Stem Vegetables	1,13	729	1.98	830.0	0,44	41	1.00	83
Flower Vegetables	2,00	1350	1.65	691.7	1,22	117	0.50	42
Fruit Vegetables	8,27	4873	23.19	9729.4	3,71	314	10.55	876
Bulb Vegetables	37,05	23139	3.30	1383.3	17,04	1523	1.00	83
Tuber Vegetables	16,87	9873	4.40	1844.4	10,85	913	2.00	166
Root Vegetables	4,95	2948	0.76	319.2	3,45	293	1.00	83
Leafy Vegetables	3,54	2162	33.91	14228.6	6,47	563	12.00	996
Browse	13,68	8195	20.95	8788.2	31,81	2750	36.00	2988
Others	0,50	328	0.00	0,00	0.00	0	0,0	0
Total	100	60936	100	41958.2	100	8705	100	8300

Table 21: Nutrient composition of sample diet and comparison with NRC recommendations and the current diet of Zoo Basel's gorilla group (National Research Council, 2003). Values in green are above recommended and values in red are below.

Sample Diet		Sum	Requirements	Difference	Current diet
Crude protein	% DM	20.24	15.00	5.24	1.24
Crude fat	% DM	6.58	No value	6.58	5.36
Linoleic Acid	% DM	2.00	2.00	0.00	-0.73
Linolenic Acid	% DM	0.98	0.50	0.48	0.36
Crude ash	% DM	9.01	No value	9.01	8.78
NDF	% DM	35.50	10.00	25.50	18.74
ADF	% DM	23.42	5.00	18.42	13.79
Starch	% DM	6.41	No value	6.41	7.04
Ca	% DM	1.04	1.00	0.045	-0.16
P	% DM	0.40	0.80	-0.40	-0.47
Na	% DM	0.22	0.20	0.02	-0.07
Cl	% DM	0.36	0.20	0.16	0.12
K	% DM	2.12	0.40	1.72	1.81
Mg	% DM	0.26	0.08	0.18	0.12
Co	mg/kg DM	0.22	No value	0.22	0.62
Cu	mg/kg DM	14.10	20.00	-5.90	-10.35
I	mg/kg DM	0.71	0.35	0.36	0.00
Fe	mg/kg DM	108.90	100.00	8.90	-8.90
Mn	mg/kg DM	98.82	20.00	78.82	58.20
Se	mg/kg DM	0.46	0.30	0.16	1.08
Zn	mg/kg DM	72.16	100.00	-27.84	-55.95
Vitamin A	IU/kg DM	16930.50	8000.00	8930.50	12760.18
Beta Carotenes	mg/kg DM	89.91	No value	89.91	115.55
D (calciferol)	IU/kg DM	701.74	2500.00	-1798.26	-2279.58
E (a-tocopherol)	mg/kg DM	134.28	45.00	89.28	26.71
K (phylloquinone)	mg/kg DM	7.31	0.50	6.81	6.36
Biotin	mg/kg DM	0.35	0.20	0.15	0.31
Vitamin B1	mg/kg DM	21.86	3.00	18.86	6.31
Vitamin B2	mg/kg DM	14.66	4.00	10.66	2.87
Vitamin B6	mg/kg DM	13.22	4.00	9.22	4.87
Vitamin B12	mg/kg DM	0.04	0.03	0.011	0.22
Niacin	mg/kg DM	70.65	25.00	45.65	21.55
Pantothenic Acid	mg/kg DM	51.36	12.00	39.36	15.20
Folate	mg/kg DM	6.11	4.00	2.11	0.33
Choline	mg/kg DM	1493.56	750.00	743.56	166.82
Vitamin C	mg/kg DM	1636.67	200.00	1436.67	1224.15

The sample diet is effective at correcting deficiencies in linoleic acid, Ca and Fe. It further decreases deficiencies in Cu, Zn and P, reaching the aforementioned goals for these minerals. It also positively increases crude protein, linolenic acid, fibre and folic acid concentrations. There is a considerable increase in all water soluble vitamins that was probably not necessary, but should not lead to toxicities. Even with the increase in pellets, due to the reduction of vegetables rich in starch the sample diet is actually lower in total starch than the current diet. It should be noted that sunlight exposure is still required for all animals, as even with the increase in vitamin D, its concentration remains quite below requirements.

Negative aspects of the sample diet consist in the small increase of fat percentage, although that was to be expected with the increase in linoleic acid, and in the fact that Na rises very slightly above the recommended level, as it was considered a positive aspect that the current diet maintained low levels of this mineral.

In the big picture, however, the sample diet seems more balanced than the current one, and could provide a good baseline for changes in the diet Zoo Basel currently offers its gorilla group.

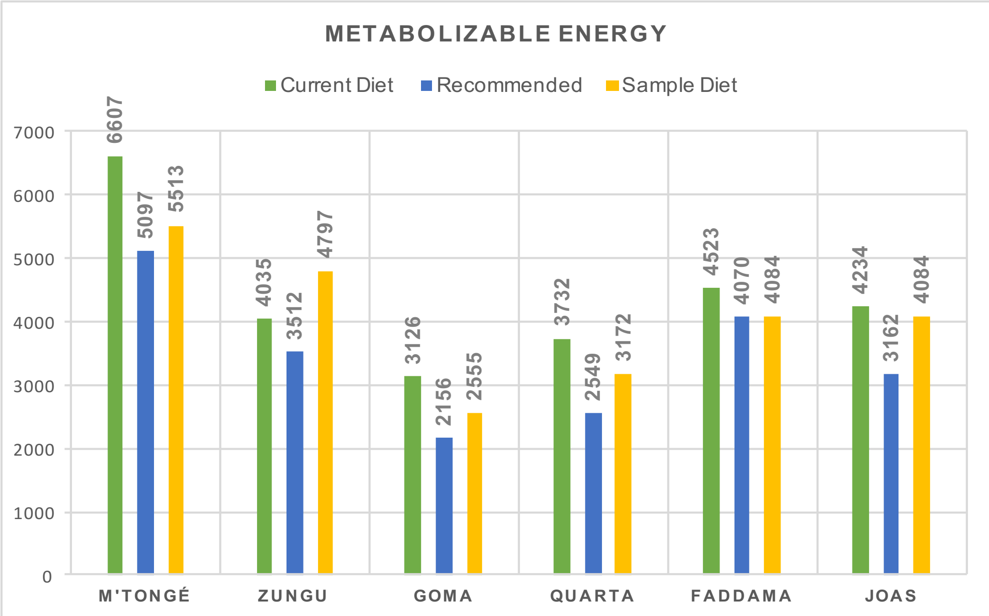
In order to assess if the quantities of the sample diet would provide enough energy for the gorillas estimated requirements, the average ME per food category was used. To determine the total DM intake in g, the percentages of DM/BW were adapted, by following the previous individual recommendations and so the total group DM would be 8.3 kg, as can be seen in Table 22. Therefore, it was possible to calculate how many grams of each category an individual would consume and then sum all the energy contributions per category.

Table 22: DM/BW % in Zoo Basel's gorillas sample diet and current diet and total DM intake per individual

	M'Tongé	Zungu	Goma	Quarta	Faddama	Joas
Weight (kg)	189	115	60	75	140	100
Current DM/BW %	1.13	1.2	1.66	1.67	1.09	1.41
Sample DM/BW %	1.00	1.43	1.46	1.45	1.00	1.40
DM Intake (g)	1890	1644,5	876	1087,5	1400	1400
Total DM (g)	8298					

Figure 16 summarizes the energy each individual would consume if following the sample diet. Overall, all intakes of the sample diet would respect the requirements. M'Tongé and Faddama's caloric consumption would be reduced, and as advised for Faddama this would only be a slight decrease to try and start reducing fatty tissue. Joas caloric intake would remain similar, while Goma and Quarta's consumption would be somewhat reduced, but as these hypothetical calculations don't have consumption overestimations, this intake is still correct if not slightly excessive. And finally, Zungu's kcal intake would be considerably increased to allow for body mass accumulation.

Figure 16: Individual kcal/day intake in Zoo Basel's gorillas in the sample diet and comparison with previous results and NRC recommendations (National Research Council, 2003)



The sample diet would then provide all individuals with proper nutrient concentrations, while accounting for the required energy intake adaptations identified earlier. The total dry matter intake can also be adapted to fit different needs identified in the future.

4.6.2 Feeding Protocol and Enrichment

The main identified gap in the enrichment program of Zoo Basel's gorillas is the strict feeding protocol, regarding time schedules and class of food offered at each time slot. In this chapter some suggestions to change that and further enrich the program are presented.

- Occasionally change the order and time the enclosures are opened and closed.
- Vary the types of foods offered at different times: spreading vegetables on the roof in the early morning, dividing browse in two or three portions offered throughout the day or switching the usual salad lunch meal by the afternoon meal are a few examples.
- Balance the food given by hand, particularly to the individuals with reduced access to spread. Varying between root vegetables, fruit vegetables, seeds, pellets and even special browse like sugar cane or bamboo would provide them with a more complete diet.
- Decreasing time spent resting or inactive is important. Installing several automatic belt feeders that drop desirable items at random times has proven very effective in a previous study, by increasing the need to explore the environment for something new (Charmoy et al., 2015). Other less expensive ways could be created to mimic this enrichment's effect.

- Varying the order food is placed in the enclosure and doors are opened and closed might also stimulate exploring behaviour. It would be interesting to occasionally remove the direct association between doors opening and food being available.
- Increase number of training sessions.
- Introduce new smells and flavours with perfumes and spices.
- Install artificial termite mound or find other ways to provide invertebrates.
- The current frequency of food enrichment stimuli and variability in its presentation is very positive and should be continued.
- The level of seasonality in the current diet is unknown, but given its impact on the wild diets (see Figure 2, page 6), it is advised to implement seasonal fluctuations in diet composition throughout the year. According to Alvarez et al. (2006), implementing true diet seasonality might actually be more important than daily variations in offered food.

An important change to be made in the enclosure architecture is the position of the scale. Weighing the gorillas is a very valuable tool, as proven before, and in Miller & Fowler (2015) it is advised to record weights on a monthly basis. Changing the scale to a common place of passage, like one of the grated corridors, would provide easy and regular measurements.

5. Conclusions and Future Studies

While free-ranging gorilla populations are declining, captive gorillas face serious health problems like obesity and heart disease. A proper dietary management is essential to maintain healthy and thriving populations, but in captivity it can be difficult to provide diets that are both nutritionally and functionally analogous to natural diets.

Gorillas have been kept in zoos since the end of the 19th century, when the daily ration could consist "of two sausages and a pint of beer in the morning, followed later in the day by cheese sandwiches, boiled potatoes and mutton, and more beer" (Kawata, 2009). It is clear their overall management has continuously improved, largely due to increased studies and understanding of free-ranging gorillas' biology and ecology. However, as noted in the literature review, diets offered in captivity still can't mimic natural diets on all their features, and some health and behavioural issues have arisen from that difference.

The purpose of this study was to perform a complete dietary evaluation of Zoo Basel's specific gorilla group, with a particular focus on the repercussion of factors like age, gender and hierarchy on the individual diet adequacy.

This was assessed by conducting an intake study and, consequently, estimating average individual nutrient intake. To complement this information, the enrichment program was analysed and a clinical evaluation was performed, with the measurement of anthropometric features and investigation of previous biochemical analyses and medical records.

It was concluded that there were some important differences in diet composition and nutritional intake between individuals. The silverback male's high hierarchical position allowed him to consume more desirable items, leading to the biggest difference between energy required and actual kcal intake. He had a slight weight increase during the study, which should be monitored and managed in the future.

The two individuals lowest in the hierarchy had less access to spread food which, complemented with the attempts of the keepers to provide them with additional caloric items, lead to an unbalanced nutritional intake and overall diet composition, when compared with the rest of the group. This allowed a geriatric female to keep consuming appropriate amounts of food, despite her poor dental status. However, it was not enough to correct an energy deficient diet on the other male of the group.

Pregnant and lactating females consumed high quantities of food, and given their elevated anthropometric calculations and levels of adiposity serum biomarkers, it is advised to start implementing a caloric restricted diet, especially in the female with the highest PMI. However, extra care should be taken to provide enough quantities of the essential nutrients that support the different reproductive stages, including gestation, lactation, and early post-natal growth.

Overall, when comparing with previous studies and recommendations, the diet offered at Zoo Basel was still complete and mostly adequate to the gorilla's behavioural and nutritional needs, which can be further confirmed by the current good health status of the babies born during the study. With the conclusions from this integrated approach to nutritional assessment it was also possible to elaborate a few individual recommendations and suggest a modified diet, that can resolve the few identified flaws.

To keep improving the welfare of gorilla's in captivity, it is essential to keep learning from studies in the wild and adapt current management to new information.

Complete nutritional analysis of produce and especially browse that is offered to gorillas is necessary. This must take into account not only how gorillas choose and process their food before ingestion, but also what is already known about their digestive physiology.

Non-invasive tools to assess diet adequacy should be developed and/or validated. This includes, for example, a standard scoring system that can be implemented through observation and anthropometric measurements like the ones used in this study, or a more complete understanding of the connection between faecal bile acid secretion and cholesterol production in the body. New technologies are also currently being developed in human medicine to perform serum analysis with very little blood quantities or even without skin perforation (see non-invasive glucose monitor http://www.gluco-wise.com, accessed on May 4, 2016). Keeping up to date with the latest technologies while also developing and implementing an effective training program will likely be essential in the future to successfully manage a captive population as socially complex and challenging as a gorilla group.

It is hoped that the complete and updated literature review and the recommendations given on diet composition, nutritional concentrations and dietary enrichment can be of help not only to Zoo Basel gorilla caretakers, but that they can also be adapted to assist in the management of different individuals and populations in other institutions.

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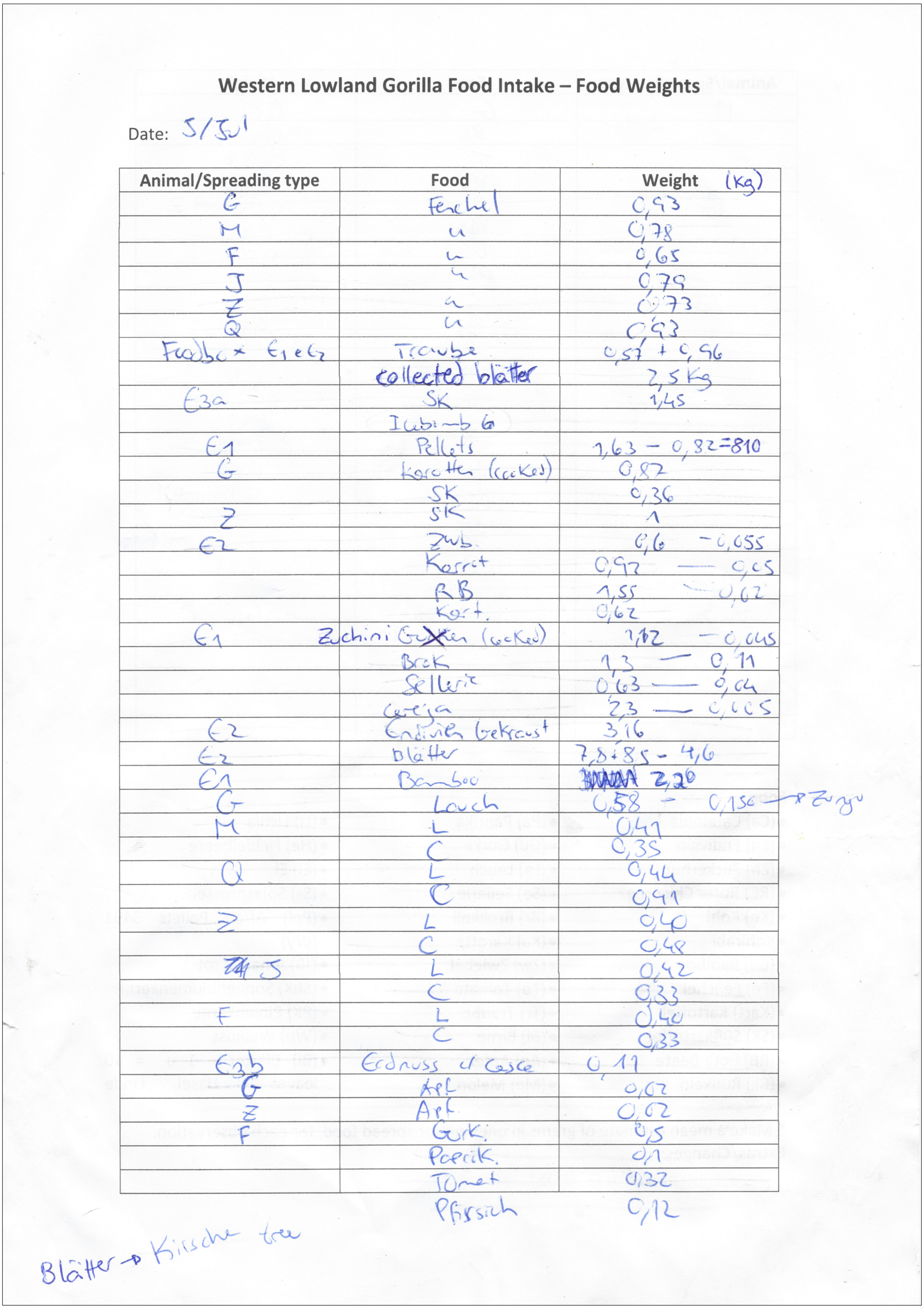
Annexes

Annex 1: Example of Daily Data Collection – Food Weights and Distribution



Western Lowland Gorilla Food Intake – Food Weights

Date: 5/Jul

Animal/Spreading type	Food	Weight (Kg)
G	Fenchel	0,93
M	"	0,78
F	"	0,65
J	"	0,79
Z	"	0,73
Q	"	0,93
Foodbox E1 e E2	Traube	0,57 + 0,96
	collected blätter	2,5 Kg
E3a	SK	1,45
	Iubi-b 6	
E1	Pellets	1,63 – 0,82 = 810
G	Karotten (cooked)	0,82
	SK	0,36
Z	SK	1
E2	Zwb.	0,6 – 0,055
	Karrot	0,97 — 0,05
	RB	1,55 — 0,62
	Kart.	0,62
E1	Zuchini Gurken (cooked)	1,12 – 0,045
	Brok	1,3 — 0,11
	Sellerie	0,63 — 0,04
	Cereja	2,3 — 0,005
E2	Endivien bekraust	3,16
E2	blätter	7,8 + 8,5 – 4,6
E1	Bamboo	2,20
G	Lauch	0,58 – 0,150 → Zugu
M	L	0,41
	C	0,35
Q	L	0,44
	C	0,41
Z	L	0,40
	C	0,48
J	L	0,42
	C	0,33
F	L	0,40
	C	0,33
E3b	Erdnuss u Casca	0,11
G	Apf	0,02
Z	Apf	0,02
F	Gurk.	0,5
	Paprik.	0,1
	Tomat	0,32
	Pfirsich	0,12

Blätter → Kirsche tree

Annex 1 (cont.): Example of Daily Data Collection – Food Weights and Distribution

Animal/Spreading type	Food	Weight
M	G	0,39
	Pa	0,1
	T	0,37
	Pf	0,15
G	G	0,24 → Z
	Pa	0,1
	T	0,55
	Pf	0,15
J	G	0,26
	Pa	0,11
	T	0,51
	Pf	0,12
Z	G	0,20
	Pa	0,11
	T	0,55
	Pf	0,13
Q	G	0,19 → M+
	Pa	0,10
	To	0,54 → M+
	Pf	0,13
Rooftop	Endivien	10,9
G, Q, J	Endivien	5,4

Food*:

- (Ca) Catalonia
- (En) Endivien
- (Zh) Zuckerhut
- (RC) Roter Chicorée
- (Ko) Kohl
- Kohlrabi
- (Bb) Bamboo
- (Fe) Fenchel
- (Kart) Kartoffel
- (SK) Süßkartoffel
- (RB) Rote Beete
- (Rk) Runkeln
- (Pa) Paprika
- (Gu) Gurke
- (La) Lauch
- (Se) Sellerie
- (Br) Brokkoli
- (Ka) Karotte
- (Zw) Zwiebel
- (To) Tomate
- (Tr) Traube
- (Bi) Birne
- (Ap) Apfel
- (Me) Melon
- (Li) Lichia
- (He) Heidelbeere
- (Ei) Ei
- (Ss) Sojasprossen
- (Pel) Affen Pellets 3491 (dry)
- (JB) Johanisbrot
- (SbK) Sonnenblumenkerne
- (PK) Pinienkerne
- (Wn) Walnuss
- (Bl) Blätter – 1 u = 10 leaves Hasel, Linde

* Make a mean estimate of grams in one unit for spread food, for each observation.

