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Comparative feeding ecology of two chimpanzee communities in Kibale National Park, Uganda

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Abstract

Several recent studies have documented considerable intraspecific and intrapopulation ecological variation in primates. However, we generally lack an understanding of how such variability may be linked to concomitant demographic variation among groups and/or populations of the same species, particularly in regards to large-bodied and wide-ranging species with high ecological flexibility, such as chimpanzees (*Pan troglodytes*). We compared the feeding ecology of chimpanzees inhabiting two sites in Kibale National Park, Uganda that differ three-fold in chimpanzee density and support notably different plant communities. Chimpanzees at Ngogo, a site with the largest known chimpanzee community and unusually high chimpanzee density, spent a significantly lower percentage of time resting (and pregnant and lactating females spent more time feeding), incorporated higher percentages of ripe fruit in their diet, had lower dietary diversity values, and had shorter and less variable average patch residency times than did their counterparts at the nearby Kanyawara site, which supports a relatively low density of chimpanzees. Additionally, feeding party size was significantly and positively related to feeding patch size at Ngogo, but not at Kanyawara. Together these findings aid in explaining the noted disparity in chimpanzee community size and density between Ngogo and Kanyawara by suggesting that the diet of Ngogo chimpanzees is of higher overall quality than that of Kanyawara chimpanzees. They also highlight the potentially profound influence of even small-scale habitat heterogeneity on the ecology of primates. Researchers must take such influences into account when attempting to draw conclusions about species- or population-level characteristics.

Key words: feeding ecology, foraging efficiency, chimpanzee, population density

Introduction

Recent studies of feeding ecology in primates have documented considerable intraspecific dietary variation in several species (e.g., *Gorilla gorilla beringei*: Watts 1996; *Procolobus tephrosceles*: Chapman and Chapman 1999; *Cercopithecus* spp.: Glenn and Cords 2002; *Colobus guereza*: Harris and Chapman 2007). Despite the increased awareness of ecological variability at the species level (Strier 2009), we generally lack sufficient information on how variation in diet and habitat use within species is tied to intraspecific differences in group size and gregariousness. Based on the limited data that are available, it is clear that noteworthy variation in diet and habitat use in primates exists not only between populations of the same species, but also among social groups of the same population (e.g., *Colobus guereza* [Harris and Chapman 2007] and *Cercopithecus mitis* [Butynski 1990] in Kibale National Park, Uganda; *Gorilla beringei beringei* in Bwindi National Park, Uganda [Ganas et al. 2004], *Hapalemur griseus* in Ranomafana National Park, Madagascar [Grassi 2006]), particularly in highly heterogeneous environments (e.g., *Lemur catta* in Beza Mahafaly, Madagascar [Yamashita 2002]). While data indicate that chimpanzee (*Pan troglodytes*) feeding ecology and habitat use vary considerably across populations (e.g., Gombe: Wrangham 1977; Lopé: Tutin et al. 1991; Bossou: Yamakoshi 1998; Budongo: Newton-Fisher 1999; Kibale: Wrangham 2000; Kahuzi-Biega: Basabose 2002), few comparative data exist regarding the extent of diversity within populations, and how such diversity may be tied to differences among communities in size and density. Our goal in this study was to compare the feeding ecology of two well-habituated study communities in Kibale National Park, Uganda to assess intraspecific ecological diversity in chimpanzees on a finer scale than is generally possible, and examine how ecological variability between these communities may be tied to noted disparities in chimpanzee density between the sites (see below).

The two well-habituated chimpanzee study communities in Kibale National Park (Ngogo and Kanyawara) differ dramatically in overall size, density, and composition. The Ngogo community is the largest ever known (with approximately 155 individuals; Watts 1998, Mitani and Watts 1999, Watts and Mitani

2002). In contrast, the much smaller community at Kanyawara, located 10 kilometers from Ngogo in the same forest, has an overall size (approximately 45-50 individuals) and demographic composition comparable to the average for many study sites (Wrangham et al. 1992; Muller 2002). Kibale is composed of a mosaic of habitats that vary both within and between sites in vegetation composition, canopy structure, elevation, and human impact (Wing and Buss 1970, Chapman et al. 1997, Struhsaker 1997, Lwanga et al. 2000). Extensive botanical analyses conducted at both sites indicate that the spatiotemporal availability of key classes of food resources is notably higher at Ngogo than at Kanyawara (Chapman et al. 1997, Potts et al. 2009). Previous research on the feeding ecology of the Kanyawara community (e.g., Isabirye-Basuta 1987, 1988; Conklin-Brittain et al. 1998; Wrangham et al. 1998), more limited analysis on the ecology of the Ngogo community (e.g., Ghiglieri 1984, Mitani et al. 2002), and general comparisons of the dietary profiles of the two communities (Wrangham et al. 1991), combined with the botanical differences noted above, suggest that the Kibale population provides a unique opportunity to address the extent to which chimpanzee ecology may vary over small spatial scales.

Based on the botanical evidence of a higher-quality resource base at Ngogo compared to Kanyawara (Chapman et al. 1997, Potts et al. 2009), combined with the markedly higher density of chimpanzees at Ngogo, we hypothesize that the diet of chimpanzees at Ngogo is of overall higher quality than is that of Kanyawara chimpanzees. We present data here on the activity budgets, diets, food patch characteristics and patterns of patch use, and feeding party sizes from both Kanyawara and Ngogo collected during overlapping time periods as qualitative indicators of dietary quality and foraging efficiency in these communities. We specifically predict that Ngogo chimpanzees: 1) incorporate a higher percentage of ripe fruit in their diet, 2) spend less time feeding and more time resting, 3) have lower dietary diversity values, and 3) remain in feeding patches for shorter periods than Kanyawara chimpanzees. We also predict that the relationship between feeding party size and feeding patch size is more strongly positive at Ngogo than at Kanyawara. Elsewhere (Potts et al., in prep) we present data on quantitative measures of foraging efficiency in the same

two communities, incorporating values of food wet weights, ingestion rates, and energetic costs associated with travel between feeding sites. Also, see Potts (2008) for discussion of the differences between these sites in other variables not directly related to feeding ecology (e.g., anthropogenic disturbance, predation, disease risk), and how they might be impacting density differences between the two communities.