Extras/Changes:

New Icebomb 6 – Lichies + 42g Apfel

Annex 2: Example of Daily Data Collection – Focal Observation

Western Lowland Gorilla Food Intake – Focal Observations

Date: 5/Jul Observation day number: 4 Enclosure: E2

Starting Hour: 10h10 Finishing Hour: 10h45

Focus Animal	Food	Units
Z	ZW.	
	Karrot	I
	Rote Bete	𝍸 IIII
	Kartoffel	
	Endivien	
	Blätter	𝍸 𝍸 𝍸 III

Food*:

- (Ca) Catalonia
- (En) Endivien
- (Zh) Zuckerhut
- (RC) Roter Chicorée
- (Ko) Kohl
- Kohlrabi
- (Bb) Bamboo
- (Fe) Fenchel
- (Kart) Kartoffel
- (SK) Süßkartoffel
- (RB) Rote Beete
- (Rk) Runkeln
- (Pa) Paprika
- (Gu) Gurke
- (La) Lauch
- (Se) Sellerie
- (Br) Brokkoli
- (Ka) Karotte
- (Zw) Zwiebel
- (To) Tomate
- (Tr) Traube
- (Bi) Birne
- (Ap) Apfel
- (Me) Melon
- (Li) Lichia
- (He) Heidelbeere
- (Ei) Ei
- (Ss) Sojasprossen
- (Pel) Affen Pellets 3491 (dry)
- (JB) Johanisbrot
- (SbK) Sonnenblumenkerne
- (PK) Pinienkerne
- (Wn) Walnuss
- (Bl) Blätter – 1 u = 10 leaves
  Hasel, Linden

* Make a mean estimate of grams in one unit for spread food, for each observation.

Extras/Changes:

Annex 3: Example of Daily Data Collection – Excel Table

		Time of Day	Day 4 (05-07-2015)	
			Food	Weight (g)
By Hand	Goma	Morning	Fenchel	930
		Extra (cooked)	Karotten	870
			Süßkartoffel	360
		Lunch Time	Lauch	430
		Afternoon	Apfel	20
			Gurke	0
			Paprika	100
			Tomate	550
			Pfirsich	150
	Quarta	Morning	Fenchel	930
		Lunch Time	Lauch	440
			Catalonia	410
		Afternoon	Gurke	0
			Paprika	100
			Tomate	0
			Pfirsich	130
	Faddama	Morning	Fenchel	650
		Lunch Time	Lauch	400
			Catalonia	330
		Afternoon	Gurke	500
			Paprika	100
			Tomate	320
			Pfirsich	120
	Joas	Morning	Fenchel	790
		Lunch Time	Lauch	420
			Catalonia	330
		Afternoon	Gurke	200
			Paprika	110
			Tomate	510
			Pfirsich	120
	M'Tongé	Morning	Fenchel	780
		Lunch Time	Lauch	410
			Catalonia	350
		Afternoon	Gurke	580
			Paprika	100
			Tomate	850
			Pfirsich	150
	Zungu	Morning	Fenchel	730
		Extra	Süßkartoffel	1000
		Lunch Time	Lauch	550
			Catalonia	480
		Afternoon	Apfel	20
			Gurke	440
			Paprika	110
			Tomate	590
			Pfirsich	130

Annex 3 (cont.): Example of Daily Data Collection – Excel Table

Spread	Wood Chips Enclosure (E1)	8h30	Pellets	810
	Outside (E3a)	8h35 - 9h	Süßkartoffel	1450
	Small enclosures + Rooftop (E2)	10h10 - 11h	Blätter (Kirsche)	9000
			Zwiebel	600
			Karotten	920
			Rote Beete	1550
			Kartoffel	620
			Endivien	3160
			Bamboo	2200
			Traube (FB)	1530
	Wood Chips Enclosure (E1)	11h30 - 12h	Zuchinni	1120
			Brokkoli	1300
			Sellerie	630
			Kirsche	2300
	Outside (E3b)	14h20 - 14h40	Erdnuss (mit Schale)	110
			Ice bomb - all to M'tongé	described below
	Roof (E1 + E2)	16h30	Endivien	10900
	Hand (G + Q + J)	16h30	Endivien	5400
Extras	Ice Block a	Lunch Time	Lichias ***	255
			Apfel ***	520
			Aprikosen	410
			Süßkartoffel ***	400

Animal Products	Stem Vegetables	Bulb Vegetables
Pellets	Flower Vegetables	Root Vegetables
Seeds/Nuts	Fruit Vegetables	Tuber Vegetables
Fruit	Leafy Vegetables	Browse
Others		

Observation Day Number	Enclosure	Focus Animal	Food	Units	Unit Average Weight (g)	Total grams	Percentage	Notes
4	E3a	Goma	Süßkartoffel	0	-	-	0%	Doesn't go
	E2	Zungu	Zwiebel	0	-	-	3%	-
			Karotte	1	50	50		
			Rote Beete	9	20	180		
			Kartoffel	0	-	-		
			Endivien	0	-	-		
			Blätter	18	10 leaves	-		
	E1	Quarta	Zuchinni	0	-	-	7%	-
			Brokkoli	1	110	110		
			Sellerie	0	-	-		
			Kirsche	45	6	270		
			Bamboo	0	-	-		
	E3b	Zungu	Erdnuss	0	-	-	0%	Doesn't go

Annex 4: Animal Products Nutrient Concentrations

	Animal Products		Egg		Yoghurt		Ø Animal Products
			per 100g EP	DM	per 100g EP	DM	DM
	DM	%	26,40		14,40		20,40
	ME Primate	kcal/g		6,10		3,99	5,05
EP Input in g	Crude protein	% DM	13,20	50,00	4,00	27,78	38,89
	Crude fat	% DM	11,40	43,18	3,60	25,00	34,09
	Linoleic Acid	% DM	1,66	6,29	0,04	0,28	3,29
	Linolenic Acid	% DM	0,10	0,38	0,01	0,08	0,23
	Crude ash	% DM	1,50	5,68	0,75	5,21	5,45
	NDF	% DM					
	ADF	% DM					
	Starch	% DM	0,00	0,00	0,00	0,00	0,00
	Ca	% DM	0,06	0,21	0,14	0,97	0,59
	P	% DM	0,22	0,83	0,11	0,76	0,80
	Na	% DM	0,15	0,57	0,05	0,34	0,45
	Cl	% DM	0,18	0,68	0,12	0,83	0,76
	K	% DM	0,13	0,49	0,17	1,18	0,84
	Mg	% DM	0,01	0,03	0,01	0,08	0,06
EP Input in mg	Co	mg/kg DM	0,00	0,02	0,00	0,01	0,01
	Cu	mg/kg DM	0,07	2,46	0,01	0,63	1,54
	I	mg/kg DM	0,03	1,29	0,02	1,11	1,20
	Fe	mg/kg DM	1,90	71,97	0,04	3,06	37,51
	Mn	mg/kg DM	0,07	2,69	0,00	0,17	1,43
	Se	mg/kg DM	0,01	0,38	0,00	0,23	0,30
	Zn	mg/kg DM	1,60	60,61	0,40	27,78	44,19
	*A	IU/kg DM	218,00	27525,25	38,00	8796,30	18160,77
	Beta Carotenes	mg/kg DM	0,00	0,15	0,02	1,25	0,70
	**D (calciferol)	IU/kg DM	3,10	4696,97	0,10	277,78	2487,37
	E (a-tocopherol)	mg/kg DM	2,00	75,76	0,04	2,78	39,27
	K (phylloquinone)	mg/kg DM	0,01	0,34	0,00	0,01	0,18
	Biotin	mg/kg DM	0,03	0,95	0,00	0,23	0,59
	B1	mg/kg DM	0,30	11,36	0,02	1,39	6,38
	B2	mg/kg DM	0,45	17,05	0,16	11,11	14,08
	B6	mg/kg DM	0,19	7,20	0,04	2,78	4,99
	B12	mg/kg DM	0,01	0,20	0,50	34,72	17,46
	Niacin	mg/kg DM	0,04	1,52	0,09	6,25	3,88
	Pantothenic Acid	mg/kg DM	1,40	53,03	0,36	25,00	39,02
	Folate	mg/kg DM	0,07	2,54	0,01	0,35	1,44
	Cholin	mg/kg DM	293,80	11128,79	15,20	1055,56	6092,17
	Vit C	mg/kg DM	0,00	0,00	2,00	138,89	69,44
	Notes		Values from chicken egg, hardboiled		Values from natural yoghurt, 1,5 to 1,8% fat		Beef excluded due to very low consumption

Zootrition	*Input values in µg RE per 100g EP, conversion to IU (1 IU = 0,3 µg RE)
Swiss Database	** Input values in µg calciferol, conversion to IU (1 IU = 0,025 µg calciferol)
German Database	
US Database	
NRC	
Other (See notes)	

Annex 5: Pellets Nutrient Concentrations

Pellets		Leaf Eating Primate Pellets 3491		Mixed Pellets 2850	
		per 100g EP	DM	per 100g EP	DM
DM	%	88,00	88,00	88,00	88,00
ME	kcal/g	2,51	2,85		3,31
Crude protein	% DM	18,90	21,48	15,00	17,05
Crude fat	% DM	4,10	4,66	6,70	7,61
Linoleic Acid	% DM	2,00	2,27	4,10	4,66
Linolenic Acid	% DM	0,49	0,56	0,07	0,08
Crude ash	% DM	8,00	9,09	4,70	5,34
NDF	% DM	31,60	35,91	19,00	21,59
ADF	% DM	19,30	21,93	10,00	11,36
Starch	% DM	15,10	17,16	20,00	22,73
Ca	% DM	0,80	0,91	0,62	0,70
P	% DM	0,40	0,45	0,38	0,43
Na	% DM	0,40	0,45	0,03	0,04
Cl	% DM	0,50	0,57	0,09	0,10
K	% DM	1,30	1,48	0,78	0,89
Mg	% DM	0,30	0,34	0,14	0,16
Co	mg/kg DM	0,04	0,05	0,07	0,08
Cu	mg/kg DM	23,00	26,14	10,00	11,36
I	mg/kg DM	1,60	1,82	0,30	0,34
Fe	mg/kg DM	100,00	113,64	120,00	136,36
Mn	mg/kg DM	69,00	78,41	22,00	25,00
Se	mg/kg DM	0,70	0,80	0,12	0,13
Zn	mg/kg DM	120,00	136,36	30,00	34,09
A	IU/kg DM	22000,00	25000,00	200,00	227,27
Beta Carotenes	mg/kg DM			0,00	0,00
Vitamin D3	IU/kg DM	1900,00	2159,09	0,00	0,00
Vitamin E	mg/kg DM	300,00	340,91	6,00	6,82
Vitamin K3	mg/kg DM	9,00	10,23	0,00	0,00
Biotin	mg/kg DM	0,60	0,68	0,10	0,11
Vitamin B1	mg/kg DM	55,00	62,50	1,80	2,05
Vitamin B2	mg/kg DM	34,00	38,64	1,60	1,82
Vitamin B6	mg/kg DM	25,00	28,41	1,60	1,82
Vitamin B12	mg/kg DM	0,10	0,11	0,00	0,00
Niacin	mg/kg DM	135,00	153,41	19,00	21,59
Pantothenic Acid	mg/kg DM	97,00	110,23	4,80	5,45
Folate	mg/kg DM	10,00	11,36	0,18	0,20
Cholin	mg/kg DM	2000,00	2272,73	1114,00	1265,91
Vit C	mg/kg DM	250,00	284,09	0,00	0,00
Notes					

KLIBA

Mixed Pellets	in original	in DM (88%)
GE MJ/kg	17,3	19,7
kcal/g	4,13	4,7
ME MJ/kg	12,2	13,86
kcal/g	2,91	3,31

ME calculated with modified Atwater factors

Primate Pellets	in original	in DM (88%
ME MJ/kg	10,5	11,93
kcal/g	2,51	2,85

ME calculated with modified Atwater factors

Annex 6: Seeds and Nuts Nutrient Concentrations

	Seeds and Nuts		Sunflower Seeds		Walnut		Pine Nut		Almond		Hazelnut		Peanut		Pumpkin Seeds		Ø Seeds and Nuts
			per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	DM
	DM	%	95,50		95,90		94,90		88,30		96,00		93,00		94,40		94,00
	ME Primate	kcal/g		6,02		6,35		6,68		6,16				5,94		5,81	6,16
EP Input in g	Crude protein	% DM	21,30	22,30	15,90	16,58	31,60	33,30	21,20	24,01	15,20	15,83	26,00	27,96	32,60	34,53	24,93
	Crude fat	% DM	53,00	55,50	70,80	73,83	44,90	47,31	49,90	56,51	59,50	61,98	48,50	52,15	49,10	52,01	57,04
	Linoleic Acid	% DM	28,00	29,32	34,00	35,45			13,00	14,72	8,50	8,85	14,00	15,05	46,00	48,73	25,36
	Linolenic Acid	% DM	0,09	0,09	7,83	8,16			0,26	0,29	0,11	0,11	0,53	0,57	0,16	0,17	1,57
	Crude ash	% DM	1,20	1,26	1,98	2,06	0,80	0,84	0,20	0,23	4,70	4,90	2,22	2,39	2,00	2,12	1,97
	NDF	% DM								5,00							5,00
	ADF	% DM		39,00		5,00				3,30							15,77
	Starch	% DM	9,40	9,84	1,50	1,56	1,40	1,48	4,00	4,53	1,40	1,46	6,70	7,20	1,50	1,59	3,95
	Ca	% DM	0,09	0,10	0,08	0,08	0,02	0,02	0,27	0,31	0,16	0,17	0,07	0,07	0,08	0,08	0,12
	P	% DM	0,67	0,70	0,36	0,38	0,70	0,74	0,51	0,58	0,32	0,33	0,38	0,41	1,10	1,17	0,61
	Na	% DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,02	0,01	0,01	0,01
	Cl	% DM	0,05	0,05	0,02	0,02	0,04	0,04	0,04	0,05	0,01	0,01	0,01	0,01	0,08	0,08	0,04
	K	% DM	0,75	0,79	0,42	0,44	0,83	0,87	0,76	0,86	0,72	0,75	0,70	0,75	0,95	1,01	0,78
	Mg	% DM	0,33	0,35	0,14	0,15	0,40	0,42	0,24	0,27	0,16	0,17	0,16	0,17	0,53	0,56	0,30
EP Input in mg	Co	mg/kg DM			0,01	0,10					0,01	0,13	0,03	0,37			0,20
	Cu	mg/kg DM	1,60	16,75	0,88	9,18	1,32	13,95	0,85	9,63	1,30	13,54	0,77	8,25	1,34	14,23	12,22
	I	mg/kg DM	0,01	0,05	0,00	0,02	0,00	0,00	0,00	0,02	0,01	0,07	0,00	0,03	0,01	0,13	0,05
	Fe	mg/kg DM	5,00	52,36	3,00	31,28	7,80	82,19	4,80	54,36	3,60	37,50	6,00	64,52	9,10	96,40	59,80
	Mn	mg/kg DM	2,80	29,32	2,00	20,86	8,80	92,75	1,90	21,52	5,70	59,38	1,60	17,20	4,54	48,13	41,31
	Se	mg/kg DM	0,05	0,55	0,01	0,06	0,00	0,01	0,00	0,04	0,00	0,05	0,01	0,06	0,01	0,10	0,12
	Zn	mg/kg DM	5,80	60,73	4,00	41,71	9,00	94,84	6,00	67,95	2,90	30,21	4,00	43,01	8,20	86,86	60,76
	*A	IU/kg DM	2,00	69,81	8,00	278,07	1,00	35,12	20,00	755,00	4,80	166,67	0,30	10,75	19,00	670,90	283,76
	Beta Carotenes	mg/kg DM	0,03	0,31	0,05	0,50	0,02	0,18	0,12	1,36	0,03	0,30	0,00	0,02	0,23	2,42	0,73
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	35,17	368,27	1,90	19,81	9,33	98,31	26,00	294,45	26,00	270,83	10,00	107,53	2,18	23,09	168,90
	K (phylloquinone)	mg/kg DM	0,00	0,00	0,00	0,02	0,05	0,57	0,00	0,00	0,01	0,09	0,00	0,00	0,01	0,08	0,11
	Biotin	mg/kg DM		1,47	0,00	0,00			0,00	0,00			0,03	0,37			0,46
	B1	mg/kg DM	1,50	15,71	0,36	3,75	1,50	15,81	0,30	3,40	0,27	2,81	1,50	16,13	0,21	2,22	8,55
	B2	mg/kg DM	0,36	3,77	0,14	1,46	0,28	2,95	0,44	4,98	0,05	0,52	0,09	0,97	0,32	3,39	2,58
	B6	mg/kg DM	1,30	13,61	0,41	4,28	0,01	0,11	0,15	1,70	0,50	5,21	0,59	6,34	0,22	2,33	4,80
	B12	mg/kg DM	0,00	0,00	0,10	1,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,15
	Niacin	mg/kg DM	8,30	86,91	1,30	13,56	4,40	46,36	2,10	23,78	1,30	13,54	12,00	129,03	1,70	18,01	47,31
	Pantothenic Acid	mg/kg DM	1,10	11,52	0,81	8,45	0,31	3,27	0,49	5,55	1,20	12,50	1,80	19,35	0,34	3,60	9,18
	Folate	mg/kg DM	0,23	2,41	0,14	1,46	0,03	0,36	0,05	0,54	0,04	0,43	0,24	2,58	0,06	0,61	1,20
	Cholin	mg/kg DM	55,10	576,96	39,20	408,76	55,80	587,99	52,10	590,03	45,60	475,00	52,50	564,52	63,00	667,37	552,95
	Vit C	mg/kg DM	1,00	10,47	2,10	21,90	3,00	31,61	0,00	0,00	2,00	20,83	0,00	0,00	2,00	21,19	15,14
	Notes								http://www.feedipedia.org/node/11757 (accessed 17/04/2016)						http://www.ncbi.nlm.nih.gov/pubmed/8873459 (accessed 17/04/2016)		

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Annex 7: Fruit Nutrient Concentrations

	Fruit		Pineapple		Apple		Apricot		Banana		Grape		Melon		Peach		Plum	
			per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM
	DM	%	13,50		15,00		13,30		26,00		19,90		10,00		13,00		16,30	
	ME Primate	kcal/g		1,67		3,67		3,52		3,57		3,65		3,42		3,48		3,72
EP Input in g	Crude protein	% DM	0,40	2,96	0,30	2,00	0,80	6,02	1,10	4,23	0,70	3,52	0,70	7,00	0,50	3,85	0,60	3,68
	Crude fat	% DM	0,20	1,48	0,30	2,00	0,10	0,75	0,30	1,15	0,30	1,51	0,10	1,00	0,20	1,54	0,20	1,23
	Linoleic Acid	% DM	0,05	0,33	0,20	1,33	0,03	0,22	0,03	0,13	0,11	0,54	0,01	0,13	0,04	0,33	0,05	0,29
	Linolenic Acid	% DM	0,03	0,24	0,04	0,29			0,02	0,09	0,04	0,18	0,00	0,02	0,00	0,01	0,03	0,19
	Crude ash	% DM	0,20	1,48	0,60	4,00	0,30	2,26	1,60	6,15	1,20	6,03	0,30	3,00	0,30	2,31	0,49	3,01
	NDF	% DM		15,33		7,60		7,30		12,30		3,20		22,00		5,00		6,13
	ADF	% DM		5,77		5,00		4,70		2,80		2,11		20,40		6,65		3,38
	Starch	% DM	0,00	0,00	0,10	0,67	0,00	0,00	3,80	14,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Ca	% DM	0,02	0,11	0,01	0,03	0,02	0,12	0,01	0,03	0,01	0,06	0,01	0,14	0,01	0,08	0,01	0,05
	P	% DM	0,01	0,08	0,01	0,06	0,02	0,15	0,02	0,08	0,02	0,10	0,02	0,17	0,02	0,15	0,02	0,10
	Na	% DM	0,00	0,01	0,00	0,03	0,00	0,02	0,00	0,00	0,00	0,01	0,02	0,18	0,00	0,01	0,00	0,01
	Cl	% DM	0,04	0,29	0,00	0,01	0,00	0,01	0,11	0,42	0,00	0,01	0,01	0,08	0,00	0,02	0,00	0,01
	K	% DM	0,15	1,11	0,12	0,80	0,32	2,41	0,38	1,46	0,20	1,01	0,30	3,00	0,16	1,23	0,18	1,10
	Mg	% DM	0,02	0,11	0,00	0,03	0,01	0,08	0,03	0,12	0,01	0,04	0,01	0,14	0,01	0,06	0,01	0,05
EP Input in mg	Co	mg/kg DM	0,00	0,13	0,60	39,80	0,00	0,14	0,00	0,00	0,00	0,05			0,00	0,01	0,00	0,04
	Cu	mg/kg DM	0,06	4,52	0,05	3,47	0,13	10,08	0,11	4,15	0,10	4,97	0,05	4,60	0,07	5,23	0,06	3,93
	I	mg/kg DM	0,00	0,10	0,00	0,05	0,00	0,04	0,00	0,08	0,00	0,05	0,00	0,10	0,00	0,22	0,00	0,09
	Fe	mg/kg DM	0,30	22,22	0,20	13,33	0,40	30,08	0,40	15,38	0,40	20,10	0,20	20,00	0,40	30,77	0,30	18,40
	Mn	mg/kg DM	0,32	23,70	0,04	2,87	0,17	12,56	0,26	9,92	0,07	3,62	0,04	4,30	0,06	4,85	0,06	3,93
	Se	mg/kg DM	0,55	40,74	0,00	0,09	0,00	0,10	0,00	0,05	0,00	0,09	0,50	50,00	0,00	0,10	0,00	0,04
	Zn	mg/kg DM	0,10	7,41	0,10	6,67	0,10	7,52	0,20	7,69	0,10	5,03	0,10	10,00	0,10	7,69	0,10	6,13
	*A	IU/kg DM	5,00	1234,57	2,00	444,44	167,00	41854,64	9,00	1153,85	0,01	0,92	4,00	1333,33	9,00	2307,69	8,00	1635,99
	Beta Carotenes	mg/kg DM	0,06	4,15	0,03	1,73	2,00	150,38	0,08	2,96	0,00	0,15	0,05	5,30	0,06	4,92	0,07	4,29
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	0,10	7,41	0,49	32,67	0,50	37,59	0,27	10,38	0,63	31,66	0,14	14,00	0,96	73,85	0,85	52,15
	K (phylloquinone)	mg/kg DM	0,00	0,01	0,00	0,25	0,00	0,25	0,26	10,00	0,02	0,75	0,52	52,00	0,00	0,18	0,01	0,51
	Biotin	mg/kg DM		0,00	0,00	0,30			0,01	0,21	0,00	0,08			0,00	0,15	0,00	0,01
	B1	mg/kg DM	0,08	5,93	0,03	2,00	0,04	3,01	0,04	1,54	0,05	2,51	0,04	4,00	0,02	1,54	0,07	4,29
	B2	mg/kg DM	0,03	2,22	0,02	1,33	0,05	3,76	0,07	2,69	0,02	1,01	0,02	2,00	0,05	3,85	0,04	2,45
	B6	mg/kg DM	0,09	6,67	0,05	3,33	0,07	5,26	0,47	18,08	0,07	3,52	0,09	9,00	0,02	1,54	0,04	2,45
	B12	mg/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Niacin	mg/kg DM	0,30	22,22	0,10	6,67	0,60	45,11	0,60	23,08	0,23	11,56	0,50	50,00	1,00	76,92	0,44	26,99
	Pantothenic Acid	mg/kg DM	0,20	14,81	0,10	6,67	0,30	22,56	0,30	11,54	0,06	3,02	0,20	20,00	0,20	15,38	0,18	11,04
	Folate	mg/kg DM	0,01	1,04	0,01	0,87	0,01	0,53	0,02	0,88	0,04	2,16	0,10	10,00	0,02	1,23	0,00	0,12
	Cholin	mg/kg DM	5,50	407,41	3,40	226,67	2,80	210,53	9,80	376,92	5,60	281,41	7,60	760,00	6,10	469,23	1,90	116,56
	Vit C	mg/kg DM	18,00	1333,33	5,00	333,33	7,00	526,32	12,00	461,54	4,20	211,06	25,00	2500,00	7,30	561,54	5,40	331,29
	Notes		ME Horse						Schmidt, D. A., Kerley, M. S., Porter, J. H., & Dempsey, J. L. (2005). Structural and Nonstructural Carbohydrate, Fat, and Protein Composition of Commercially Available, Whole Produce. Zoo Biology, 24, 359–373.				(Melon with rind) Schmidt, D. A., Kerley, M. S., Porter, J. H., & Dempsey, J. L. (2005). Structural and Nonstructural Carbohydrate, Fat, and Protein Composition of Commercially Available, Whole Produce. Zoo Biology, 24, 359–373.					

Annex 7 (cont.): Fruit Nutrient Concentrations

	Fruit		Mango		Pear		Lychee		Cherry		Coconut		Watermelon		Blueberry		Ø Fruits
			per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	DM
	DM	%	17,00		15,30		20,30		19,20		55,40		8,00		17,00		18,61
	ME Primate	kcal/g		3,55		3,64		3,62		3,74		6,68		3,77		3,64	3,69
EP Input in g	Crude protein	% DM	0,60	3,53	0,40	2,61	0,90	4,43	1,30	6,77	3,92	7,08	0,50	6,25	0,60	3,53	4,50
	Crude fat	% DM	0,20	1,18	0,30	1,96	0,30	1,48	0,50	2,60	36,50	65,88	0,30	3,75	0,50	2,94	6,03
	Linoleic Acid	% DM	0,01	0,05	0,11	0,71		0,37	0,05	0,24	0,68	1,23	0,03	0,34			0,45
	Linolenic Acid	% DM	0,07	0,39	0,02	0,12		0,36	0,05	0,24	0,00	0,00	0,04	0,50			0,20
	Crude ash	% DM	0,50	2,94	0,10	0,65	0,45	2,25	0,40	2,08	0,97	1,75	0,60	7,50	0,40	2,35	3,18
	NDF	% DM		11,51		14,90						55,80		11,65		13,22	14,30
	ADF	% DM		6,26		9,39						27,70		9,86		7,07	8,55
	Starch	% DM	0,30	1,76	0,00	0,00			0,00	0,00			0,00	0,00	0,00	0,00	1,31
	Ca	% DM	0,02	0,12	0,01	0,07	0,01	0,05	0,02	0,09	0,02	0,04	0,01	0,09	0,01	0,05	0,07
	P	% DM	0,02	0,13	0,01	0,08	0,03	0,16	0,02	0,09	0,09	0,17	0,01	0,11	0,01	0,06	0,11
	Na	% DM	0,00	0,01	0,00	0,01	0,00	0,01	0,00	0,02	0,04	0,06	0,00	0,03	0,00	0,01	0,03
	Cl	% DM	0,01	0,03	0,00	0,01			0,00	0,02	0,12	0,22	0,01	0,10	0,01	0,03	0,09
	K	% DM	0,15	0,88	0,12	0,78	0,19	0,94	0,25	1,28	0,38	0,68	0,11	1,38	0,07	0,40	1,23
	Mg	% DM	0,01	0,05	0,01	0,05	0,01	0,03	0,01	0,07	0,04	0,07	0,01	0,13	0,00	0,02	0,07
EP Input in mg	Co	mg/kg DM			0,01	0,36			0,00	0,08					0,00	0,01	4,06
	Cu	mg/kg DM	0,06	3,76	0,08	4,90	0,20	9,85	0,10	5,21	0,44	7,85	0,03	3,50	0,08	4,41	5,36
	I	mg/kg DM	0,00	0,06	0,00	0,05			0,00	0,05	0,00	0,02	0,01	1,25	0,00	0,06	0,16
	Fe	mg/kg DM	1,20	70,59	0,20	13,07	0,35	17,24	0,40	20,83	2,20	39,71	0,20	25,00	0,50	29,41	25,74
	Mn	mg/kg DM	0,17	10,00	0,06	3,92	0,11	5,42	0,09	4,48	1,30	23,47	0,03	4,00	4,20	247,06	24,27
	Se	mg/kg DM	0,00	0,04	0,00	0,04	0,00	0,00	0,00	0,06	0,81	14,62	0,40	50,00	0,00	0,01	10,40
	Zn	mg/kg DM	0,10	5,88	0,10	6,54	0,21	10,34	0,10	5,21	0,79	14,17	0,10	12,50	0,10	5,88	7,91
	*A	IU/kg DM	195,00	38235,29	2,60	566,45	0,00	0,16	3,00	520,83	0,00	0,00	9,00	3750,00	3,00	588,24	6241,76
	Beta Carotenes	mg/kg DM	2,30	135,29	4,00	261,44	0,01	0,69	0,02	1,04	0,00	0,00	0,08	9,63	0,03	1,59	38,90
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	1,00	58,82	0,43	28,10	0,12	5,91	0,13	6,77	0,70	12,64	0,05	6,25	1,80	105,88	32,27
	K (phylloquinone)	mg/kg DM	0,00	0,25	0,00	0,32	0,00	0,22	0,00	0,08	0,00	0,00	0,00	0,03	0,01	0,71	4,37
	Biotin	mg/kg DM			0,00	0,01			0,40	20,83					0,00	0,06	2,40
	B1	mg/kg DM	0,03	1,76	0,03	1,96	0,05	2,46	0,05	2,60	0,06	1,10	0,03	3,75	0,03	1,76	2,68
	B2	mg/kg DM	0,05	2,94	0,03	1,96	0,05	2,46	0,07	3,65	0,01	0,14	0,02	2,50	0,03	1,76	2,32
	B6	mg/kg DM	0,08	4,71	0,02	1,31	0,03	1,43	0,05	2,60	0,06	1,08	0,10	12,50	0,05	2,94	5,09
	B12	mg/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Niacin	mg/kg DM	0,40	23,53	0,20	13,07	0,53	26,11	0,40	20,83	0,38	6,86	0,20	25,00	0,40	23,53	26,77
	Pantothenic Acid	mg/kg DM	0,20	11,76	0,10	6,54	0,05	2,41	0,20	10,42	0,20	3,61	0,20	25,00	0,10	5,88	11,38
	Folate	mg/kg DM	0,05	3,00	0,01	0,65	0,01	0,50	0,03	1,77	0,03	0,54	0,00	0,50	0,01	0,35	1,61
	Cholin	mg/kg DM	7,60	447,06	5,10	333,33	7,10	349,75	6,10	317,71	12,10	218,41	4,10	512,50	6,00	352,94	358,70
	Vit C	mg/kg DM	44,00	2588,24	5,00	326,80	39,00	1921,18	6,00	312,50	2,00	36,10	11,00	1375,00	20,00	1176,47	932,98
	Notes												NDF and ADF - with rind				

For references see page 90

Annex 8: Stem Vegetables Nutrient Concentrations

	Stem Vegetables		Celery	
			per 100g EP	DM
	DM	%	5,60	5,60
	ME Primate	kcal/g		2,99
EP Input in g	Crude protein	% DM	0,90	16,07
	Crude fat	% DM	0,10	1,79
	Linoleic Acid	% DM		1,29
	Linolenic Acid	% DM		0,00
	Crude ash	% DM	0,30	5,36
	NDF	% DM		14,40
	ADF	% DM		14,10
	Starch	% DM	0,00	0,00
	Ca	% DM	0,05	0,93
	P	% DM	0,03	0,57
	Na	% DM	0,11	1,96
	Cl	% DM	0,13	2,32
	K	% DM	0,30	5,36
	Mg	% DM	0,01	0,25
EP Input in mg	Co	mg/kg DM	0,00	0,02
	Cu	mg/kg DM	0,08	13,39
	I	mg/kg DM	0,00	0,18
	Fe	mg/kg DM	0,50	89,29
	Mn	mg/kg DM	4,20	750,00
	Se	mg/kg DM	0,00	0,02
	Zn	mg/kg DM	0,10	17,86
	*A	IU/kg DM	48,00	28571,43
	Beta Carotenes	mg/kg DM	0,57	101,79
	D (calciferol)	IU/kg DM	0,00	0,00
	E (a-tocopherol)	mg/kg DM	1,80	321,43
	K (phylloquinone)	mg/kg DM	0,01	2,14
	Biotin	mg/kg DM	0,00	0,20
	B1	mg/kg DM	0,05	8,93
	B2	mg/kg DM	0,04	7,14
	B6	mg/kg DM	0,07	12,50
	B12	mg/kg DM	0,00	0,00
	Niacin	mg/kg DM	0,40	71,43
	Pantothenic Acid	mg/kg DM	0,40	71,43
	Folate	mg/kg DM	0,02	3,21
	Cholin	mg/kg DM	6,10	1089,29
	Vit C	mg/kg DM	8,00	1428,57
	Notes		Crude Fibre: 13,3	

Legend
Zootrition
Swiss Database
German Database
US Database
NRC
Other (See notes)

*Input values in µg RE per 100g EP, conversion to IU (1 IU = 0,3 µg RE)

Annex 9: Flower Vegetables Nutrient Concentrations

	Flower Vegetables		Broccoli		Cauliflower		Ø Flower Vegetables
			per 100g EP	DM	per 100g EP	DM	DM
	DM	%	9,3		8,1		8,7
	ME Primate	kcal/g		3,01		3,09	3,05
EP Input in g	Crude protein	% DM	3,00	32,26	2,40	29,63	30,94
	Crude fat	% DM	0,40	4,30	0,30	3,70	4,00
	Linoleic Acid	% DM		0,41	0,03	0,36	0,38
	Linolenic Acid	% DM		1,39	0,11	1,35	1,37
	Crude ash	% DM	0,50	5,38	0,70	8,64	7,01
	NDF	% DM		18,40		16,00	17,20
	ADF	% DM		16,30		12,30	14,30
	Starch	% DM	0,10	1,08	0,30	3,70	2,39
	Ca	% DM	0,09	1,00	0,02	0,25	0,62
	P	% DM	0,07	0,72	0,05	0,59	0,66
	Na	% DM	0,01	0,14	0,01	0,17	0,16
	Cl	% DM	0,08	0,84	0,02	0,23	0,54
	K	% DM	0,37	3,98	0,32	3,95	3,96
	Mg	% DM	0,03	0,27	0,02	0,19	0,23
EP Input in mg	Co	mg/kg DM	0,00	0,27	0,00	0,07	0,17
	Cu	mg/kg DM	0,06	6,02	0,05	5,56	5,79
	I	mg/kg DM	0,02	1,61	0,00	0,07	0,84
	Fe	mg/kg DM	1,40	150,54	0,50	61,73	106,13
	Mn	mg/kg DM	0,47	50,43	0,18	22,22	36,33
	Se	mg/kg DM	0,00	0,08	0,00	0,12	0,10
	Zn	mg/kg DM	0,50	53,76	0,30	37,04	45,40
	*A	IU/kg DM	46,00	16487,46	0,00	0,00	8243,73
	Beta Carotenes	mg/kg DM	0,55	59,14	0,00	0,25	29,69
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	0,61	65,27	0,07	8,64	36,96
	K (phylloquinone)	mg/kg DM	0,16	16,67	0,06	7,04	11,85
	Biotin	mg/kg DM	0,00	0,05	0,00	0,19	0,12
	B1	mg/kg DM	0,10	10,75	0,09	11,11	10,93
	B2	mg/kg DM	0,13	13,98	0,08	9,88	11,93
	B6	mg/kg DM	0,19	20,43	0,20	24,69	22,56
	B12	mg/kg DM	0,00	0,00	0,00	0,00	0,00
	Niacin	mg/kg DM	1,00	107,53	0,60	74,07	90,80
	Pantothenic Acid	mg/kg DM	0,90	96,77	0,70	86,42	91,60
	Folate	mg/kg DM	0,11	11,83	0,08	10,25	11,04
	Cholin	mg/kg DM	18,70	2010,75	44,30	5469,14	3739,94
	Vit C	mg/kg DM	110,00	11827,96	55,00	6790,12	9309,04
	Notes		Crude Fibre: 13,8		Crude Fibre: 10,3		