Methods

Study communities

Isabirye-Basuta (1988) was the first to intensively study the chimpanzees at Kanyawara between 1983 and 1985. Wrangham and colleagues began to habituate the community in the late 1980s and early 1990s, and now conduct all-day follows of focal chimpanzees (though prior to August 2009 all-day follows were focused on parties rather than individuals; Wrangham et al. 1991, 1996, 1998; Conklin-Brittain et al. 1998; Emery-Thompson et al. 2007; Muller et al. 2007). Community size at Kanyawara has varied between 39 and 52 since the onset of habituation. The community had 11 adult males, one adolescent male, 15 adult females, three nulliparous females, eight juveniles, and 13 infants during our study (Potts 2008). The density of chimpanzees at Kanyawara was approximately 1.4 individuals/km².

Ghiglieri (1984) conducted the first study of the chimpanzee community at Ngogo in the late 1970s and early 1980s. Wrangham et al. (1991) briefly studied chimpanzees there in the late 1980s and 1990, and B. Grieser-Johns worked on habituation of the community in the early 1990s. However, intensive research and habituation at Ngogo (by D.P. Watts and J.C. Mitani) did not commence until 1995. The community has been continuously observed since (Watts 1998; Mitani and Watts 1999, 2005; Watts and Mitani 2001; Watts et al. 2006). It is the largest ever observed, with over 150 members. At the time of this study, 23-26 adult males, 15 adolescent males, at least 44 adult females, 15 adolescent females, 17 juveniles, and 34 infants resided within the community. The density of chimpanzees at Ngogo was approximately 5.1 individuals/km².

We conducted this study over 19 months, from June 2005 to December 2006, but we were only able to conduct simultaneous data collection on both communities between January and June 2006 (hereafter referred

to as the “overlap” period). In all, we observed Ngogo chimpanzees between June 2005 and June 2006 and Kanyawara chimpanzees between January and December 2006. The data we present here came from 1,059 and 961 hours of focal animal sampling at Ngogo and Kanyawara, respectively. Detailed ecological overviews of Kibale and of both the study sites can be found in Wing and Buss 1970, Ghiglieri 1984, Butynski 1990, Struhsaker 1997, Chapman and Lambert 2000, Lwanga et al. 2000, and Potts 2008.

Data collection

KBP or a trained field assistant conducted focal follows of individual chimpanzees at both sites. KBP collected all of the focal data from Ngogo, while a single field assistant following an identical sampling protocol collected the majority of the data on chimpanzees at Kanyawara. Following a period of intensive training in the data collection protocol, KBP occasionally followed chimpanzees at Kanyawara with this assistant and collected data on the same focal chimpanzees at the same time to ensure inter-observer reliability.

The length of each focal follow varied, but ideally lasted for one full feeding bout and one full travel bout between consecutive feeding patches (i.e., we observed the animal enter a feeding patch, forage and ingest [and/or chew] food items within it, leave the patch, travel to a new patch and enter it. We then designated a new individual to follow, and began focal observation of the individual as soon as it began its next feeding bout). We chose the first adult or adolescent chimpanzee encountered in the morning as our first focal individual of the day, and subsequently rotated focal effort among individuals present in the party. We occasionally left a party to find others if we completed focal follows on all members of the current party, but usually remained with the same party of chimpanzees throughout the day.

During each focal follow, we continuously recorded the behavioral state of the focal animal as either “feeding/foraging” (defined as ingestion and/or chewing of plant or animal matter uninterrupted by other behaviors for at least one minute), “traveling” (defined as sustained movements [longer than one minute],

generally occurring outside of feeding patches and involving movement between successive patches), “resting” (defined as any sustained period in which neither feeding nor traveling occurred [this included time spent grooming]), “hunting” (defined as in Mitani and Watts 1999), or “border patrolling” (as in Goodall 1986 and Watts and Mitani 2001). To make between-site comparisons of activity budgets, we used data pooled across all individuals at each site and also compared data on adult males, on cycling females, and on pregnant and lactating females separately.

We defined “feeding bout length” as the total amount of time that the focal individual fed in a given patch. We defined a “patch” as an aggregation of food items that allowed uninterrupted feeding or foraging movements by individuals or parties (c.f., Chapman et al. 1994). Generally, this was a single tree or large sapling, but it also included multiple adjacent stems of terrestrial vegetation and, for species growing in dense groves (e.g., *Uvariopsis congensis* or *Teclea nobilis*), multiple adjacent trees when their crowns overlapped sufficiently to allow direct tree-to-tree travel. We indexed the size of a feeding patch as its diameter at breast height (DBH), in the case of single trees, or as the sum total of the DBH of each tree used within a single grove. For strangler figs, we visually assessed the diameter of the fig stem just above the point at which the stem branched from its host tree (the presumed germination point). We did not assess patch size in the case of patches consisting of terrestrial herbaceous vegetation.

With the aid of field assistants, we noted the number and age/sex class of all independently traveling chimpanzees present in the same party as the focal individual on first encounter. We then assessed party membership continuously, considering individuals to have joined the party when we first noted their presence and to have left if they had not been seen in over one hour. Assessing party membership over this time scale reduced the possibility of omitting animals that were present in the party but temporarily (<1 hour) out of view (Chapman et al. 1993). We also recorded the location of the focal individual at each feeding and resting site using known crossings of the trail grid system or, if the individual was not within the trail system, using a GPS unit. We often searched for individuals of particular age/sex classes that might otherwise have been

under-represented in sampling (e.g., adult females often forage in small, inconspicuous parties and tend to be more difficult to locate than adult males, who are often in large parties).