Zootrition
Swiss Database
German Database
US Database
NRC
Other (See notes)

*Input values in µg RE per 100g EP, conversion to IU (1 IU = 0,3 µg RE)

Annex 10: Fruit Vegetables Nutrient Concentrations

	Fruit Vegetables		Tomato		Cucumber		Bell Pepper		Zucchini		Eggplant		Ø Fruit Vegetables
			per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	DM
	DM	%	6,2		4		8,7		6		7,3		6,44
	ME Primate	kcal/g		3,37		3,42		3,46		2,89		3,26	3,28
EP Input in g	Crude protein	% DM	0,80	12,90	0,70	17,50	0,90	10,34	1,80	30,00	1,00	13,70	16,89
	Crude fat	% DM	0,30	4,84	0,10	2,50	0,40	4,60	0,20	3,33	0,20	2,74	3,60
	Linoleic Acid	% DM	0,09	1,47	0,05	1,15	0,09	0,98	0,05	0,87	0,07	0,99	1,09
	Linolenic Acid	% DM	0,01	0,15	0,04	1,05	0,05	0,56	0,09	1,45	0,02	0,21	0,68
	Crude ash	% DM	0,70	11,29	0,40	10,00	0,20	2,30	1,00	16,67	0,60	8,22	9,70
	NDF	% DM		16,63		18,61		17,20		15,10		21,80	17,87
	ADF	% DM		14,24		15,46		14,50		10,20		17,20	14,32
	Starch	% DM	0,00	0,00	0,10	2,50	0,10	1,15	0,10	1,67	0,30	4,11	1,89
	Ca	% DM	0,01	0,14	0,02	0,38	0,01	0,10	0,02	0,32	0,01	0,14	0,21
	P	% DM	0,02	0,27	0,02	0,45	0,02	0,23	0,03	0,52	0,02	0,29	0,35
	Na	% DM	0,00	0,03	0,00	0,02	0,00	0,03	0,00	0,05	0,00	0,04	0,03
	Cl	% DM	0,03	0,48	0,04	0,93	0,02	0,21	0,02	0,40	0,06	0,75	0,55
	K	% DM	0,22	3,55	0,14	3,50	0,17	1,95	0,23	3,83	0,26	3,56	3,28
	Mg	% DM	0,01	0,10	0,01	0,25	0,01	0,14	0,02	0,38	0,01	0,18	0,21
EP Input in mg	Co	mg/kg DM	0,00	0,27	0,00	0,25							0,26
	Cu	mg/kg DM	0,06	9,19	0,04	8,75	0,07	8,39	0,05	7,50	0,09	12,33	9,23
	I	mg/kg DM	0,00	0,18	0,00	0,73	0,00	0,11	0,00	0,38	0,00	0,03	0,29
	Fe	mg/kg DM	0,20	32,26	0,20	50,00	0,40	45,98	0,80	133,33	0,30	41,10	60,53
	Mn	mg/kg DM	0,11	17,42	0,08	20,50	0,13	14,48	0,13	20,83	0,11	15,34	17,72
	Se	mg/kg DM	0,00	0,16	0,00	0,20	0,00	0,49	0,00	0,17	0,00	0,53	0,31
	Zn	mg/kg DM	0,10	16,13	0,10	25,00	0,30	34,48	0,20	33,33	0,10	13,70	24,53
	*A	IU/kg DM	47,00	25268,82	25,00	20833,33	189,00	72413,79	14,00	7777,78	4,00	1826,48	25624,04
	Beta Carotenes	mg/kg DM	0,49	79,68	0,22	55,00	2,00	229,89	0,15	24,33	0,05	6,85	79,15
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	0,80	129,03	0,06	14,25	2,50	287,36	0,12	20,00	0,03	4,11	90,95
	K (phylloquinone)	mg/kg DM	0,01	0,90	0,01	3,25	0,01	1,26	0,01	1,83	0,00	0,07	1,46
	Biotin	mg/kg DM	0,00	0,65	0,00	0,23							0,44
	B1	mg/kg DM	0,06	9,68	0,02	5,00	0,04	4,60	0,05	8,33	0,04	5,48	6,62
	B2	mg/kg DM	0,04	6,45	0,02	5,00	0,03	3,45	0,04	6,67	0,03	4,11	5,14
	B6	mg/kg DM	0,08	12,90	0,04	10,00	0,30	34,48	0,11	18,33	0,08	10,96	17,34
	B12	mg/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Niacin	mg/kg DM	0,60	96,77	0,20	50,00	0,90	103,45	0,60	100,00	0,60	82,19	86,48
	Pantothenic Acid	mg/kg DM	0,30	48,39	0,30	75,00	0,10	11,49	0,20	33,33	0,20	27,40	39,12
	Folate	mg/kg DM	0,02	3,87	0,01	3,25	0,02	2,53	0,05	8,33	0,02	2,60	4,12
	Cholin	mg/kg DM	6,70	1080,65	6,00	1500,00	5,60	643,68	9,50	1583,33	6,90	945,21	1150,57
	Vit C	mg/kg DM	18,00	2903,23	5,00	1250,00	165,00	18965,52	20,00	3333,33	2,00	273,97	5345,21
	Notes						Crude Fibre: 14,5				Crude Fibre: 18,6		

For references see page 96

Annex 11: Leafy Vegetables Nutrient Concentrations

	Leafy Vegetables		Endive Lettuce		Chicory		Butterhead Lettuce		Kohlrabi		White Cabbage		Iceberg Lettuce		Ø Leafy Vegetables
			per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	DM
	DM	%	5,8		5,3		5		8,4		9,6		5,4		6,58
	ME Primate	kcal/g		2,74		2,88		2,94		3		3,18		2,92	2,94
EP Input in g	Crude protein	% DM	1,80	31,03	1,00	18,87	1,20	24,00	1,90	22,62	1,40	14,58	1,00	18,52	21,60
	Crude fat	% DM	0,20	3,45	0,20	3,77	0,20	4,00	0,20	2,38	0,20	2,08	0,20	3,70	3,23
	Linoleic Acid	% DM		1,21	0,07	1,36	0,05	1,04	0,02	0,29	0,03	0,27		0,71	0,81
	Linolenic Acid	% DM		0,21	0,03	0,55	0,07	1,42	0,05	0,56	0,09	0,91		1,73	0,90
	Crude ash	% DM	0,90	15,52	0,90	16,98	0,90	18,00	1,20	14,29	0,80	8,33	0,80	14,81	14,66
	NDF	% DM								20,10		14,20		16,93	17,08
	ADF	% DM								17,50		10,50		13,08	13,69
	Starch	% DM	0,00	0,00	0,10	1,89	0,00	0,00	0,10	1,19	0,10	1,04	0,00	0,00	0,69
	Ca	% DM	0,05	0,93	0,02	0,38	0,03	0,62	0,06	0,76	0,06	0,58	0,03	0,63	0,65
	P	% DM	0,05	0,93	0,03	0,47	0,02	0,34	0,05	0,60	0,03	0,34	0,02	0,41	0,51
	Na	% DM	0,04	0,74	0,00	0,08	0,00	0,05	0,02	0,24	0,00	0,05	0,00	0,07	0,20
	Cl	% DM	0,07	1,22	0,03	0,47	0,06	1,14	0,04	0,48	0,04	0,39	0,04	0,78	0,75
	K	% DM	0,33	5,69	0,20	3,77	0,14	2,80	0,32	3,81	0,26	2,71	0,18	3,33	3,69
	Mg	% DM	0,01	0,17	0,01	0,19	0,01	0,15	0,04	0,51	0,01	0,13	0,01	0,13	0,21
EP Input in mg	Co	mg/kg DM					0,00	0,19	0,00	0,20	0,00	0,17			0,19
	Cu	mg/kg DM	0,04	7,41	0,10	19,06	0,05	9,80	0,05	5,60	0,03	3,44	0,03	4,63	8,32
	I	mg/kg DM	0,00	0,50	0,00	0,19	0,00	0,66	0,00	0,08	0,00	0,31	0,00	0,37	0,35
	Fe	mg/kg DM	1,40	241,38	0,74	139,62	0,40	80,00	0,50	59,52	0,30	31,25	0,40	74,07	104,31
	Mn	mg/kg DM	0,15	25,86	0,30	56,60	0,18	36,00	0,11	13,10	0,20	20,83	0,13	23,15	29,26
	Se	mg/kg DM	0,00	0,48	0,00	0,06	0,00	0,08	0,00	0,08	0,00	0,25	0,00	0,02	0,16
	Zn	mg/kg DM	0,40	68,97	0,20	37,74	0,20	40,00	0,20	23,81	0,20	20,83	0,20	37,04	38,06
	*A	IU/kg DM	91,00	52298,85	294,00	184905,66	94,00	62666,67	1,00	396,83	4,00	1388,89	4,00	2469,14	50687,67
	Beta Carotenes	mg/kg DM	0,89	153,45	3,53	666,04	1,13	226,00	0,01	1,07	0,05	5,21	0,05	8,89	176,78
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	0,44	75,86	2,26	426,42	0,57	113,40	0,48	57,14	1,70	177,08	0,18	33,33	147,21
	K (phylloquinone)	mg/kg DM	0,23	39,83	0,30	56,15	0,11	21,80	0,01	0,83	0,07	6,88	0,02	4,46	21,66
	Biotin	mg/kg DM			0,00	0,91	0,00	0,38	0,00	0,32	0,00	0,32			0,48
	B1	mg/kg DM	0,05	8,62	0,09	16,98	0,06	12,00	0,05	5,95	0,04	4,17	0,05	9,26	9,50
	B2	mg/kg DM	0,12	20,69	0,05	9,43	0,08	16,00	0,05	5,95	0,04	4,17	0,03	5,56	10,30
	B6	mg/kg DM	0,05	8,62	0,03	5,66	0,06	12,00	0,07	8,33	0,19	19,79	0,03	5,56	9,99
	B12	mg/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Niacin	mg/kg DM	0,41	70,69	0,30	56,60	0,40	80,00	1,80	214,29	0,32	33,33	0,20	37,04	81,99
	Pantothenic Acid	mg/kg DM	0,90	155,17	0,40	75,47	0,11	22,00	0,10	11,90	0,26	27,08	0,05	9,26	50,15
	Folate	mg/kg DM	0,11	18,97	0,05	9,81	0,04	7,40	0,07	8,33	0,03	3,23	0,05	9,81	9,59
	Cholin	mg/kg DM	16,80	2896,55	12,80	2415,09	8,40	1680,00	12,30	1464,29	10,70	1114,58	6,70	1240,74	1801,88
	Vit C	mg/kg DM	9,40	1620,69	5,00	943,40	13,00	2600,00	63,00	7500,00	48,00	5000,00	3,90	722,22	3064,38
	Notes								NDF and ADF from Christina		Crude Fibre: 8,4		Extra due to lack of Catalogna Lettuce and other NDF/ADF values on this category		

For references see page 96

Annex 12: Bulb Vegetables Nutrient Concentrations

	Root Vegetables		Fennel		Leek		Onion		Chives		Ø Bulb
			per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	DM
	DM	%	7,80		9,50		11,00		8,70		9,25
	ME Primate	kcal/g		3,17		3,59		3,68		3,21	3,41
EP Input in g	Crude protein	% DM	1,10	14,10	1,60	16,84	1,30	11,82	3,00	34,48	19,31
	Crude fat	% DM	0,30	3,85	0,30	3,16	0,20	1,82	0,60	6,90	3,93
	Linoleic Acid	% DM			0,14	1,46	0,09	0,85	0,13	1,52	1,28
	Linolenic Acid	% DM			0,04	0,39	0,01	0,12	0,29	3,31	1,27
	Crude ash	% DM	0,80	10,26	1,10	11,58	0,70	6,36	0,90	10,34	9,64
	NDF	% DM						7,60			7,60
	ADF	% DM						6,80			6,80
	Starch	% DM	2,20	28,21	0,20	2,11	0,00	0,00	0,00	0,00	7,58
	Ca	% DM	0,04	0,47	0,03	0,33	0,03	0,25	0,09	0,99	0,51
	P	% DM	0,04	0,49	0,04	0,37	0,03	0,31	0,05	0,62	0,45
	Na	% DM	0,02	0,19	0,01	0,13	0,00	0,03	0,00	0,03	0,10
	Cl	% DM	0,03	0,35	0,02	0,25	0,02	0,17	0,07	0,85	0,41
	K	% DM	0,47	6,03	0,26	2,74	0,10	0,91	0,28	3,22	3,22
	Mg	% DM	0,01	0,15	0,01	0,12	0,01	0,09	0,04	0,46	0,20
EP Input in mg	Co	mg/kg DM			0,00	0,03	0,00	0,05			0,04
	Cu	mg/kg DM	0,07	8,46	0,05	5,58	0,04	4,00	0,06	6,78	6,21
	I	mg/kg DM	0,01	0,64	0,01	0,91	0,00	0,16	0,00	0,48	0,55
	Fe	mg/kg DM	0,50	64,10	0,90	94,74	0,30	27,27	1,50	172,41	89,63
	Mn	mg/kg DM	0,19	24,49	0,19	20,00	0,13	11,45	0,37	42,87	24,70
	Se	mg/kg DM	0,00	0,09	0,00	0,08	0,00	0,14	0,00	0,10	0,10
	Zn	mg/kg DM	0,30	38,46	0,30	31,58	0,20	18,18	0,50	57,47	36,42
	*A	IU/kg DM	12,00	5128,21	7,00	2456,14	1,20	363,64	218,00	83524,90	22868,22
	Beta Carotenes	mg/kg DM	0,14	17,95	0,07	7,26	0,00	0,18	2,61	300,00	81,35
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	0,58	74,36	0,53	55,47	0,07	6,09	0,21	24,14	40,02
	K (phylloquinone)	mg/kg DM	0,06	8,05	0,05	4,95	0,00	0,06	0,38	43,68	14,19
	Biotin	mg/kg DM			0,00	0,17	0,00	0,32			0,24
	B1	mg/kg DM	0,08	10,26	0,07	7,37	0,06	5,45	0,08	9,20	8,07
	B2	mg/kg DM	0,02	2,56	0,04	4,21	0,02	1,82	0,11	12,64	5,31
	B6	mg/kg DM	0,06	7,69	0,30	31,58	0,14	12,73	0,13	14,94	16,74
	B12	mg/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Niacin	mg/kg DM	0,70	89,74	0,40	42,11	0,30	27,27	0,70	80,46	59,90
	Pantothenic Acid	mg/kg DM	0,20	25,64	0,10	10,53	0,10	9,09	0,30	34,48	19,94
	Folate	mg/kg DM	0,06	7,05	0,10	10,11	0,02	1,82	0,13	14,94	8,48
	Cholin	mg/kg DM	13,20	1692,31	9,50	1000,00	6,10	554,55	5,20	597,70	961,14
	Vit C	mg/kg DM	8,00	1025,64	18,00	1894,74	7,00	636,36	60,00	6896,55	2613,32
	Notes						Crude Fibre: 6,1				

For references see page 96

Annex 13: Root Vegetables Nutrient Concentrations

	Root Vegetables		Carrot		Beetroot		Radish		Ø Root
			per 100g EP	DM	per 100g EP	DM	per 100g EP	DM	DM
	DM	%	10,80		13,80		5,20		9,93
	ME Primate	kcal/g		3,52		3,46		3,88	3,62
EP Input in g	Crude protein	% DM	0,80	7,41	1,50	10,87	0,60	11,54	9,94
	Crude fat	% DM	0,30	2,78	0,10	0,72	0,30	5,77	3,09
	Linoleic Acid	% DM	0,10	0,96	0,04	0,30	0,02	0,35	0,54
	Linolenic Acid	% DM	0,01	0,11	0,01	0,06	0,06	1,06	0,41
	Crude ash	% DM	0,50	4,63	1,30	9,42	0,50	9,62	7,89
	NDF	% DM		9,20		11,80		14,30	11,77
	ADF	% DM		8,00		5,40		9,80	7,73
	Starch	% DM	0,20	1,85	0,00	0,00	0,00	0,00	0,62
	Ca	% DM	0,03	0,29	0,02	0,12	0,02	0,38	0,26
	P	% DM	0,03	0,24	0,05	0,33	0,02	0,35	0,30
	Na	% DM	0,03	0,26	0,06	0,42	0,01	0,23	0,30
	Cl	% DM	0,06	0,55	0,08	0,59	0,04	0,85	0,66
	K	% DM	0,16	1,48	0,41	2,97	0,24	4,62	3,02
	Mg	% DM	0,01	0,08	0,02	0,15	0,01	0,13	0,12
EP Input in mg	Co	mg/kg DM	0,00	0,12	0,00	0,12			0,12
	Cu	mg/kg DM	0,05	4,54	0,08	5,94	0,04	7,31	5,93
	I	mg/kg DM	0,00	0,15	0,00	0,03	0,00	0,23	0,14
	Fe	mg/kg DM	0,20	18,52	0,90	65,22	0,80	153,85	79,19
	Mn	mg/kg DM	0,17	15,74	0,24	17,68	0,08	15,77	16,40
	Se	mg/kg DM	0,00	0,13	0,00	0,04	0,00	0,37	0,18
	Zn	mg/kg DM	0,10	9,26	0,40	28,99	0,20	38,46	25,57
	*A	IU/kg DM	790,00	243827,16	1,00	241,55	2,00	1282,05	81783,59
	Beta Carotenes	mg/kg DM	7,84	725,93	0,01	0,51	0,02	3,85	243,43
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	0,44	40,74	0,04	3,12	0,00	0,00	14,62
	K (phylloquinone)	mg/kg DM	0,02	1,39	0,00	0,01	0,00	0,07	0,49
	Biotin	mg/kg DM	0,01	0,46					0,46
	B1	mg/kg DM	0,10	9,26	0,02	1,45	0,03	5,77	5,49
	B2	mg/kg DM	0,05	4,63	0,04	2,90	0,04	7,69	5,07
	B6	mg/kg DM	0,16	14,81	0,05	3,62	0,07	13,46	10,63
	B12	mg/kg DM	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Niacin	mg/kg DM	0,60	55,56	0,23	16,67	0,30	57,69	43,30
	Pantothenic Acid	mg/kg DM	0,20	18,52	0,13	9,42	0,10	19,23	15,72
	Folate	mg/kg DM	0,03	2,78	0,08	6,01	0,05	9,62	6,14
	Cholin	mg/kg DM	8,80	814,81	6,00	434,78	6,50	1250,00	833,20
	Vit C	mg/kg DM	7,00	648,15	10,00	724,64	23,00	4423,08	1931,95
	Notes		Crude Fibre: 11,5 (Marcus Clauss, Futterungspraxis in der Haltung von Elchen (Alces alces), Munchen 2000, Doctoral Thesis)		Crude Fibre: 4,7		Crude Fibre: 11,4		

- Zootrition
- Swiss Database
- German Database
- US Database
- NRC
- Other (See notes)

*Input values in µg RE per 100g EP, conversion to IU (1 IU = 0,3 µg RE)

Annex 14: Tuber Vegetables Nutrient Concentrations

	Root Vegetables		Potato		Sweet Potato		Ø Tuber
			per 100g EP	DM	per 100g EP	DM	DM
	DM	%	21,30		30,80		26,05
	ME Primate	kcal/g		3,75		3,87	3,81
EP Input in g	Crude protein	% DM	2,00	9,39	1,63	5,29	7,34
	Crude fat	% DM	0,10	0,47	0,60	1,95	1,21
	Linoleic Acid	% DM	0,03	0,15		0,41	0,28
	Linolenic Acid	% DM	0,02	0,11		0,07	0,09
	Crude ash	% DM	1,50	7,04	1,12	3,64	5,34
	NDF	% DM		7,54		20,04	13,79
	ADF	% DM		2,54		4,86	3,70
	Starch	% DM	14,70	69,01		50,70	59,86
	Ca	% DM	0,01	0,03	0,02	0,07	0,05
	P	% DM	0,05	0,23	0,04	0,13	0,18
	Na	% DM	0,00	0,01	0,00	0,01	0,01
	Cl	% DM	0,05	0,23	0,05	0,15	0,19
	K	% DM	0,40	1,88	0,36	1,17	1,52
	Mg	% DM	0,02	0,09	0,02	0,06	0,07
EP Input in mg	Co	mg/kg DM	0,00	0,04			0,04
	Cu	mg/kg DM	0,09	4,18	0,13	4,22	4,20
	I	mg/kg DM	0,00	0,19	0,00	0,08	0,13
	Fe	mg/kg DM	0,40	18,78	0,66	21,56	20,17
	Mn	mg/kg DM	0,15	6,90	0,24	7,79	7,35
	Se	mg/kg DM	0,00	0,07	0,00	0,06	0,06
	Zn	mg/kg DM	0,30	14,08	0,39	12,50	13,29
	*A	IU/kg DM	1,00	156,49	709,00	76731,60	38444,05
	Beta Carotenes	mg/kg DM	0,01	0,23	7,90	256,49	128,36
	D (calciferol)	IU/kg DM	0,00	0,00	0,00	0,00	0,00
	E (a-tocopherol)	mg/kg DM	0,05	2,49	0,26	8,44	5,46
	K (phylloquinone)	mg/kg DM	0,00	0,10	0,00	0,06	0,08
	Biotin	mg/kg DM	0,00	0,02	0,00	0,14	0,08
	B1	mg/kg DM	0,12	5,63	0,06	2,08	3,86
	B2	mg/kg DM	0,05	2,35	0,05	1,62	1,99
	B6	mg/kg DM	0,33	15,49	0,27	8,77	12,13
	B12	mg/kg DM	0,00	0,00	0,00	0,00	0,00
	Niacin	mg/kg DM	1,20	56,34	0,60	19,48	37,91
	Pantothenic Acid	mg/kg DM	0,38	17,84	0,83	26,95	22,39
	Folate	mg/kg DM	0,03	1,31	0,01	0,39	0,85
	Cholin	mg/kg DM	12,10	568,08	12,30	399,35	483,71
	Vit C	mg/kg DM	17,00	798,12	30,00	974,03	886,07
	Notes		Crude Fibre: 4,2 (Marcus Clauss, Futterungspraxis in der Haltung von Elchen (Alces alces), Munchen 2000, Doctoral Thesis)		Schmidt, D. A., Kerley, M. S., Porter, J. H., & Dempsey, J. L. (2005). Structural and Nonstructural Carbohydrate, Fat, and Protein Composition of Commercially Available, Whole Produce. Zoo Biology, 24, 359–373.		

Legend
Zootrition
Swiss Database
German Database
US Database
NRC
Other (See notes)

*Input values in µg RE per 100g EP, conversion to IU (1 IU = 0,3 µg RE)

Annex 15: Browse Nutrient Concentrations

	Browse		Ash Leaves	Linden Leaves	Hazel Leaves	Birch Leaves	Cherry Leaves	Bamboo Culms	Sugar Cane	Garden Cress		Ø Browse
			DM	DM	DM	DM	DM	DM	DM	per 100g EP	DM	DM
	DM	%	32,00	35,00	37,30	34,00	40,70	50,00	26,70	12,80		33,56
	ME Primate	kcal/g									3,02	
EP Input in g	Crude protein	% DM	20,10	23,70	14,50	17,50	10,50	3,20	3,50	4,20	32,81	15,73
	Crude fat	% DM	3,90	3,00	4,30	10,20			2,00	0,70	5,47	4,81
	Linoleic Acid	% DM		0,40			0,61			0,10	0,75	0,59
	Linolenic Acid	% DM		0,44			1,19			0,29	2,27	1,30
	Crude ash	% DM	11,80	8,50	8,10	5,60	8,30	5,00	8,00	1,90	14,84	8,77
	NDF	% DM	47,60		49,50	46,20		70,00	62,00			55,06
	ADF	% DM	35,20		35,50	19,50		50,00	34,50			34,94
	Starch	% DM										
	Ca	% DM	2,70	1,98	1,47	1,80		0,39		0,21	1,67	1,67
	P	% DM	0,10	0,25	0,28	0,14		0,22		0,04	0,30	0,21
	Na	% DM	0,04	0,01	0,03	0,11		0,06		0,01	0,04	0,05
	Cl	% DM										
	K	% DM	1,32	1,36	1,74	0,73		0,44		0,55	4,30	1,65
	Mg	% DM	0,42	0,12	0,28	0,23		0,06		0,04	0,30	0,23
EP Input in mg	Co	mg/kg DM	0,20		0,36	0,20						0,25
	Cu	mg/kg DM	10,00	8,00	13,10	10,00		8,25		0,17	13,28	10,44
	I	mg/kg DM										
	Fe	mg/kg DM	91,00	139,00	129,00	94,00		55,00		2,90	226,56	122,43
	Mn	mg/kg DM	24,00	418,00	402,50	83,00		55,00		0,55	43,20	170,95
	Se	mg/kg DM	0,05	0,02	0,07	0,03				0,00	0,07	0,05
	Zn	mg/kg DM	14,00	19,00	34,30	181,00		27,50		0,23	17,97	48,96
	*A	IU/kg DM								365,00	95052,08	
	Beta Carotenes	mg/kg DM	134,00	180,00						2,20	171,88	161,96
	D (calciferol)	IU/kg DM								0,00	0,00	
	E (a-tocopherol)	mg/kg DM								0,70	54,69	
	K (phylloquinone)	mg/kg DM								0,54	42,34	
	Biotin	mg/kg DM										
	B1	mg/kg DM								0,15	11,72	
	B2	mg/kg DM								0,19	14,84	
	B6	mg/kg DM								0,30	23,44	
	B12	mg/kg DM								0,00	0,00	
	Niacin	mg/kg DM								1,80	140,63	
	Pantothenic Acid	mg/kg DM								0,24	18,91	
	Folate	mg/kg DM								0,25	19,14	
	Cholin	mg/kg DM								19,50	1523,44	
	Vit C	mg/kg DM	211,00	169,00				4,00		59,00	4609,38	128,00
	Notes		Crude Fibre: 15,4	Crude Fibre: 19,8 Fatty acid content from lemon tree: http://dx.doi.org/10.1080/10942912.2014.973964	Crude Fibre: 16,3	Extra for average	Fatty acid content from average of nine fruit tree leaves, considering calculated average fat of all browse: http://dx.doi.org/10.1080/10942912.2014.973964		Crude Fibre: 29,3 (Lam, E., Carrer, H., Silva, J. A., Kole, C., Compendium of Bioenergy Plants: Sugarcane (2015). CRC Press			Only averages from 2 or more values presented; Cress Vit C excluded. Knotweed not found.
			http://www.voederbomen.nl/nutritionalvalues/ --> Netherlands Fodder Tree Analysis, accessed 21/04/2016				Corleto A., Cazzato E., Laudadio V. 1994. Quantitative and qualitative evaluation of tree and shrubby pasture species in Southern Italy					

Zootrition
Swiss Database
German Database
US Database
Marcus Clauss, Futterungspraxis in der Haltung von Elchen (Alces alces), Munchen 2000, Doctoral Thesis
Other (See notes)

*Input values in µg RE per 100g EP, conversion to IU (1 IU = 0,3 µg RE)

Averages	NDF	ADF
Leaves	49,6	30,6
Branches	72,1	49,9
Bark	50,5	46,7

Annex 16: Complete Dietary Intake per Individual

Complete Diet per Individual as fed (g) - 14 days		Goma		Quarta		Faddama		Joas		M'Tongé		Zungu	
		Total	**1 day**	**Total**	**1 day**	**Total**	**1 day**	**Total**	**1 day**	**Total**	**1 day**	**Total**	**1 day**
Animal Products	Egg	710	50,7	790	56,4	720	51,4	670	47,9	690	49,3	730	52,1
	Yogurt	381	27,2	381	27,2	405	28,9	405	28,9	405	28,9	405	28,9
	Beef	310	22,1	150	10,7	250	17,9	50	3,6	0	0,0	160	11,4
Pellets	Primate Pellets	1781	127,2	1832	130,8	1941	138,7	1941	138,7	2094	149,6	1890	135,0
	Mixed Pellets	57	4,0	259	18,5	617	44,1	617	44,1	1314	93,9	57	4,0
Seeds and Nuts	Sunflower Seeds	90	6,5	149	10,7	153	10,9	153	10,9	330	23,6	94	6,7
	Pine Nuts	0	0,0	5	0,4	25	1,8	25	1,8	45	3,2	0	0,0
	Almonds	11	0,8	18	1,3	29	2,0	29	2,0	54	3,8	11	0,8
	Hazelnuts	3	0,2	3	0,2	3	0,2	3	0,2	3	0,2	3	0,2
	Peanuts	0	0,0	12	0,8	58	4,1	58	4,1	104	7,4	0	0,0
	Pumpkin Seeds	20	1,4	59	4,2	59	4,2	59	4,2	176	12,5	20	1,4
Browse	Hazel	970	69,3	1746	124,7	1746	124,7	1746	124,7	1746	124,7	1746	124,7
	Linden	220	15,7	396	28,3	396	28,3	396	28,3	396	28,3	396	28,3
	Cherry	8081	577	14546	1039	14546	1039	14546	1039	14546	1039	14546	1039
	Ash	235	16,8	423	30,2	423	30,2	423	30,2	423	30,2	423	30,2
	Cress	130	9,3	234	16,7	234	16,7	234	16,7	234	16,7	234	16,7
	Bamboo	220	15,7	396	28,3	396	28,3	396	28,3	396	28,3	396	28,3
	Knotweed (Japanese)	490	35,0	1357	96,9	3257	232,6	3257	232,6	5157	368,4	882	63,0
	Sugar cane	0	0,0	221	15,8	442	31,6	221	15,8	442	31,6	442	31,6
Leafy Vegetables	Catalogna Lettuce	0	0,0	7620	544,3	6357	454,1	6710	479,3	7083	505,9	9520	680,0
	Endive Lettuce	22046	1575	27288	1949	49078	3506	29948	2139	65469	4676	41176	2941
	Sugarloaf Chicory	2296	164,0	3027	216,2	4872	348,0	3027	216,2	7065	504,6	4141	295,8
	Butterhead Lettuce	272	19,4	815	58,2	815	58,2	815	58,2	2444	174,5	272	19,4
	Red Chicory	1647	117,6	1740	124,3	3143	224,5	1740	124,3	3422	244,4	3050	217,8
	Kohlrabi	548	39,1	613	43,8	673	48,0	583	41,6	1658	118,4	238	17,0
	Cabbage	137	9,8	411	29,4	411	29,4	411	29,4	1233	88,1	137	9,8
Root Vegetables	Fennel	12497	892,6	14761	1054	13561	968,6	14201	1014	20003	1429	14617	1044
	Carrot	7036	502,5	2732	195,1	2732	195,1	2732	195,1	8195	585,3	1661	118,6
	Leek	8855	632,5	5570	397,9	6454	461,0	6635	473,9	5226	373,3	7440	531,4
	Sweet Potato	2122	151,6	1146	81,9	2933	209,5	3013	215,2	5491	392,2	6705	478,9
	Potato	2118	151,3	863	61,6	863	61,6	863	61,6	2588	184,8	1568	112,0

Annex 16 (cont.): Complete Dietary Intake per Individual

Complete Diet per Individual as fed (g) - 14 days		Goma		Quarta		Faddama		Joas		M'Tongé		Zungu	
		Total	**1 day**	**Total**	**1 day**	**Total**	**1 day**	**Total**	**1 day**	**Total**	**1 day**	**Total**	**1 day**
Root Vegetables	Onion	389	27,8	1166	83,3	1166	83,3	1166	83,3	3497	249,8	389	27,8
	Beetroot	3285	234,6	1934	138,1	1934	138,1	1934	138,1	5801	414,3	1035	73,9
	Radish	260	18,6	0	0,0	0	0,0	0	0,0	0	0,0	0	0,0
	Chives	32	2,3	95	6,8	95	6,8	95	6,8	284	20,3	32	2,3
Fruit Vegetables	Cucumber	2550	182,1	3040	217,1	6260	447,1	3370	240,7	6230	445,0	3590	256,4
	Tomato	5770	412,1	5745	410,3	4233	302,3	5513	393,8	5151	367,9	5840	417,1
	Bell Pepper	1121	80,0	1242	88,7	1362	97,3	1342	95,8	1325	94,6	1451	103,6
	Zucchini	109	7,8	326	23,3	326	23,3	326	23,3	977	69,8	109	7,8
	Eggplant	140	10,0	180	12,9	170	12,1	170	12,1	130	9,3	130	9,3
Flower Vegetables	Broccoli	791	56,5	2372	169,4	2372	169,4	2372	169,4	7115	508,2	791	56,5
	Cauliflower	155	11,0	464	33,1	464	33,1	464	33,1	1391	99,3	155	11,0
Stem Vegetables	Celery	1337	95,5	1401	100,1	1401	100,1	1401	100,1	4203	300,2	467	33,4
Fruit	Pear	1689	120,7	1391	99,3	1303	93,1	1363	97,4	1316	94,0	1435	102,5
	Grape	510	36,4	1482	105,8	1564	111,7	1564	111,7	4500	321,4	512	36,6
	Apple	745	53,2	995	71,1	1920	137,1	1920	137,1	3967	283,3	1066	76,1
	Peach	385	27,5	165	11,8	157	11,2	157	11,2	187	13,4	367	26,2
	Litchi	326	23,3	326	23,3	347	24,8	347	24,8	602	43,0	347	24,8
	Melon	205	14,6	391	27,9	510	36,4	540	38,6	764	54,6	460	32,9
	Banana	508	36,3	550	39,3	186	13,3	186	13,3	234	16,7	126	9,0
	Cherry	127	9,0	437	31,2	667	47,6	667	47,6	1656	118,3	127	9,0
	Coconut	0	0,0	96	6,8	478	34,1	478	34,1	860	61,4	0	0,0
	Apricots	140	10,0	110	7,9	120	8,6	110	7,9	540	38,6	130	9,3
	Watermelon	4047	289,1	4018	287,0	5004	357,4	5104	364,5	7162	511,5	3627	259,1
	Pineapple	202	14,4	232	16,5	364	26,0	364	26,0	484	34,6	214	15,3
	Blueberry	53	3,8	159	11,4	159	11,4	159	11,4	477	34,1	53	3,8
	Plum	170	12,1	97	6,9	251	17,9	251	17,9	522	37,3	20	1,4
	Mango	230	16,4	230	16,4	220	15,7	220	15,7	220	15,7	220	15,7
Others	Corn	32	2,3	32	2,3	34	2,4	34	2,4	34	2,4	34	2,4
	Soybean Sprout	135	9,6	405	28,9	405	28,9	405	28,9	1215	86,8	135	9,6
	Rice Wafers	0	0,0	10	0,7	50	3,6	50	3,6	90	6,4	0	0,0
	Oat Flakes	18	1,3	18	1,3	19	1,3	19	1,3	19	1,3	19	1,3
	Dried Liquorice Root	88	6,3	88	6,3	94	6,7	94	6,7	94	6,7	94	6,7
	Corn Leaves	35	2,5	105	7,5	105	7,5	105	7,5	315	22,5	35	2,5
	Cornflake	21	1,5	21	1,5	22	1,6	22	1,6	22	1,6	22	1,6