This methodology allowed for straightforward assessment and between-site comparisons of monthly activity budgets (the total percentage of time each month individuals devoted to feeding, resting, traveling, hunting, or border patrolling), diet composition and diversity, food patch size, feeding party size (the maximum number of independently-feeding chimpanzees, including the focal individual, co-feeding in a given patch during a particular feeding bout), and patch occupancy times. To assess feeding patch productivity, we multiplied the DBH of the feeding tree by the phenology score for the patch (indexed as 0-4, with 0 indicating no fruit in the crown and 4 indicating maximum fruit concentration within the crown). To ensure precision in the assignment of phenology scores to feeding patches, only one of us (KBP) assigned scores at Ngogo, while the same field assistant conducting behavioral sampling at Kanyawara assigned scores to feeding patches there. KBP conducted extensive inter-observer reliability tests with this field assistant and randomly spot-checked scored feeding patches to ensure that assignment of phenology scores was consistent between sites. We used the Shannon-Wiener diversity index ($H' = -\sum[P_i \log P_i]$, where P_i is the proportion of species “i” in the sample area) to estimate dietary diversity (Pielou 1974), and Hill’s index ($J' = H'/x$, where “x” is the total number of species sampled) to estimate dietary evenness (Hill 1973, Pielou 1974). Larger H' values indicate higher diversity, with a minimum score of zero. J' ranges from zero to one, with a score of one indicating maximum equitability of feeding time among all items included in the diet.

Data analysis

We used parametric procedures whenever possible and used ln-transformed values (or arcsine transformed values for percentages) when the data did not meet the assumptions of parametric statistics. For most comparisons of feeding ecology variables between the sites, we used independent samples t-tests; we used Mann-Whitney U tests if the data could not be transformed to meet the assumptions of a t-test. For specific comparisons of monthly values during the overlap period, we assessed differences between the sites

using paired samples t-tests or, when necessary, Wilcoxon signed rank tests. We assessed the differences between the sites in coefficients of variation (CV) using Levene's test for equality of variance (Sokal and Braumann 1980, Schultz 1985). Significance was set at $\alpha = 0.05$ for all tests.

Results

Diet

Chimpanzees at Ngogo devoted proportionally more of their feeding time to ripe fruit than did chimpanzees at Kanyawara (80.5% versus 64.4%; Mann-Whitney U based on monthly averages: $N_{\text{Ngogo}} = 11$, $N_{\text{Kanyawara}} = 12$, $U = 35.0$, $P = 0.05$; Figure 1a). Of the time spent feeding on ripe fruit, 70.6% and 46.6% was spent feeding on figs at Kanyawara and Ngogo, respectively. Kanyawara chimpanzees ate relatively more pith and stems of terrestrial vegetation ($K = 17.4\%$, $N = 1.0\%$ of total feeding time; $U = 11.5$, $P = 0.001$), whereas Ngogo chimpanzees ate more unripe fruit ($K = 2.0\%$, $N = 11.7\%$ of feeding time; $U = 24.0$, $P = 0.009$). These differences were apparent during both the overlap and non-overlap periods (Figure 1b).

Ngogo and Kanyawara chimpanzees shared only eight items among those that were the top 20 dietary items for each community (40%; Tables 1 and 2), and only four out of the top ten. These eight common items made up 25.4% of the diet at Ngogo and 51.87% of the diet at Kanyawara. There was no difference between the communities in the proportion of feeding time devoted to these common species (paired samples t-test; $t = -1.311$, $N = 8$, $P = 0.231$) or to the top 20 items considered together (Mann-Whitney U test; $U = 229.0$, $N = 20$, $P = 0.441$). In total, 40% (24/60) of all items included in the diet of Ngogo chimpanzees were also included in the Kanyawara chimpanzee diet, whereas 37.5% (24/64) of items eaten by Kanyawara chimpanzees were also eaten by Ngogo chimpanzees. Furthermore, of the 12 food items included in the top 20 at Ngogo that were not common to the top 20 at Kanyawara, ten (83%) were from species that are locally absent from or rare at Kanyawara (defined as fewer than three stems appearing in botanical plot sampling summarized in Potts 2008). Thus much of the inter-site difference in diet composition was apparently due to

heterogeneity in floral composition within Kibale. Conversely, none of the top 20 items at Kanyawara were from species that are absent from or rare at Ngogo.

Diet diversity was low at both sites (Shannon-Wiener diversity index [H']; Ngogo: monthly mean = 1.553, Kanyawara: monthly mean = 1.781). The average monthly equitability index (J') was 0.58 (range: 0.36 – 0.74) and 0.70 (range: 0.51 – 0.86) at Ngogo and Kanyawara, respectively. Over the entire study period, monthly dietary diversity did not differ between Ngogo and Kanyawara (independent samples t-test; $N_{\text{Kanyawara}} = 12$, $N_{\text{Ngogo}} = 11$, $t_{1,21} = 1.253$, $P = 0.224$). However, during the overlap period, dietary diversity at Kanyawara (mean = 2.003) was higher than at Ngogo (mean = 1.330; $t = -6.998$, $N = 4$, $P = 0.002$). Monthly variation in dietary diversity was similar at Kanyawara ($CV = 0.275$) and Ngogo ($CV = 0.237$; $F = 0.699$, $P = 0.413$). The top 20 items in the diet accounted for 91.5% and 89.1% of all feeding time at Ngogo and Kanyawara, respectively.

Activity budgets

Pooling data for all individuals revealed that the activity budgets of chimpanzees at the two sites were roughly similar (Figure 2). The primary difference between the two communities was that chimpanzees at Kanyawara devoted a relatively large proportion of time to resting, at the expense of feeding, traveling, and energetically costly hunting and border patrolling. This was the only significant difference between the sites (monthly means: Ngogo = 34.0%, Kanyawara = 44.8%; independent samples t-test, $t = -3.511$, $N_{\text{Ngogo}} = 12$, $N_{\text{Kanyawara}} = 12$, $P = 0.002$; all other $P > 0.05$).

Differences between the two communities were more apparent when males and females were considered separately (Figure 3). Ngogo and Kanyawara cycling females and males had broadly similar activity budgets (though males at Kanyawara spent more time resting). However, the activity budgets of pregnant/lactating females diverged considerably between the sites. Those at Ngogo devoted more time to feeding and less time to resting than did those at Kanyawara (Figure 3).