Annex 17: Complete Metabolizable Energy Calculations

Average	Complete Diet per Individual as fed (g) - 14 days		DM %	ME (kcal/g)	Goma			Quarta			Faddama			Joas			M'tongé			Zungu			All Group		
					Total	Total (DM)	ME	Total	Total (DM)	ME	Total	Total (DM)	ME	Total	Total (DM)	ME	Total	Total (DM)	ME	Total	Total (DM)	ME	Total	Total (DM)	ME
6,10	Animal Products	Egg	25	6,1	710	178	1083	790	198	1205	720	180	1098	670	168	1022	690	173	1052	730	183	1113	3910	978	5963
		Yogurt	15	3,99	381	57	228	381	57	228	405	61	242	405	61	242	405	61	242	405	61	242	1416	212	848
		Beef	26	5,78	310	81	466	150	39	225	250	65	376	50	13	75	0	0	0	160	42	240	680	177	1022
2,85	Pellets	Affen Pellets	90	2,85	1781	1603	4567	1832	1649	4698	1941	1747	4980	1941	1747	4980	2094	1885	5372	1890	1701	4849	17836	16053	45750
		Mixed Pellets	88	3,31	57	50	165	259	228	754	617	543	1797	617	543	1797	1314	1156	3827	57	50	165	8148	7171	23734
6,13	Seeds and Nuts	Sunflower Seeds	93,4	6,02	90	84	508	149	139	839	153	143	861	153	143	861	330	308	1856	94	88	529	3431	3205	19291
		Pine Nuts	94,9	6,68	0	0	0	5	5	32	25	24	158	25	24	158	45	43	285	0	0	0	537	510	3407
		Almonds	95,6	6,16	11	10	62	18	17	106	29	27	168	29	27	168	54	51	315	11	11	65	603	576	3549
		Hazelnuts	96	6,16	3	3	19	3	3	19	3	3	20	3	3	20	3	3	20	3	3	20	54	51	317
		Peanuts	93	5,94	0	0	0	12	11	64	58	53	318	58	53	318	104	96	572	0	0	0	1104	1027	6098
		Pumpkin Seeds	94,8	5,81	20	18	107	59	55	322	59	55	322	59	55	322	176	166	967	20	18	107	1597	1514	8795
2,42	Browse	Hazel	34,3	2,23	970	333	743	1746	599	1337	1746	599	1337	1746	599	1337	1746	599	1337	1746	599	1337	7364	2526	5639
		Linden	30	1,98	220	66	130	396	119	235	396	119	235	396	119	235	396	119	235	396	119	235	1499	450	889
		Cherry	46	2,00	8081	3717	7445	14546	6691	13401	14546	6691	13401	14546	6691	13401	14546	6691	13401	14546	6691	13401	69275	31867	63822
		Ash	27	1,99	235	63	126	423	114	228	423	114	228	423	114	228	423	114	228	423	114	228	1530	413	823
		Cress	12,8	3,02	130	17	50	234	30	90	234	30	90	234	30	90	234	30	90	234	30	90	709	91	274
		Bamboo	36,3	2,99	220	80	239	396	144	430	396	144	430	396	144	430	396	144	430	396	144	430	1939	704	2105
		Knotweed*	12,8	3,02	490	63	189	1357	174	525	3257	417	1259	3257	417	1259	5157	660	1993	882	113	341	12196	1561	4715
		Sugar cane	36,3	2,09	0	0	0	221	80	168	442	160	335	221	80	168	442	160	335	442	160	335	1795	652	1362
2,94	Leafy Vegetables	Catalogna Lettuce	6,34	2,94	0	0	0	7620	483	1420	6357	403	1185	6710	425	1251	7083	449	1320	9520	604	1774	16974	1076	3164
		Endive Lettuce	6,21	2,74	22046	1369	3751	27288	1695	4643	49078	3048	8351	29948	1860	5096	65469	4066	11140	41176	2557	7006	138454	8598	23558
		Sugarloaf Chicory	5,9	2,88	2296	135	390	3027	179	514	4872	287	828	3027	179	514	7065	417	1200	4141	244	704	14388	849	2445
		Butterhead	5	2,94	272	14	40	815	41	120	815	41	120	815	41	120	2444	122	359	272	14	40	3791	190	557
		Red Chicory	5,9	2,88	1647	97	280	1740	103	296	3143	185	534	1740	103	296	3422	202	581	3050	180	518	7962	470	1353
		Kohlrabi	8,9	3	548	49	146	613	55	164	673	60	180	583	52	156	1658	148	443	238	21	63	3025	269	808
		Cabbage	7,8	3,18	137	11	34	411	32	102	411	32	102	411	32	102	1233	96	306	137	11	34	2095	163	520
Bulb	Root Vegetables	Fennel	7,8	3,17	12497	975	3090	14761	1151	3650	13561	1058	3353	14201	1108	3511	20003	1560	4946	14617	1140	3614	44111	3441	10907
3,41		Carrot	12	3,52	7036	844	2972	2732	328	1154	2732	328	1154	2732	328	1154	8195	983	3461	1661	199	701	16068	1928	6787
		Leek	13,9	3,59	8855	1231	4419	5570	774	2779	6454	897	3221	6635	922	3311	5226	726	2608	7440	1034	3713	19465	2706	9713
Tuber		Sweet Potato	22,7	3,87	2122	482	1864	1146	260	1007	2933	666	2577	3013	684	2647	5491	1246	4824	6705	1522	5890	18030	4093	15840
3,81		Potato	22,2	3,75	2118	470	1763	863	191	718	863	191	718	863	191	718	2588	574	2154	1568	348	1305	6862	1523	5712
		Onion	11	3,68	389	43	157	1166	128	472	1166	128	472	1166	128	472	3497	385	1415	389	43	157	6720	739	2720
Root		Beetroot	13,8	3,46	3285	453	1568	1934	267	923	1934	267	923	1934	267	923	5801	800	2770	1035	143	494	11836	1633	5652
3,62		Radish	5,2	3,88	260	14	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Chives	8,7	3,21	32	3	9	95	8	26	95	8	26	95	8	26	284	25	79	32	3	9	495	43	138

Annex 17 (cont.): Complete Metabolizable Energy Calculations

3,28	Fruit Vegetables	Cucumber	4	3,42	2550	102	349	3040	122	416	6260	250	856	3370	135	461	6230	249	852	3590	144	491	14477	579	1980
		Tomato	6,2	3,37	5770	358	1206	5745	356	1200	4233	262	884	5513	342	1152	5151	319	1076	5840	362	1220	12047	747	2517
		Bell Pepper	7,8	3,46	1121	87	302	1242	97	335	1362	106	367	1342	105	362	1325	103	357	1451	113	391	3629	283	979
		Zucchini	5,2	2,89	109	6	16	326	17	49	326	17	49	326	17	49	977	51	147	109	6	16	1520	79	228
		Eggplant	7,3	3,26	140	10	33	180	13	43	170	12	40	170	12	40	130	9	31	130	9	31	393	29	94
3,05	Flower Veg	Broccoli	9	3,01	791	71	214	2372	213	642	2372	213	642	2372	213	642	7115	640	1927	791	71	214	12340	1111	3343
		Cauliflower	8,5	3,09	155	13	41	464	39	122	464	39	122	464	39	122	1391	118	365	155	13	41	2393	203	629
2,99	Stem Veg	Celery	6	2,99	1337	80	240	1401	84	251	1401	84	251	1401	84	251	4203	252	754	467	28	84	6721	403	1206
3,69	Fruit	Pear	16,2	3,64	1689	274	996	1391	225	820	1303	211	768	1363	221	804	1316	213	776	1435	232	846	4617	748	2723
		Grape	19,4	3,65	510	99	361	1482	287	1049	1564	303	1107	1564	303	1107	4500	873	3186	512	99	362	10760	2087	7619
		Apple	16	3,67	745	119	438	995	159	584	1920	307	1127	1920	307	1127	3967	635	2329	1066	171	626	9820	1571	5766
		Peach	13	3,48	385	50	174	165	21	75	157	20	71	157	20	71	187	24	85	367	48	166	569	74	257
		Lichia	20	3,62	326	65	236	326	65	236	347	69	251	347	69	251	602	120	436	347	69	251	1774	355	1284
		Melon	7,5	3,42	205	15	53	391	29	100	510	38	131	540	41	139	764	57	196	460	35	118	1676	126	430
		Banana	25	3,57	508	127	454	550	138	491	186	46	166	186	46	166	234	58	209	126	31	112	872	218	778
		Cherry	19,2	3,74	127	24	91	437	84	314	667	128	479	667	128	479	1656	318	1189	127	24	91	4143	796	2975
		Coconut	55,4	6,68	0	0	0	96	53	353	478	265	1767	478	265	1767	860	476	3181	0	0	0	6549	3628	24237
		Apricots	14	3,52	140	20	69	110	15	54	120	17	59	110	15	54	540	76	266	130	18	64	1019	143	502
		Watermelon	8	3,77	4047	324	1221	4018	321	1212	5004	400	1509	5104	408	1539	7162	573	2160	3627	290	1094	16532	1323	4986
		Pineapple	13,5	1,67	202	27	45	232	31	52	364	49	82	364	49	82	484	65	109	214	29	48	1118	151	252
		Blueberry	17	3,64	53	9	33	159	27	98	159	27	98	159	27	98	477	81	295	53	9	33	1066	181	659
		Plum	16,3	3,72	170	28	103	97	16	59	251	41	152	251	41	152	522	85	317	20	3	12	1286	210	780
		Mango	17	3,55	230	39	139	230	39	139	220	37	133	220	37	133	220	37	133	220	37	133	780	133	471
	Others	Corn	89		32	28	0	32	28	0	34	30	0	34	30	0	34	30	0	34	30	0	129	114	0
		Soybean Sprout	31	3,94	135	42	165	405	126	495	405	126	495	405	126	495	1215	377	1484	135	42	165	3766	1167	4600
		Rice Wafers	94,2	4,11	0	0	0	10	9	39	50	47	194	50	47	194	90	85	348	0	0	0	729	687	2823
		Oat Flakes	93,5	2,63	18	16	43	18	16	43	19	17	46	19	17	46	19	17	46	19	17	46	164	154	404
		Liquorice Root			88	0	0	88	0	0	94	0	0	94	0	0	94	0	0	94	0	0	187	0	0
		Corn Leaves			35	0	0	105	0	0	105	0	0	105	0	0	315	0	0	35	0	0	420	0	0
		Cornflake	97,4	3,83	21	20	78	21	20	78	22	22	82	22	22	82	22	22	82	22	22	82	252	246	941
Kcal/14 days:					43762			52244			63328			59273			92502			56489			361742		
Kcal/day:					3126			3732			4523			4234			6607			4035			25839		

*No values, copied from Cress

Average per animal:	4306

ME - Primate (Zootrition)	Average from Category	ME - Horse (Zootrition)	From product label	Calculated

Annex 18: Browse Metabolizable Energy Calculations

Source

NRC Horses 2007 and

Kinzle, E., Zeiner, A., 2010. The development of a metabolizable energy system for horses, Journal of Animal Physiology and Animal Nutrition 94

Equations		
1	DE (Mj/Kg) =	8,86 + 0,05097 %CP - 0,0392 %ADF - 0,0160 (%NDF - %ADF) + 0,197 %Fat + 0,085 (100 - %CP - %NDF - %Fat - %Ash) - 0,110 %Ash
	ME (Mj/Kg) =	DE – 0.008 CP (g/Kg) – 0.002 CF (g/Kg)
2	ME (Mj/Kg) =	(-)3,54 + 0,0129 CP (g/kg) + 0,042 Fat (g/kg) - 0,0019 DF (g/kg) + 0,0185 ((DM - (CP - Ash - Fat - CF))*10)
1 Mj/Kg = 0.2386635 Kcal/g		

										Equation 1			Equation 2	
	%	%	g/Kg	%	%	%	%	%	g/Kg	(Mj/Kg)	(Mj/Kg)	(Kcal/g)	(Mj/Kg)	(Kcal/g)
	DM	CP	CP	NDF	ADF	Crude Fat	Crude Ash	CF	CF	DE	ME	ME	ME	ME
Linden	35	23,7	237	49,60	30,60	3	8,5	19,8	198	9,512	7,220	1,72	8,28	1,98
Cherry	40,7	10,5	105	49,60	30,60	1	8,3	17,2	171,7	9,777	8,593	2,05	8,39	2,00
Ash	32	20,1	201	47,6	35,2	3,9	11,8	15,4	154	9,188	7,272	1,74	8,35	1,99
Hazel	37,3	14,5	145	49,5	35,5	4,3	8,1	16,3	163	9,946	8,460	2,02	9,35	2,23
Bamboo	50	3,2	32	70	50	2	5	29,3	293	8,270	7,428	1,77	12,53	2,99
Sugar cane	26,7	3,5	35	62	34,5	2	8	29,3	293	8,842	7,976	1,90	8,76	2,09
Notes	Averages of NDF and ADF for trees come from Marcus Clauss, 2000 (see Browse Nutrient Ratios). For Bamboo, values taken from Sugar Cane. For CF and DM, averages taken only from trees and not grasses (bamboo and sugar cane)													

CP - Crude Protein
CF - Crude Fibre

Legend
Zootrition
Marcus Clauss, Futterungspraxis in der Haltung von Elchen (Alces alces), Munchen 2000, Doctoral Thesis
Average from Category
Others (see Nutrient Ratios tables)

Annex 19: M'Tongé's Complete Nutritional Analysis

Percentage each element contributes to diet		Animal Products	Primate Pellets	Mixed Pellets	Seeds/Nuts	Fruit	Stem Veg	Flower Veg	Fruit Veg	Leafy Veg	Bulb Veg	Root Veg	Tuber Veg	Browse	Sum	Concentration Requirements	Diff
		0,75	**6,15**	**3,86**	**2,23**	**14,59**	**0,79**	**2,47**	**2,97**	**19,42**	**8,96**	**4,64**	**7,02**	**26,15**	**100,00**		
DM	%	0,15	5,41	3,40	2,10	2,72	0,04	0,21	0,19	1,28	0,83	0,46	1,83	8,78	27,40	-	
ME	kcal/g	0,04	0,18	0,13	0,14	0,54	0,02	0,08	0,10	0,57	0,31	0,17	0,27	0,00	2,53	-	
Crude protein	% DM	0,29	1,32	0,66	0,56	0,66	0,13	0,76	0,50	4,20	1,73	0,46	0,52	4,11	15,89	15,00	0,89
Crude fat	% DM	0,25	0,29	0,29	1,27	0,88	0,01	0,10	0,11	0,63	0,35	0,14	0,08	1,26	5,67		5,67
Linoleic Acid	% DM	0,02	0,14	0,18	0,57	0,07	0,01	0,01	0,03	0,16	0,11	0,02	0,02	0,15	1,50	2,00	-0,50
Linolenic Acid	% DM	0,00	0,03	0,00	0,03	0,03	0,00	0,03	0,02	0,17	0,11	0,02	0,01	0,34	0,81	0,50	0,31
Crude ash	% DM	0,04	0,56	0,21	0,04	0,46	0,04	0,17	0,29	2,85	0,86	0,37	0,38	2,29	8,56		8,56
NDF	% DM	0,00	2,21	0,83	0,11	2,09	0,11	0,42	0,53	3,32	0,68	0,55	0,97	14,40	26,22	10,00	16,22
ADF	% DM	0,00	1,35	0,44	0,35	1,25	0,11	0,35	0,43	2,66	0,61	0,36	0,26	9,14	17,30	5,00	12,30
Starch	% DM	0,00	1,06	0,88	0,09	0,19	0,00	0,06	0,06	0,13	0,68	0,03	4,20	0,00	7,37		7,37
Ca	% DM	0,00	0,06	0,03	0,00	0,01	0,01	0,02	0,01	0,13	0,05	0,01	0,00	0,44	0,75	1,00	-0,25
P	% DM	0,01	0,03	0,02	0,01	0,02	0,00	0,02	0,01	0,10	0,04	0,01	0,01	0,06	0,33	0,80	-0,47
Na	% DM	0,00	0,03	0,00	0,00	0,00	0,02	0,00	0,00	0,04	0,01	0,01	0,00	0,01	0,13	0,20	-0,07
Cl	% DM	0,01	0,03	0,00	0,00	0,01	0,02	0,01	0,02	0,14	0,04	0,03	0,01	0,00	0,33	0,20	0,13
K	% DM	0,01	0,09	0,03	0,02	0,18	0,04	0,10	0,10	0,72	0,29	0,14	0,11	0,43	2,25	0,40	1,85
Mg	% DM	0,00	0,02	0,01	0,01	0,01	0,00	0,01	0,01	0,04	0,02	0,01	0,01	0,06	0,19	0,08	0,11
Co	mg/kg DM	0,00	0,00	0,00	0,00	0,59	0,00	0,00	0,01	0,04	0,00	0,01	0,00	0,07	0,73		0,73
Cu	mg/kg DM	0,01	1,61	0,44	0,27	0,78	0,11	0,14	0,27	1,62	0,56	0,28	0,30	2,73	9,11	20,00	-10,89
I	mg/kg DM	0,01	0,11	0,01	0,00	0,02	0,00	0,02	0,01	0,07	0,05	0,01	0,01	0,00	0,32	0,35	-0,03
Fe	mg/kg DM	0,28	6,99	5,27	1,33	3,76	0,70	2,62	1,80	20,26	8,03	3,67	1,42	32,01	88,14	100,00	-11,86
Mn	mg/kg DM	0,01	4,82	0,97	0,92	3,54	5,89	0,90	0,53	5,68	2,21	0,76	0,52	44,70	71,45	20,00	51,45
Se	mg/kg DM	0,00	0,05	0,01	0,00	1,52	0,00	0,00	0,01	0,03	0,01	0,01	0,00	0,01	1,65	0,30	1,35
Zn	mg/kg DM	0,33	8,39	1,32	1,36	1,15	0,14	1,12	0,73	7,39	3,26	1,19	0,93	12,80	40,11	100,00	-59,89
A	IU/kg DM	135,41	1538,06	8,78	6,33	910,96	224,48	203,61	760,79	9843,57	2048,32	3795,11	2700,59	0,00	22175,99	8000,00	14175,99
Beta Carotenes	mg/kg DM	0,01	0,00	0,00	0,02	5,68	0,80	0,73	2,35	34,33	7,29	11,30	9,02	42,35	113,86		113,86
D (calciferol)	IU/kg DM	18,55	132,83	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	151,38	2500,00	-2348,62
E (a-tocopherol)	mg/kg DM	0,29	20,97	0,26	3,77	4,71	2,53	0,91	2,70	28,59	3,58	0,68	0,38	0,00	69,38	45,00	24,38
K (phylloquinone)	mg/kg DM	0,00	0,63	0,00	0,00	0,64	0,02	0,29	0,04	4,21	1,27	0,02	0,01	0,00	7,13	0,50	6,63
Biotin	mg/kg DM	0,00	0,04	0,00	0,01	0,35	0,00	0,00	0,01	0,09	0,02	0,02	0,01	0,00	0,57	0,20	0,37
B1	mg/kg DM	0,05	3,85	0,08	0,19	0,39	0,07	0,27	0,20	1,84	0,72	0,25	0,27	0,00	8,18	3,00	5,18
B2	mg/kg DM	0,10	2,38	0,07	0,06	0,34	0,06	0,29	0,15	2,00	0,48	0,24	0,14	0,00	6,30	4,00	2,30
B6	mg/kg DM	0,04	1,75	0,07	0,11	0,74	0,10	0,56	0,51	1,94	1,50	0,49	0,85	0,00	8,66	4,00	4,66
B12	mg/kg DM	0,13	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,14	0,03	0,11
Niacin	mg/kg DM	0,03	9,44	0,83	1,06	3,91	0,56	2,24	2,57	15,92	5,36	2,01	2,66	0,00	46,59	25,00	21,59
Pantothenic Acid	mg/kg DM	0,29	6,78	0,21	0,20	1,66	0,56	2,26	1,16	9,74	1,79	0,73	1,57	0,00	26,96	12,00	14,96
Folate	mg/kg DM	0,01	0,70	0,01	0,03	0,23	0,03	0,27	0,12	1,86	0,76	0,28	0,06	0,00	4,37	4,00	0,37
Cholin	mg/kg DM	45,42	139,82	48,88	12,34	52,35	8,56	92,37	34,16	349,93	86,09	38,66	33,98	0,00	942,57	750,00	192,57
Vit C	mg/kg DM	0,52	17,48	0,00	0,34	136,16	11,22	229,93	158,70	595,11	234,08	89,65	62,24	33,47	1568,90	200,00	1368,90