Food patch characteristics and patch use

Chimpanzees at Kanyawara and Ngogo used food patches of roughly the same size (66.87 vs. 63.38 cm DBH, respectively; independent samples t-test: $t = 1.209$, $P = 0.102$). However, at both sites over 20% of food patches used by chimpanzees were of growth forms other than trees (Table 3), and thus the size of the patch could not be meaningfully assessed or quantified by the measure used here.

Chimpanzees at Kanyawara occupied feeding patches (including both arboreal [trees and figs] and terrestrial patches) for longer periods than Ngogo chimpanzees (46.2 vs. 27.0 minutes/patch/visit; MWU test, $Z = -9.188$, $N_{\text{Ngogo}} = 348$, $N_{\text{Kanyawara}} = 317$; $P < 0.001$). Patch occupancy times also varied less at Kanyawara ($CV = 0.94$) than at Ngogo ($CV = 1.32$; $F = 6.24$, $P = 0.013$). After controlling for the number of individuals co-feeding in the patch, focal chimpanzees at Kanyawara fed longer than those at Ngogo in patches of the same species and similar productivity (tree/fig size x phenology score) in four out of seven cases (Table 4). In no case was mean patch residency longer at Ngogo, suggesting that *per capita* patch exploitation levels were more intense at Kanyawara than at Ngogo.

Feeding party size

On average, feeding party size (FPS) was higher at Kanyawara ($x = 8.39$, range = 1-32) than at Ngogo ($x = 7.29$, range = 1-40; MWU, $Z = -4.680$, $P < 0.001$). There was no difference in the variability in FPS among feeding bouts between the two sites (CV in FPS; Kanyawara = 0.836, Ngogo = 1.01; $F = 0.010$, $P = 0.920$).

At Ngogo, FPS was positively related to the size (DBH) of the food patch, which explained 80% of the variance in FPS (simple linear regression with ln-transformed data, $R^2 = 0.801$, $P < 0.001$). The relationship between these variables was similar, but far weaker, at Kanyawara, where DBH explained only 22.7% of the variance in FPS ($R^2 = 0.227$, $P < 0.001$; Figure 4).

Discussion

Dietary quality

The most frequently consumed dietary items at Ngogo and Kanyawara overlapped relatively little. This is at first surprising, especially considering the close proximity of the sites, but most of the important items in the Ngogo diet that were not also among the most important items in the Kanyawara diet were from species absent or locally rare at Kanyawara. This contrast highlights the potentially profound influence of habitat heterogeneity at this scale on the ecology of primate populations (Watts 1984, Butynski 1990, Kool 1993, Chapman and Chapman 1999, Ganas et al. 2004, Harris and Chapman 2007).

Perhaps related to this inter-site floristic heterogeneity, the proportion of ripe fruit in the diet (a putative indicator of dietary quality for frugivores; Wrangham et al. 1998) was higher at Ngogo than at Kanyawara, whereas the Kanyawara chimpanzee diet included a higher percentage of young leaves and pith. Additionally, all of the top ten, and 18 of the top 20, most important items in the Ngogo diet were fruit (including unripe fruit of *Pterygota mildbraedii*), whereas at Kanyawara, only six of the top ten, and 11 of the top 20, were fruit. Finally, figs accounted for a considerably higher proportion of the ripe fruit component of the diet at Kanyawara than at Ngogo. The water-soluble carbohydrate concentrations in figs are generally lower than in similarly sized non-fig ripe fruits eaten by Kibale chimpanzees (Conklin and Wrangham 1994), and large-bodied frugivores typically prefer non-fig drupes over figs (Leighton 1993, Wrangham et al. 1996; though figs often provide a balanced supply of different macronutrients, Felton et al. 2009a). Thus the Ngogo chimpanzee diet apparently included a higher proportion of readily-digestible sugars than the Kanyawara diet. However, it is also noteworthy that the most common item in the Ngogo diet was ripe figs of *Ficus mucoso*, a species important in promoting large parties due to its unusually large crown (Potts 2008). Also, it is clear that equating the percentage of ripe fruit in the diet with dietary quality is an oversimplification (see Raubenheimer et al. 2009). The nutritional goal of omnivores is to achieve a balanced intake of necessary macronutrients (proteins, lipids, carbohydrates, etc.), rather than to necessarily maximize the intake of any

single food type (Felton et al. 2009b). By this rationale, ripe fruit alone may not adequately index diet quality, as it is assumed that only through the incorporation of other food types (e.g., leaves and pith) are chimpanzees able to maintain macronutrient balance. However, to some extent this simplification is warranted in the case of chimpanzees in Kibale. For example, intake of lipids and carbohydrates by Kanyawara chimpanzees positively correlates with ripe fruit abundance (Conklin-Brittain et al. 1998), and fruit mesocarp eaten by chimpanzees at Ngogo appears to be unusually high in protein concentration (Hohmann et al. 2010, Watts et al, in prep). Kibale chimpanzees may therefore achieve macronutrient balancing primarily through a fruit-based diet (as shown in spider monkeys [*Ateles chamek*] feeding on figs; Felton et al. 2009a). We nonetheless acknowledge that using dietary ripe fruit component as primary proxy of dietary quality is largely based on energy optimization principles (Emlen 1966) that are beginning to fall out of favor with nutritional ecologists (Felton et al. 2009b, Raubenheimer et al. 2009).

Dietary diversity

At all sites where they have been intensively studied, chimpanzees show high preference and selectivity for a small number of foods (Wrangham et al. 1996, Newton-Fisher 1999), and both Ngogo and Kanyawara conform to this pattern. In fact, the dietary diversity of Kibale chimpanzees is relatively low compared to that of some populations of other large-bodied ripe fruit specialists with similar dietary niches (e.g., *Lagothrix lagotricha poeppigii* in Yasuni National Park, Ecuador: Di Fiore 2004). For example, monthly dietary diversity (H') indices ranged from 1.8 to 3.6 and 1.9 to 3.0 for gibbons (*Hylobates muelleri x agilis*) in Kalimantan (McConkey et al. 2003) and mangabeys (*Lophocebus albigena*) in Cameroon (Poulsen et al. 2001), respectively. However, dietary diversity at Ngogo and Kanyawara was similar to that of other frugivorous great ape populations, including populations of chimpanzees (Budongo: Newton-Fisher 1999; Kahuzi-Biega, DRC: Basabose 2002; Goualougo Triangle, Republic of Congo: Morgan and Sanz 2006; Gashaka, Nigeria: Hohmann et al. 2006), bonobos (*P. paniscus* - Lomako, DRC: Badrian et al. 1981, White 1998; Wamba, DRC: Kano and Mulavwa 1984; LuiKotal, Salonga, DRC: Hohmann et al. 2006), western

lowland gorillas (*Gorilla gorilla gorilla* - Lopé Reserve, Gabon: Rogers et al. 1990, Williamson et al. 1990, Tutin and Fernandez 1993a; Bai Hokou, Central African Republic: Masi 2007), and orangutans (*Pongo* spp. - Kutai National Park, East Kalimantan, Borneo: Rodman 1977, Leighton 1993; Tanjung Puting, Central Kalimantan: Galdikas 1988).