Annex 20: Zungu's Complete Nutritional Analysis

Percentage each element contributes to diet		Animal Products	Primate Pellets	Mixed Pellets	Seeds/Nuts	Fruit	Stem Veg	Flower Veg	Fruit Veg	Leafy Veg	Bulb Veg	Root Veg	Tuber Veg	Browse	Sum	Concentration Requirements	Diff
		1,37	**8,62**	**0,26**	**0,62**	**8,40**	**0,14**	**0,43**	**3,71**	**19,97**	**10,78**	**1,39**	**11,17**	**33,16**	**100,00**		
DM	%	0,28	7,59	0,22	0,59	1,56	0,01	0,04	0,24	1,31	1,00	0,14	2,91	11,13	27,01	-	
ME	kcal/g	0,07	0,25	0,01	0,04	0,31	0,00	0,01	0,12	0,59	0,37	0,05	0,43	0,00	2,24	-	
Crude protein	% DM	0,53	1,85	0,04	0,16	0,38	0,02	0,13	0,63	4,31	2,08	0,14	0,82	5,22	16,31	15,00	1,31
Crude fat	% DM	0,47	0,40	0,02	0,36	0,51	0,00	0,02	0,13	0,65	0,42	0,04	0,14	1,60	4,75		4,75
Linoleic Acid	% DM	0,04	0,20	0,01	0,16	0,04	0,00	0,00	0,04	0,16	0,14	0,01	0,03	0,19	1,03	2,00	-0,97
Linolenic Acid	% DM	0,00	0,05	0,00	0,01	0,02	0,00	0,01	0,03	0,18	0,14	0,01	0,01	0,43	0,87	0,50	0,37
Crude ash	% DM	0,07	0,78	0,01	0,01	0,27	0,01	0,03	0,36	2,93	1,04	0,11	0,60	2,91	9,13		9,13
NDF	% DM	0,00	3,10	0,06	0,03	1,20	0,02	0,07	0,66	3,41	0,82	0,16	1,54	18,26	29,33	10,00	19,33
ADF	% DM	0,00	1,89	0,03	0,10	0,72	0,02	0,06	0,53	2,73	0,73	0,11	0,41	11,59	18,92	5,00	13,92
Starch	% DM	0,00	1,48	0,06	0,02	0,11	0,00	0,01	0,07	0,14	0,82	0,01	6,69	0,00	9,40		9,40
Ca	% DM	0,01	0,08	0,00	0,00	0,01	0,00	0,00	0,01	0,13	0,06	0,00	0,01	0,55	0,85	1,00	-0,15
P	% DM	0,01	0,04	0,00	0,00	0,01	0,00	0,00	0,01	0,10	0,05	0,00	0,02	0,07	0,33	0,80	-0,47
Na	% DM	0,01	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,04	0,01	0,00	0,00	0,02	0,13	0,20	-0,07
Cl	% DM	0,01	0,05	0,00	0,00	0,01	0,00	0,00	0,02	0,15	0,04	0,01	0,02	0,00	0,32	0,20	0,12
K	% DM	0,01	0,13	0,00	0,00	0,10	0,01	0,02	0,12	0,74	0,35	0,04	0,17	0,55	2,24	0,40	1,84
Mg	% DM	0,00	0,03	0,00	0,00	0,01	0,00	0,00	0,01	0,04	0,02	0,00	0,01	0,08	0,20	0,08	0,12
Co	mg/kg DM	0,00	0,00	0,00	0,00	0,34	0,00	0,00	0,01	0,04	0,00	0,00	0,00	0,08	0,49		0,49
Cu	mg/kg DM	0,02	2,25	0,03	0,08	0,45	0,02	0,02	0,34	1,66	0,67	0,08	0,47	3,46	9,56	20,00	-10,44
I	mg/kg DM	0,02	0,16	0,00	0,00	0,01	0,00	0,00	0,01	0,07	0,06	0,00	0,01	0,00	0,35	0,35	0,00
Fe	mg/kg DM	0,51	9,80	0,35	0,37	2,16	0,12	0,45	2,25	20,83	9,66	1,10	2,25	40,60	90,45	100,00	-9,55
Mn	mg/kg DM	0,02	6,76	0,06	0,26	2,04	1,02	0,15	0,66	5,84	2,66	0,23	0,82	56,69	77,21	20,00	57,21
Se	mg/kg DM	0,00	0,07	0,00	0,00	0,87	0,00	0,00	0,01	0,03	0,01	0,00	0,01	0,02	1,03	0,30	0,73
Zn	mg/kg DM	0,61	11,75	0,09	0,38	0,66	0,02	0,19	0,91	7,60	3,92	0,35	1,48	16,24	44,22	100,00	-55,78
A	IU/kg DM	248,64	2154,96	0,58	1,77	524,01	38,72	35,13	950,94	10122,67	2464,15	1134,68	4293,66	0,00	21969,91	8000,00	13969,91
Beta Carotenes	mg/kg DM	0,01	0,00	0,00	0,00	3,27	0,14	0,13	2,94	35,30	8,77	3,38	14,34	53,71	121,97		121,97
D (calciferol)	IU/kg DM	34,05	186,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	220,16	2500,00	-2279,84
E (a-tocopherol)	mg/kg DM	0,54	29,39	0,02	1,05	2,71	0,44	0,16	3,38	29,40	4,31	0,20	0,61	0,00	72,19	45,00	27,19
K (phylloquinone)	mg/kg DM	0,00	0,88	0,00	0,00	0,37	0,00	0,05	0,05	4,33	1,53	0,01	0,01	0,00	7,23	0,50	6,73
Biotin	mg/kg DM	0,01	0,06	0,00	0,00	0,20	0,00	0,00	0,02	0,10	0,03	0,01	0,01	0,00	0,43	0,20	0,23
B1	mg/kg DM	0,09	5,39	0,01	0,05	0,23	0,01	0,05	0,25	1,90	0,87	0,08	0,43	0,00	9,34	3,00	6,34
B2	mg/kg DM	0,19	3,33	0,00	0,02	0,19	0,01	0,05	0,19	2,06	0,57	0,07	0,22	0,00	6,91	4,00	2,91
B6	mg/kg DM	0,07	2,45	0,00	0,03	0,43	0,02	0,10	0,64	2,00	1,80	0,15	1,35	0,00	9,04	4,00	5,04
B12	mg/kg DM	0,24	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,03	0,22
Niacin	mg/kg DM	0,05	13,22	0,06	0,30	2,25	0,10	0,39	3,21	16,37	6,45	0,60	4,23	0,00	47,23	25,00	22,23
Pantothenic Acid	mg/kg DM	0,53	9,50	0,01	0,06	0,96	0,10	0,39	1,45	10,02	2,15	0,22	2,50	0,00	27,88	12,00	15,88
Folate	mg/kg DM	0,02	0,98	0,00	0,01	0,14	0,00	0,05	0,15	1,92	0,91	0,09	0,10	0,00	4,36	4,00	0,36
Cholin	mg/kg DM	83,41	195,91	3,23	3,45	30,11	1,48	15,94	42,70	359,85	103,57	11,56	54,02	0,00	905,22	750,00	155,22
Vit C	mg/kg DM	0,95	24,49	0,00	0,09	78,33	1,94	39,67	198,37	611,98	281,60	26,80	98,96	42,45	1405,62	200,00	1205,62

Annex 21: Goma’s Complete Nutritional Analysis

Percentage each element contributes to diet		Animal Products	Primate Pellets	Mixed Pellets	Seeds/Nuts	Fruit	Stem Veg	Flower Veg	Fruit Veg	Leafy Veg	Bulb Veg	Root Veg	Tuber Veg	Browse	Sum	Concentration Requirements	Diff
		2,05	**11,23**	**0,35**	**0,83**	**12,46**	**0,54**	**0,59**	**4,47**	**12,71**	**14,43**	**7,53**	**7,92**	**24,89**	**100,00**		
DM	%	0,42	9,88	0,31	0,78	2,32	0,03	0,05	0,29	0,84	1,34	0,75	2,06	8,35	27,42	-	
ME	kcal/g	0,10	0,32	0,01	0,05	0,46	0,02	0,02	0,15	0,37	0,49	0,27	0,30	0,00	2,57	-	
Crude protein	% DM	0,80	2,41	0,06	0,21	0,56	0,09	0,18	0,76	2,75	2,79	0,75	0,58	3,91	15,84	15,00	0,84
Crude fat	% DM	0,70	0,52	0,03	0,47	0,75	0,01	0,02	0,16	0,41	0,57	0,23	0,10	1,20	5,17		5,17
Linoleic Acid	% DM	0,07	0,26	0,02	0,21	0,06	0,01	0,00	0,05	0,10	0,18	0,04	0,02	0,15	1,16	2,00	-0,84
Linolenic Acid	% DM	0,00	0,06	0,00	0,01	0,03	0,00	0,01	0,03	0,11	0,18	0,03	0,01	0,32	0,80	0,50	0,30
Crude ash	% DM	0,11	1,02	0,02	0,02	0,40	0,03	0,04	0,43	1,86	1,39	0,59	0,42	2,18	8,52		8,52
NDF	% DM	0,00	4,03	0,08	0,04	1,78	0,08	0,10	0,80	2,17	1,10	0,89	1,09	13,70	25,86	10,00	15,86
ADF	% DM	0,00	2,46	0,04	0,13	1,06	0,08	0,08	0,64	1,74	0,98	0,58	0,29	8,70	16,79	5,00	11,79
Starch	% DM	0,00	1,93	0,08	0,03	0,16	0,00	0,01	0,08	0,09	1,09	0,05	4,74	0,00	8,27		8,27
Ca	% DM	0,01	0,10	0,00	0,00	0,01	0,00	0,00	0,01	0,08	0,07	0,02	0,00	0,42	0,74	1,00	-0,26
P	% DM	0,02	0,05	0,00	0,01	0,01	0,00	0,00	0,02	0,07	0,06	0,02	0,01	0,05	0,33	0,80	-0,47
Na	% DM	0,01	0,05	0,00	0,00	0,00	0,01	0,00	0,00	0,03	0,01	0,02	0,00	0,01	0,15	0,20	-0,05
Cl	% DM	0,02	0,06	0,00	0,00	0,01	0,01	0,00	0,02	0,09	0,06	0,05	0,02	0,00	0,35	0,20	0,15
K	% DM	0,02	0,17	0,00	0,01	0,15	0,03	0,02	0,15	0,47	0,47	0,23	0,12	0,41	2,24	0,40	1,84
Mg	% DM	0,00	0,04	0,00	0,00	0,01	0,00	0,00	0,01	0,03	0,03	0,01	0,01	0,06	0,19	0,08	0,11
Co	mg/kg DM	0,00	0,01	0,00	0,00	0,51	0,00	0,00	0,01	0,02	0,01	0,01	0,00	0,06	0,63		0,63
Cu	mg/kg DM	0,03	2,94	0,04	0,10	0,67	0,07	0,03	0,41	1,06	0,90	0,45	0,33	2,60	9,63	20,00	-10,37
I	mg/kg DM	0,02	0,20	0,00	0,00	0,02	0,00	0,00	0,01	0,04	0,08	0,01	0,01	0,00	0,41	0,35	0,06
Fe	mg/kg DM	0,77	12,76	0,48	0,50	3,21	0,48	0,63	2,71	13,26	12,94	5,97	1,60	30,47	85,76	100,00	-14,24
Mn	mg/kg DM	0,03	8,81	0,09	0,34	3,02	4,02	0,21	0,79	3,72	3,57	1,24	0,58	42,54	68,97	20,00	48,97
Se	mg/kg DM	0,01	0,09	0,00	0,00	1,30	0,00	0,00	0,01	0,02	0,01	0,01	0,01	0,01	1,47	0,30	1,17
Zn	mg/kg DM	0,91	15,32	0,12	0,51	0,99	0,10	0,27	1,10	4,84	5,26	1,93	1,05	12,18	44,55	100,00	-55,45
A	IU/kg DM	372,03	2807,88	0,80	2,36	777,44	153,32	48,58	1145,92	6444,09	3300,76	6160,11	3042,94	0,00	24256,22	8000,00	16256,22
Beta Carotenes	mg/kg DM	0,01	0,00	0,00	0,01	4,85	0,55	0,17	3,54	22,47	11,74	18,34	10,16	40,31	112,14		112,14
D (calciferol)	IU/kg DM	50,96	242,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	293,45	2500,00	-2206,55
E (a-tocopherol)	mg/kg DM	0,80	38,29	0,02	1,41	4,02	1,72	0,22	4,07	18,71	5,78	1,10	0,43	0,00	76,58	45,00	31,58
K (phylloquinone)	mg/kg DM	0,00	1,15	0,00	0,00	0,54	0,01	0,07	0,07	2,75	2,05	0,04	0,01	0,00	6,69	0,50	6,19
Biotin	mg/kg DM	0,01	0,08	0,00	0,00	0,30	0,00	0,00	0,02	0,06	0,04	0,03	0,01	0,00	0,55	0,20	0,35
B1	mg/kg DM	0,13	7,02	0,01	0,07	0,33	0,05	0,06	0,30	1,21	1,16	0,41	0,31	0,00	11,06	3,00	8,06
B2	mg/kg DM	0,29	4,34	0,01	0,02	0,29	0,04	0,07	0,23	1,31	0,77	0,38	0,16	0,00	7,90	4,00	3,90
B6	mg/kg DM	0,10	3,19	0,01	0,04	0,63	0,07	0,13	0,78	1,27	2,42	0,80	0,96	0,00	10,40	4,00	6,40
B12	mg/kg DM	0,36	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,37	0,03	0,34
Niacin	mg/kg DM	0,08	17,23	0,08	0,39	3,33	0,38	0,54	3,87	10,42	8,65	3,26	3,00	0,00	51,23	25,00	26,23
Pantothenic Acid	mg/kg DM	0,80	12,38	0,02	0,08	1,42	0,38	0,54	1,75	6,38	2,88	1,18	1,77	0,00	29,57	12,00	17,57
Folate	mg/kg DM	0,03	1,28	0,00	0,01	0,20	0,02	0,07	0,18	1,22	1,22	0,46	0,07	0,00	4,76	4,00	0,76
Cholin	mg/kg DM	124,80	255,26	4,47	4,60	44,68	5,85	22,04	51,45	229,08	138,73	62,76	38,29	0,00	982,00	750,00	232,00
Vit C	mg/kg DM	1,42	31,91	0,00	0,13	116,21	7,67	54,85	239,04	389,59	377,20	145,52	70,13	31,86	1465,52	200,00	1265,52