The higher dietary diversity and equitability indices at Kanyawara than at Ngogo (particularly during the overlap period) have numerous potential explanations. Low diversity diets could result from a relative lack of available high-quality resources (Simmen et al. 2003). In a species-poor environment, few alternative dietary options may be available for frugivores, and thus dietary diversity would be low. Alternatively, diversity could be low in situations in which high-quality resources are abundant (Terborgh 1983, Isabirye-Basuta 1988, Poulsen et al. 2001, Murray et al. 2006). If widespread and abundant crops of a small number of species are available, there might be little need for frugivores to maintain a high diversity diet. This is in accordance with the principles of optimal foraging theory (OFT; MacArthur and Pianka 1966, Schoener 1971, Pyke et al. 1977), which predict that, as habitat productivity increases, the number of species (or items) incorporated into the diet should decrease. Such a principle best explains the relatively low dietary diversity and equitability values at Ngogo. Although the number of species enumerated in botanical plots at Ngogo and Kanyawara by Potts (2008) was roughly similar, a higher proportion of the tree community provides fruit at any given time at Ngogo than at Kanyawara. Chapman et al. (1997) found that, on average, 878 stems/km²/month bore fruit at Kanyawara, whereas at Ngogo this figure was 1748 stems/km²/month. Thus chimpanzees at Kanyawara are limited in the extent to which they can incorporate a higher diversity of ripe fruit into their diet. Moreover, during this study, ripe fruit made up a much higher percentage of the diet at Ngogo, and Kanyawara chimpanzees' greater use of pith and stems of herbaceous vegetation largely determined the between-site differences in dietary diversity values. Low dietary diversity at Ngogo may thus be a reflection of a relatively high abundance and low temporal variability of preferred resources (see Potts et al. 2009).

Activity budgets

Individuals inhabiting home ranges with high abundances of important foods should more easily satisfy caloric and other nutritional requirements than those inhabiting lower-quality ranges. More immediate access to essential resources, in turn, should reduce the time engaged in feeding and foraging (including traveling between patches) and allow more time for resting, socializing, or energetically-costly behaviors, as found in several studies of wild primates (e.g., female *Papio cynocephalus*: Altmann 1980; female *Theropithecus gelada*: Dunbar and Dunbar 1988) and supported by theoretical time budget models (e.g., *Papio* spp.: Dunbar 1992; *Ateles* spp.: Korstjens et al. 2006; colobines: Korstjens and Dunbar 2007). By this logic, time budget data given above would suggest that chimpanzees at Kanyawara have a higher quality home range and feed more efficiently than those at Ngogo, because Kanyawara chimpanzees spent slightly less time feeding and traveling and considerably more resting. Furthermore, pregnant and lactating females, who have particularly high energetic demands (Gittleman and Thompson 1988, Oftedal 1991), spent far more time feeding (at the expense of resting) at Ngogo than at Kanyawara.

The problem with this comparison of gross activity budgets is that it obscures important differences in diet composition between the two communities, specifically the greater contribution of ripe fruit to the diet at Ngogo. Ripe fruit typically is quantitatively the major component of chimpanzee diets (Wrangham 1977; Nishida and Uehara 1983; Tutin et al. 1991; Wrangham et al. 1996, 1998; Basabose 2002, Potts 2008), and it is likely their predominant source of metabolizable energy (Conklin-Brittain et al. 1998). Thus, although Kanyawara chimpanzees spent more time feeding and less time resting than Ngogo chimpanzees, they did not necessarily meet their caloric requirements more easily. Rather, they minimized the “cost” portion of their energy budgets by devoting more time to resting. The relatively low frequency of energetically-costly border patrolling and hunting at Kanyawara was also consistent with a cost-minimization strategy, whereas these activities constituted 4.6% of the Ngogo activity budget. Moreover, the rise in feeding time during pregnancy and lactation among Ngogo females may reflect a reproductive strategy, whereby female caloric intake spikes when energetic demands are highest due to pregnancy and lactation (Bercovitch 1987, Lee 1996, Ross 1998),

thereby increasing energy accumulation and probability of successful parturition and weaning. Similar reproductive strategies (akin to “income” breeding strategies; Stearn 1989) have been documented in other primates (*Cercopithecus mitis*: Butynski 1988; *Presbytis entellus*: Koenig et al. 1997). The activity budgets and diet composition of Kanyawara females suggest they cannot use such a strategy as efficiently as Ngogo females. This notable difference in feeding ecology may help to explain the differences in overall density of chimpanzees at the two sites, if such a strategy results in higher fecundity and offspring survival at Ngogo (which preliminary data suggest is the case; Watts et al., unpubl.).

Food patch characteristics, patch occupancy times, and feeding party size

Despite overall similarity in feeding party size and patch size between the two communities, chimpanzees adjusted their feeding efforts according to prevailing ecological conditions (e.g., patch size and per capita productivity) more readily at Ngogo. To the extent that a fission-fusion dynamic allows individuals to minimize the costs of feeding competition, the higher coefficient of variation in feeding party size at Ngogo and the higher percentage of variation in feeding party size explained by feeding tree patch size there suggest that feeding competition costs were lower there than at Kanyawara. Chapman et al. (1995) suggested that a strong positive relationship between feeding party size and patch size should exist in habitats with abundant alternative feeding sources in relatively close proximity (e.g., contagiously distributed fruiting trees), whereas in habitats in which high-quality patches are rare or sparsely distributed [or: “widely scattered”], no such relationship may exist. This is because when travel costs do not prohibit the formation of large groups, large patches will promote large foraging subgroups (*Ateles belzebuth*: Klein and Klein 1977; *A. paniscus*: Symington 1988; *Brachyteles arachnoides*: Strier 1989; *Pongo pygmaeus*: Utami et al. 1997). However, high travel costs between successive patches can constrain the ability of individuals to form large groups even in large patches (Chapman et al. 1995). The difference in R^2 values relating foraging party size to

patch size at the two sites suggests that Ngogo chimpanzees more frequently had access to a high density of relatively evenly-distributed food sources.

Increased within-group feeding competition can lead to increased mortality (e.g., *Macaca sinica*: Dittus 1979) and decreased reproductive output (e.g., *Cercopithecus aethiops*: Whitten 1983; *Theropithecus gelada*: Dunbar and Dunbar 1988). Ngogo chimpanzees therefore are able to avoid these fitness consequences more readily than Kanyawara chimpanzees. Similarly, Symington (1988) found that agonistic interactions among female black spider monkeys (*Ateles paniscus*) occurred substantially more often within a fruit patch when the feeding party size was larger than average for a patch of that size. Presumably as a consequence of food-related aggression, low-ranking females had longer interbirth intervals than high-ranking females (Symington 1988).

After controlling for the number of co-feeding individuals, residency times were longer for feeding patches of the same species, size, and phenophase at Kanyawara. This could indicate that 1) Ngogo chimpanzees more efficiently harvested items within patches, and thus required less foraging effort per patch, and/or 2) giving-up densities (resource levels at which a patch ceases to be efficiently exploitable; Brown 1988, 1989) were lower at Kanyawara. Ngogo chimpanzees might have ended feeding bouts and moved to alternative patches prior to or at the point at which current patches were functionally depleted (Chapman 1988), whereas Kanyawara chimpanzees might have more frequently reached or surpassed this point.

The first option is improbable, because it is unlikely that individuals at one site are inherently better able to forage for items within patches than conspecifics at another site (though see Muruthi et al. 1991). However, the second option is supported by theoretical expectations. Notably, giving-up densities can differ among groups of the same species when habitat-wide mean energy harvest rates vary (Brown 1988, Kotler and Brown 1988, Bowers et al. 1993, Houle et al. 2006). According to optimal foraging theory (MacArthur and Pianka 1966, Stephens and Krebs 1986), animals foraging in a heterogeneous environment composed of depletable patches should abandon a patch at the point at which the opportunity and/or energetic costs

associated with remaining there rather than moving to a new patch begin to outweigh the caloric benefits accrued from continuing to forage in it (although this requires a certain degree of knowledge about the location of alternative food sources; Hancock and Milner-Gulland 2006). Thus, all else equal, patch residence times should be longer in habitats with fewer or more widely spaced resource patches, due to relatively high inter-patch travel costs (McNair 1982). Kanyawara has a lower basal area per hectare of important food species, on average, than Ngogo (Potts et al. 2009). Longer patch occupancy times at Kanyawara thus likely result from the lower average density of alternative high-quality food patches at this site and from the lower marginal value (Charnov 1976) of food patches there. Similarly, if the resource base is of generally lower quality at Kanyawara than at Ngogo, chimpanzees at Kanyawara might require longer patch residencies to extract sufficient nutrients from a given patch (also see Hanya 2004 for a similar relationship between food availability and time devoted to feeding in Japanese macaques [*Macaca fuscata*]).

Furthermore, under equivalent patch conditions (i.e., same species, size/productivity, and number of co-feeding individuals), Ngogo and Kanyawara chimpanzees should require approximately the same foraging effort to deplete a patch. If so, and if Ngogo chimpanzees abandoned patches near the point of functional depletion (Chapman et al. 1995), then it follows that Kanyawara chimpanzees foraged sub-optimally on certain occasions by over-exploiting resource patches.

Conclusion

This study documents considerable ecological diversity within a single population of chimpanzees inhabiting Kibale National Park, Uganda. The evidence presented here suggests that chimpanzees at Ngogo, a site of unusually high chimpanzee density, have notably higher-quality diets and forage more efficiently than chimpanzees at Kanyawara, a site of average chimpanzee density located just 12 km from Ngogo. It is likely that this variability relates to the three-fold difference in density of chimpanzees at the Kanyawara and Ngogo sites, but data from chimpanzees at other Kibale sites is necessary to fully substantiate the link between

feeding ecology and population density. This study adds to the growing body of research documenting noteworthy variation in ecology among distinct social groups of a single primate population (e.g., Chapman and Chapman 1999, Ganas et al. 2004, Grassi 2006, Harris and Chapman 2007), particularly for populations inhabiting highly heterogeneous landscapes. Based on these results, it is clear that caution is warranted in drawing conclusions about species- and population-level characteristics in primates without simultaneously accounting for the potential range of variation within populations.

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Figure 1 – Proportional contribution of various plant parts to the diet of chimpanzees: a) all monthly values for each site; b) average of monthly values from the overlap period only (abbreviations: “RF” = Ripe Fruit, “UF” = Unripe Fruit, “YL” = Young Leaves).

Figure 2 – Activity budgets of all individuals (pooled percentages) at Ngogo and Kanyawara. See text for explanations of each behavioral category. Only time spent resting differed significantly between the sites.

Figure 3 – Activity budgets of pregnant/lactating females, cycling females, and males at Ngogo (top) and Kanyawara (bottom). See text for explanations of each behavioral category.

Figure 4 – Regression of feeding party size versus feeding patch size (DBH; both ln-transformed). See text for details.