Annex 22: Quarta's Complete Nutritional Analysis

Percentage each element contributes to diet		Animal Products **1,54**	Primate Pellets **9,19**	Mixed Pellets **1,30**	Seeds/Nuts **1,32**	Fruit **11,34**	Stem Veg **0,45**	Flower Veg **1,41**	Fruit Veg **3,87**	Leafy Veg **15,59**	Bulb Veg **11,39**	Root Veg **2,64**	Tuber Veg **2,98**	Browse **36,99**	Sum **100,00**	Concentration Requirements	Diff
DM	%	0,31	8,09	1,14	1,24	2,11	0,03	0,12	0,25	1,03	1,05	0,26	0,78	12,41	28,82	-	
ME	kcal/g	0,08	0,26	0,04	0,08	0,42	0,01	0,04	0,13	0,46	0,39	0,10	0,11	0,00	2,12	-	
Crude protein	% DM	0,60	1,97	0,22	0,33	0,51	0,07	0,44	0,65	3,37	2,20	0,26	0,22	5,82	16,66	15,00	1,66
Crude fat	% DM	0,52	0,43	0,10	0,75	0,68	0,01	0,06	0,14	0,50	0,45	0,08	0,04	1,78	5,54		5,54
Linoleic Acid	% DM	0,05	0,21	0,06	0,33	0,05	0,01	0,01	0,04	0,13	0,15	0,01	0,01	0,22	1,27	2,00	-0,73
Linolenic Acid	% DM	0,00	0,05	0,00	0,02	0,02	0,00	0,02	0,03	0,14	0,14	0,01	0,00	0,48	0,92	0,50	0,42
Crude ash	% DM	0,08	0,84	0,07	0,03	0,36	0,02	0,10	0,38	2,28	1,10	0,21	0,16	3,24	8,87		8,87
NDF	% DM	0,00	3,30	0,28	0,07	1,62	0,06	0,24	0,69	2,66	0,87	0,31	0,41	20,36	30,88	10,00	20,88
ADF	% DM	0,00	2,02	0,15	0,21	0,97	0,06	0,20	0,55	2,13	0,77	0,20	0,11	12,92	20,31	5,00	15,31
Starch	% DM	0,00	1,58	0,30	0,05	0,15	0,00	0,03	0,07	0,11	0,86	0,02	1,79	0,00	4,95		4,95
Ca	% DM	0,01	0,08	0,01	0,00	0,01	0,00	0,01	0,01	0,10	0,06	0,01	0,00	0,62	0,92	1,00	-0,08
P	% DM	0,01	0,04	0,01	0,01	0,01	0,00	0,01	0,01	0,08	0,05	0,01	0,01	0,08	0,33	0,80	-0,47
Na	% DM	0,01	0,04	0,00	0,00	0,00	0,01	0,00	0,00	0,03	0,01	0,01	0,00	0,02	0,13	0,20	-0,07
Cl	% DM	0,01	0,05	0,00	0,00	0,01	0,01	0,01	0,02	0,12	0,05	0,02	0,01	0,00	0,30	0,20	0,10
K	% DM	0,01	0,14	0,01	0,01	0,14	0,02	0,06	0,13	0,57	0,37	0,08	0,05	0,61	2,19	0,40	1,79
Mg	% DM	0,00	0,03	0,00	0,00	0,01	0,00	0,00	0,01	0,03	0,02	0,00	0,00	0,09	0,21	0,08	0,13
Co	mg/kg DM	0,00	0,00	0,00	0,00	0,46	0,00	0,00	0,01	0,03	0,00	0,00	0,00	0,09	0,61		0,61
Cu	mg/kg DM	0,02	2,40	0,15	0,16	0,61	0,06	0,08	0,36	1,30	0,71	0,16	0,13	3,86	9,99	20,00	-10,01
I	mg/kg DM	0,02	0,17	0,00	0,00	0,02	0,00	0,01	0,01	0,05	0,06	0,00	0,00	0,00	0,36	0,35	0,01
Fe	mg/kg DM	0,58	10,45	1,77	0,79	2,92	0,40	1,49	2,34	16,26	10,21	2,09	0,60	45,28	95,18	100,00	-4,82
Mn	mg/kg DM	0,02	7,21	0,33	0,54	2,75	3,36	0,51	0,69	4,56	2,81	0,43	0,22	63,23	86,66	20,00	66,66
Se	mg/kg DM	0,00	0,07	0,00	0,00	1,18	0,00	0,00	0,01	0,03	0,01	0,00	0,00	0,02	1,33	0,30	1,03
Zn	mg/kg DM	0,68	12,53	0,44	0,80	0,90	0,08	0,64	0,95	5,93	4,15	0,68	0,40	18,11	46,29	100,00	-53,71
A	IU/kg DM	279,19	2298,01	2,95	3,74	707,62	127,86	115,98	991,33	7901,71	2605,19	2161,75	1147,36	0,00	18342,70	8000,00	10342,70
Beta Carotenes	mg/kg DM	0,01	0,00	0,00	0,01	4,41	0,46	0,42	3,06	27,56	9,27	6,43	3,83	59,90	115,36		115,36
D (calciferol)	IU/kg DM	38,24	198,46	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	236,70	2500,00	-2263,30
E (a-tocopherol)	mg/kg DM	0,60	31,34	0,09	2,22	3,66	1,44	0,52	3,52	22,95	4,56	0,39	0,16	0,00	71,44	45,00	26,44
K (phylloquinone)	mg/kg DM	0,00	0,94	0,00	0,00	0,50	0,01	0,17	0,06	3,38	1,62	0,01	0,00	0,00	6,68	0,50	6,18
Biotin	mg/kg DM	0,01	0,06	0,00	0,01	0,27	0,00	0,00	0,02	0,08	0,03	0,01	0,00	0,00	0,49	0,20	0,29
B1	mg/kg DM	0,10	5,75	0,03	0,11	0,30	0,04	0,15	0,26	1,48	0,92	0,15	0,12	0,00	9,40	3,00	6,40
B2	mg/kg DM	0,22	3,55	0,02	0,03	0,26	0,03	0,17	0,20	1,61	0,60	0,13	0,06	0,00	6,89	4,00	2,89
B6	mg/kg DM	0,08	2,61	0,02	0,06	0,58	0,06	0,32	0,67	1,56	1,91	0,28	0,36	0,00	8,50	4,00	4,50
B12	mg/kg DM	0,27	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,28	0,03	0,25
Niacin	mg/kg DM	0,06	14,10	0,28	0,62	3,03	0,32	1,28	3,35	12,78	6,82	1,14	1,13	0,00	44,92	25,00	19,92
Pantothenic Acid	mg/kg DM	0,60	10,13	0,07	0,12	1,29	0,32	1,29	1,51	7,82	2,27	0,42	0,67	0,00	26,51	12,00	14,51
Folate	mg/kg DM	0,02	1,04	0,00	0,02	0,18	0,01	0,16	0,16	1,50	0,97	0,16	0,03	0,00	4,25	4,00	0,25
Cholin	mg/kg DM	93,66	208,91	16,46	7,28	40,67	4,87	52,62	44,51	280,89	109,49	22,02	14,44	0,00	895,82	750,00	145,82
Vit C	mg/kg DM	1,07	26,11	0,00	0,20	105,77	6,39	130,97	206,79	477,71	297,71	51,07	26,44	47,34	1377,58	200,00	1177,58

Annex 23: Faddama's Complete Nutritional Analysis

Percentage each element contributes to diet		Animal Products	Primate Pellets	Mixed Pellets	Seeds/Nuts	Fruit	Stem Veg	Flower Veg	Fruit Veg	Leafy Veg	Bulb Veg	Root Veg	Tuber Veg	Browse	Sum	Concentration Requirements	Diff
		1,31	**8,01**	**2,55**	**1,44**	**11,55**	**0,37**	**1,16**	**3,73**	**20,16**	**9,22**	**2,17**	**4,63**	**33,71**	**100,00**		
DM	%	0,27	7,05	2,24	1,35	2,15	0,02	0,10	0,24	1,33	0,85	0,22	1,21	11,32	28,33	-	
ME	kcal/g	0,07	0,23	0,08	0,09	0,43	0,01	0,04	0,12	0,59	0,31	0,08	0,18	0,00	2,23	-	
Crude protein	% DM	0,51	1,72	0,43	0,36	0,52	0,06	0,36	0,63	4,35	1,78	0,22	0,34	5,30	16,58	15,00	1,58
Crude fat	% DM	0,45	0,37	0,19	0,82	0,70	0,01	0,05	0,13	0,65	0,36	0,07	0,06	1,62	5,48		5,48
Linoleic Acid	% DM	0,04	0,18	0,12	0,36	0,05	0,00	0,00	0,04	0,16	0,12	0,01	0,01	0,20	1,31	2,00	-0,69
Linolenic Acid	% DM	0,00	0,04	0,00	0,02	0,02	0,00	0,02	0,03	0,18	0,12	0,01	0,00	0,44	0,89	0,50	0,39
Crude ash	% DM	0,07	0,73	0,14	0,03	0,37	0,02	0,08	0,36	2,95	0,89	0,17	0,25	2,96	9,01		9,01
NDF	% DM	0,00	2,87	0,55	0,07	1,65	0,05	0,20	0,67	3,44	0,70	0,26	0,64	18,56	29,67	10,00	19,67
ADF	% DM	0,00	1,76	0,29	0,23	0,99	0,05	0,17	0,53	2,76	0,63	0,17	0,17	11,78	19,52	5,00	14,52
Starch	% DM	0,00	1,37	0,58	0,06	0,15	0,00	0,03	0,07	0,14	0,70	0,01	2,77	0,00	5,88		5,88
Ca	% DM	0,01	0,07	0,02	0,00	0,01	0,00	0,01	0,01	0,13	0,05	0,01	0,00	0,56	0,88	1,00	-0,12
P	% DM	0,01	0,04	0,01	0,01	0,01	0,00	0,01	0,01	0,10	0,04	0,01	0,01	0,07	0,33	0,80	-0,47
Na	% DM	0,01	0,04	0,00	0,00	0,00	0,01	0,00	0,00	0,04	0,01	0,01	0,00	0,02	0,13	0,20	-0,07
Cl	% DM	0,01	0,05	0,00	0,00	0,01	0,01	0,01	0,02	0,15	0,04	0,01	0,01	0,00	0,32	0,20	0,12
K	% DM	0,01	0,12	0,02	0,01	0,14	0,02	0,05	0,12	0,74	0,30	0,07	0,07	0,56	2,22	0,40	1,82
Mg	% DM	0,00	0,03	0,00	0,00	0,01	0,00	0,00	0,01	0,04	0,02	0,00	0,00	0,08	0,20	0,08	0,12
Co	mg/kg DM	0,00	0,00	0,00	0,00	0,47	0,00	0,00	0,01	0,04	0,00	0,00	0,00	0,09	0,62		0,62
Cu	mg/kg DM	0,02	2,09	0,29	0,18	0,62	0,05	0,07	0,34	1,68	0,57	0,13	0,19	3,52	9,75	20,00	-10,25
I	mg/kg DM	0,02	0,15	0,01	0,00	0,02	0,00	0,01	0,01	0,07	0,05	0,00	0,01	0,00	0,34	0,35	-0,01
Fe	mg/kg DM	0,49	9,10	3,47	0,86	2,97	0,33	1,23	2,26	21,02	8,26	1,72	0,93	41,28	93,92	100,00	-6,08
Mn	mg/kg DM	0,02	6,28	0,64	0,59	2,80	2,76	0,42	0,66	5,90	2,28	0,36	0,34	57,63	80,67	20,00	60,67
Se	mg/kg DM	0,00	0,06	0,00	0,00	1,20	0,00	0,00	0,01	0,03	0,01	0,00	0,00	0,02	1,35	0,30	1,05
Zn	mg/kg DM	0,58	10,92	0,87	0,87	0,91	0,07	0,52	0,91	7,67	3,36	0,56	0,62	16,51	44,37	100,00	-55,63
A	IU/kg DM	238,66	2001,55	5,79	4,07	721,18	105,03	95,27	954,82	10216,75	2108,55	1775,63	1780,92	0,00	20008,22	8000,00	12008,22
Beta Carotenes	mg/kg DM	0,01	0,00	0,00	0,01	4,50	0,37	0,34	2,95	35,63	7,50	5,29	5,95	54,60	117,15		117,15
D (calciferol)	IU/kg DM	32,69	172,86	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	205,55	2500,00	-2294,45
E (a-tocopherol)	mg/kg DM	0,52	27,29	0,17	2,43	3,73	1,18	0,43	3,39	29,67	3,69	0,32	0,25	0,00	73,07	45,00	28,07
K (phylloquinone)	mg/kg DM	0,00	0,82	0,00	0,00	0,50	0,01	0,14	0,05	4,37	1,31	0,01	0,00	0,00	7,21	0,50	6,71
Biotin	mg/kg DM	0,01	0,05	0,00	0,01	0,28	0,00	0,00	0,02	0,10	0,02	0,01	0,00	0,00	0,50	0,20	0,30
B1	mg/kg DM	0,08	5,00	0,05	0,12	0,31	0,03	0,13	0,25	1,91	0,74	0,12	0,18	0,00	8,93	3,00	5,93
B2	mg/kg DM	0,19	3,09	0,05	0,04	0,27	0,03	0,14	0,19	2,08	0,49	0,11	0,09	0,00	6,75	4,00	2,75
B6	mg/kg DM	0,07	2,27	0,05	0,07	0,59	0,05	0,26	0,65	2,01	1,54	0,23	0,56	0,00	8,35	4,00	4,35
B12	mg/kg DM	0,23	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,24	0,03	0,21
Niacin	mg/kg DM	0,05	12,28	0,55	0,68	3,09	0,26	1,05	3,22	16,53	5,52	0,94	1,76	0,00	45,93	25,00	20,93
Pantothenic Acid	mg/kg DM	0,51	8,83	0,14	0,13	1,31	0,26	1,06	1,46	10,11	1,84	0,34	1,04	0,00	27,03	12,00	15,03
Folate	mg/kg DM	0,02	0,91	0,01	0,02	0,19	0,01	0,13	0,15	1,93	0,78	0,13	0,04	0,00	4,32	4,00	0,32
Cholin	mg/kg DM	80,06	181,96	32,22	7,94	41,44	4,00	43,22	42,87	363,19	88,62	18,09	22,41	0,00	926,04	750,00	176,04
Vit C	mg/kg DM	0,91	22,74	0,00	0,22	107,80	5,25	107,58	199,18	617,67	240,96	41,95	41,05	43,15	1428,45	200,00	1228,45

Annex 24: Joa's Complete Nutritional Analysis

Percentage each element contributes to diet		Animal Products	Primate Pellets	Mixed Pellets	Seeds/Nuts	Fruit	Stem Veg	Flower Veg	Fruit Veg	Leafy Veg	Bulb Veg	Root Veg	Tuber Veg	Browse	Sum	Concentration Requirements	Diff
		1,16	**8,64**	**2,75**	**1,55**	**12,63**	**0,40**	**1,25**	**3,49**	**14,38**	**10,33**	**2,34**	**5,10**	**35,99**	**100,00**		
DM	%	0,24	7,60	2,42	1,46	2,35	0,02	0,11	0,22	0,95	0,96	0,23	1,33	12,08	29,96	-	
ME	kcal/g	0,06	0,25	0,09	0,10	0,47	0,01	0,04	0,11	0,42	0,35	0,08	0,19	0,00	2,18	-	
Crude protein	% DM	0,45	1,85	0,47	0,39	0,57	0,06	0,39	0,59	3,11	1,99	0,23	0,37	5,66	16,14	15,00	1,14
Crude fat	% DM	0,40	0,40	0,21	0,88	0,76	0,01	0,05	0,13	0,46	0,41	0,07	0,06	1,73	5,57		5,57
Linoleic Acid	% DM	0,04	0,20	0,13	0,39	0,06	0,01	0,00	0,04	0,12	0,13	0,01	0,01	0,21	1,35	2,00	-0,65
Linolenic Acid	% DM	0,00	0,05	0,00	0,02	0,03	0,00	0,02	0,02	0,13	0,13	0,01	0,00	0,47	0,89	0,50	0,39
Crude ash	% DM	0,06	0,79	0,15	0,03	0,40	0,02	0,09	0,34	2,11	1,00	0,18	0,27	3,16	8,59		8,59
NDF	% DM	0,00	3,10	0,59	0,08	1,81	0,06	0,21	0,62	2,46	0,79	0,28	0,70	19,82	30,51	10,00	20,51
ADF	% DM	0,00	1,89	0,31	0,24	1,08	0,06	0,18	0,50	1,97	0,70	0,18	0,19	12,57	19,88	5,00	14,88
Starch	% DM	0,00	1,48	0,62	0,06	0,17	0,00	0,03	0,07	0,10	0,78	0,01	3,05	0,00	6,38		6,38
Ca	% DM	0,01	0,08	0,02	0,00	0,01	0,00	0,01	0,01	0,09	0,05	0,01	0,00	0,60	0,89	1,00	-0,11
P	% DM	0,01	0,04	0,01	0,01	0,01	0,00	0,01	0,01	0,07	0,05	0,01	0,01	0,08	0,32	0,80	-0,48
Na	% DM	0,01	0,04	0,00	0,00	0,00	0,01	0,00	0,00	0,03	0,01	0,01	0,00	0,02	0,12	0,20	-0,08
Cl	% DM	0,01	0,05	0,00	0,00	0,01	0,01	0,01	0,02	0,11	0,04	0,02	0,01	0,00	0,28	0,20	0,08
K	% DM	0,01	0,13	0,02	0,01	0,16	0,02	0,05	0,11	0,53	0,33	0,07	0,08	0,59	2,12	0,40	1,72
Mg	% DM	0,00	0,03	0,00	0,00	0,01	0,00	0,00	0,01	0,03	0,02	0,00	0,00	0,08	0,20	0,08	0,12
Co	mg/kg DM	0,00	0,00	0,00	0,00	0,51	0,00	0,00	0,01	0,03	0,00	0,00	0,00	0,09	0,66		0,66
Cu	mg/kg DM	0,02	2,26	0,31	0,19	0,68	0,05	0,07	0,32	1,20	0,64	0,14	0,21	3,76	9,85	20,00	-10,15
I	mg/kg DM	0,01	0,16	0,01	0,00	0,02	0,00	0,01	0,01	0,05	0,06	0,00	0,01	0,00	0,34	0,35	-0,01
Fe	mg/kg DM	0,44	9,81	3,74	0,93	3,25	0,35	1,32	2,11	15,00	9,26	1,85	1,03	44,06	93,17	100,00	-6,83
Mn	mg/kg DM	0,02	6,77	0,69	0,64	3,07	2,97	0,45	0,62	4,21	2,55	0,38	0,37	61,53	84,27	20,00	64,27
Se	mg/kg DM	0,00	0,07	0,00	0,00	1,31	0,00	0,00	0,01	0,02	0,01	0,00	0,00	0,02	1,46	0,30	1,16
Zn	mg/kg DM	0,51	11,78	0,94	0,94	1,00	0,07	0,57	0,86	5,47	3,76	0,60	0,68	17,62	44,79	100,00	-55,21
A	IU/kg DM	210,62	2158,92	6,24	4,39	788,45	113,28	102,76	893,96	7290,68	2362,09	1915,23	1961,43	0,00	17808,05	8000,00	9808,05
Beta Carotenes	mg/kg DM	0,01	0,00	0,00	0,01	4,91	0,40	0,37	2,76	25,43	8,40	5,70	6,55	58,29	112,84		112,84
D (calciferol)	IU/kg DM	28,85	186,45	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	215,30	2500,00	-2284,70
E (a-tocopherol)	mg/kg DM	0,46	29,44	0,19	2,62	4,08	1,27	0,46	3,17	21,17	4,13	0,34	0,28	0,00	67,61	45,00	22,61
K (phylloquinone)	mg/kg DM	0,00	0,88	0,00	0,00	0,55	0,01	0,15	0,05	3,12	1,47	0,01	0,00	0,00	6,24	0,50	5,74
Biotin	mg/kg DM	0,01	0,06	0,00	0,01	0,30	0,00	0,00	0,02	0,07	0,03	0,01	0,00	0,00	0,51	0,20	0,31
B1	mg/kg DM	0,07	5,40	0,06	0,13	0,34	0,04	0,14	0,23	1,37	0,83	0,13	0,20	0,00	8,93	3,00	5,93
B2	mg/kg DM	0,16	3,34	0,05	0,04	0,29	0,03	0,15	0,18	1,48	0,55	0,12	0,10	0,00	6,49	4,00	2,49
B6	mg/kg DM	0,06	2,45	0,05	0,07	0,64	0,05	0,28	0,60	1,44	1,73	0,25	0,62	0,00	8,25	4,00	4,25
B12	mg/kg DM	0,20	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,21	0,03	0,18
Niacin	mg/kg DM	0,05	13,25	0,59	0,73	3,38	0,28	1,13	3,02	11,79	6,19	1,01	1,93	0,00	43,36	25,00	18,36
Pantothenic Acid	mg/kg DM	0,45	9,52	0,15	0,14	1,44	0,28	1,14	1,36	7,21	2,06	0,37	1,14	0,00	25,27	12,00	13,27
Folate	mg/kg DM	0,02	0,98	0,01	0,02	0,20	0,01	0,14	0,14	1,38	0,88	0,14	0,04	0,00	3,96	4,00	-0,04
Cholin	mg/kg DM	70,65	196,27	34,76	8,56	45,31	4,32	46,62	40,14	259,17	99,28	19,51	24,68	0,00	849,27	750,00	99,27
Vit C	mg/kg DM	0,81	24,53	0,00	0,23	117,85	5,66	116,03	186,48	440,77	269,93	45,24	45,21	46,07	1298,82	200,00	1098,82