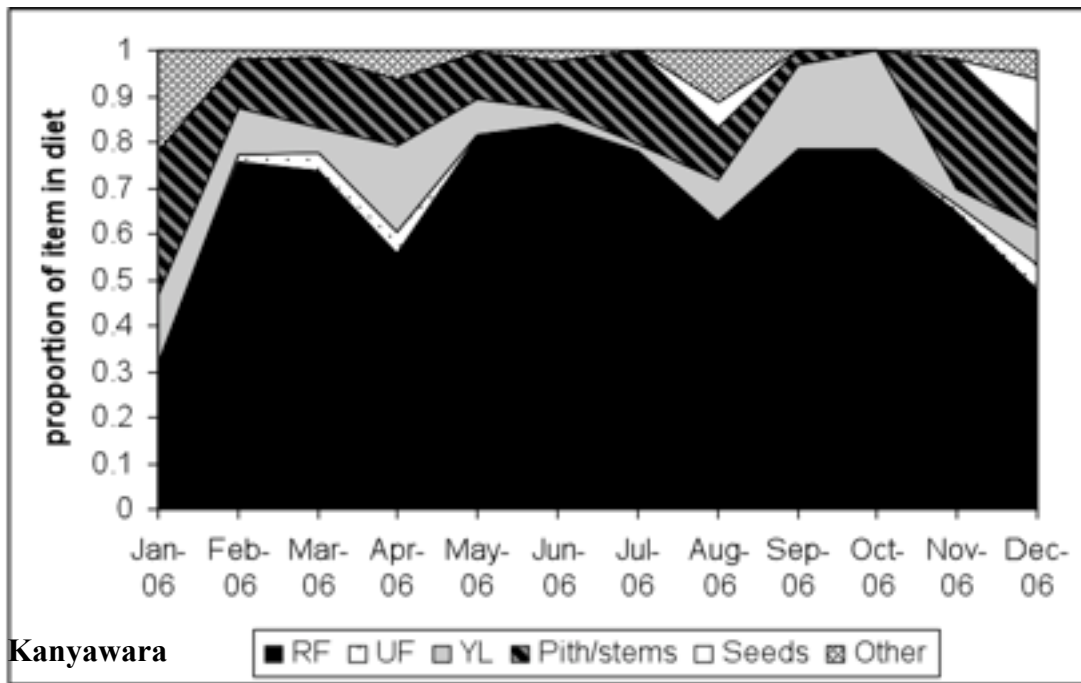
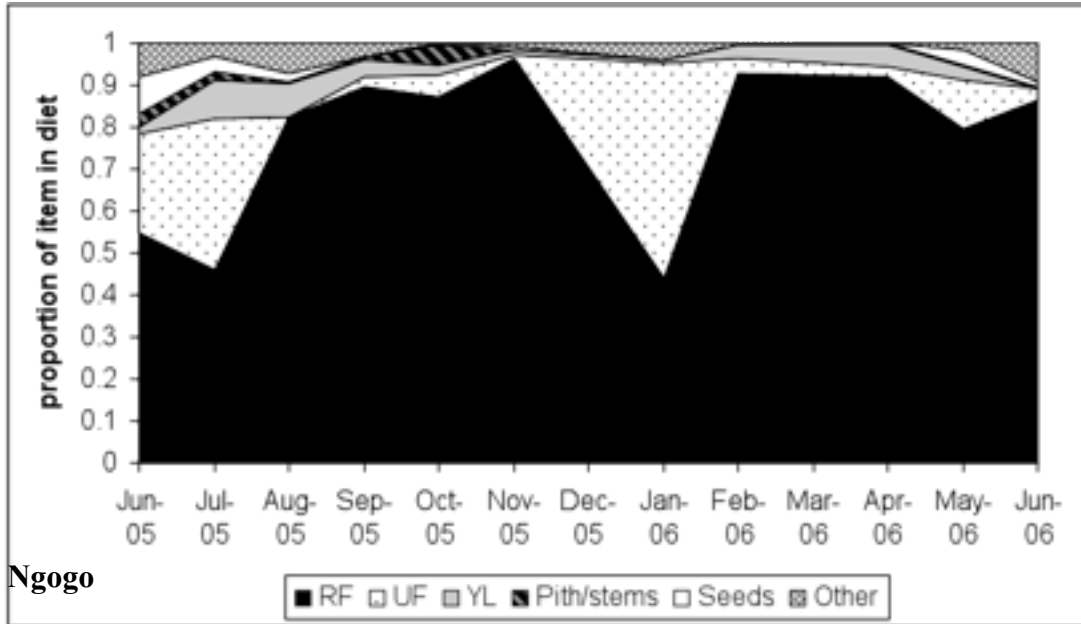


Figure 1a

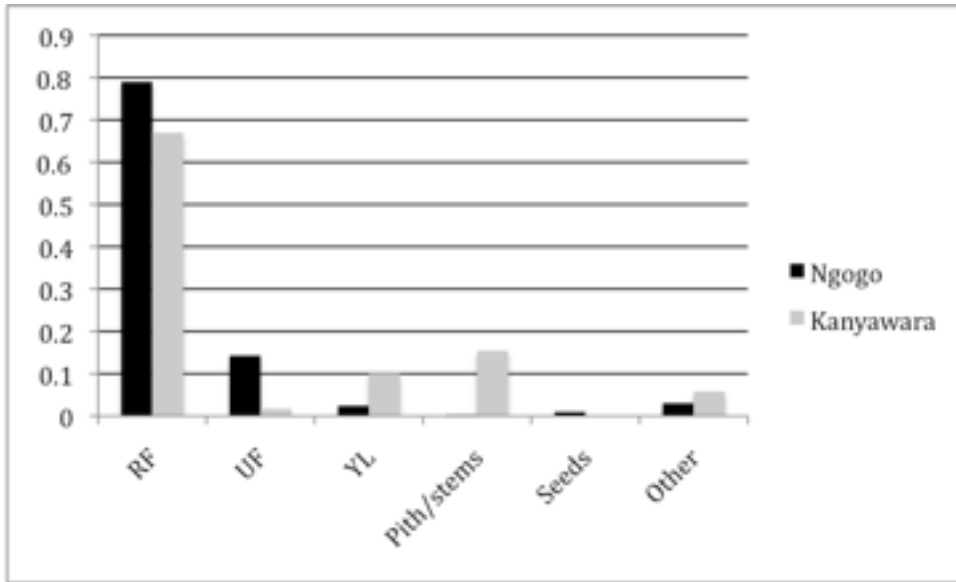


Figure 1b

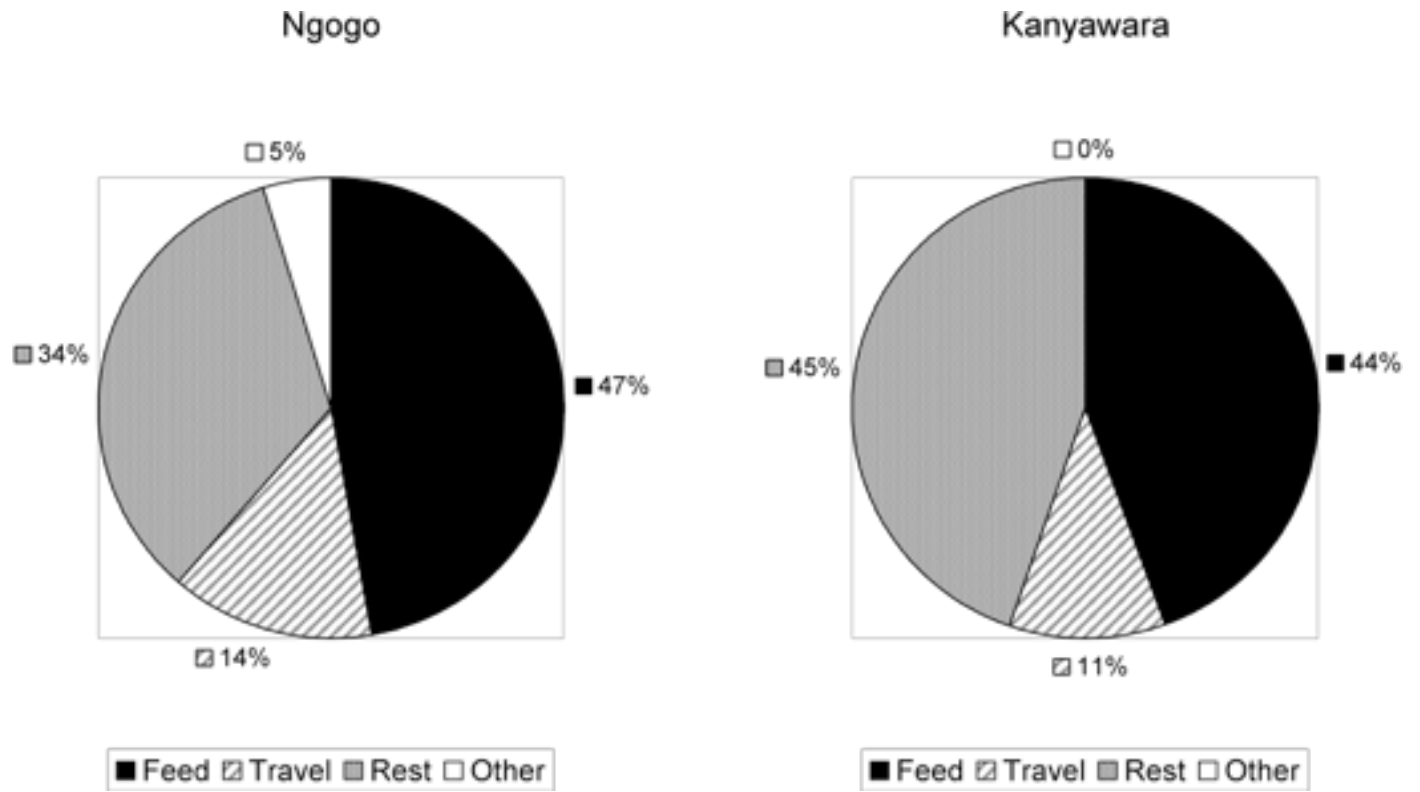


Figure 2

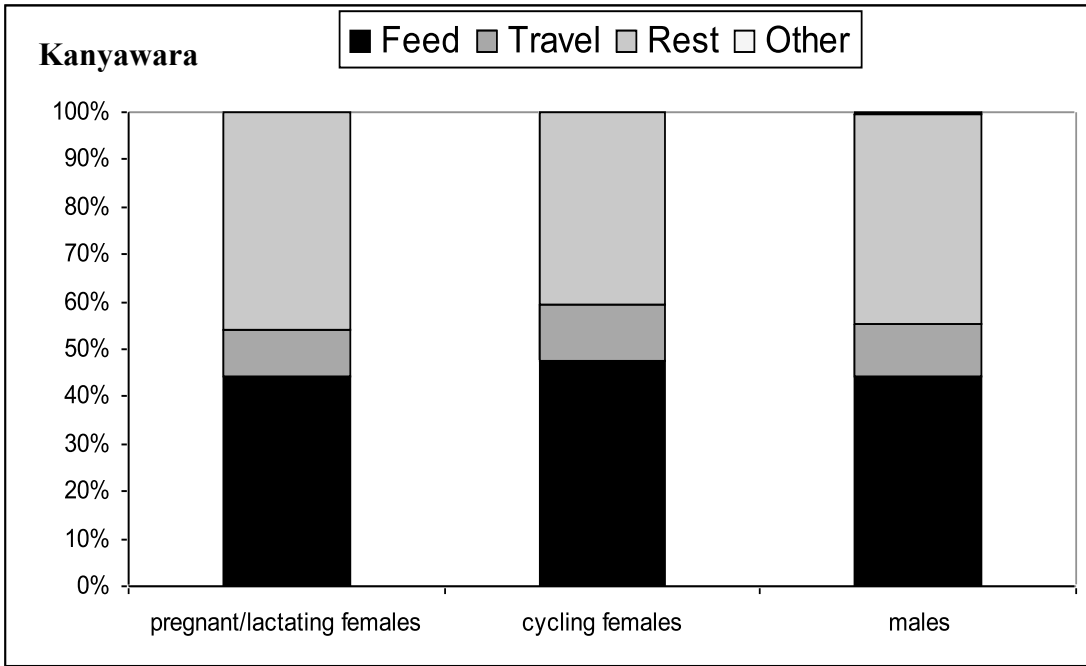
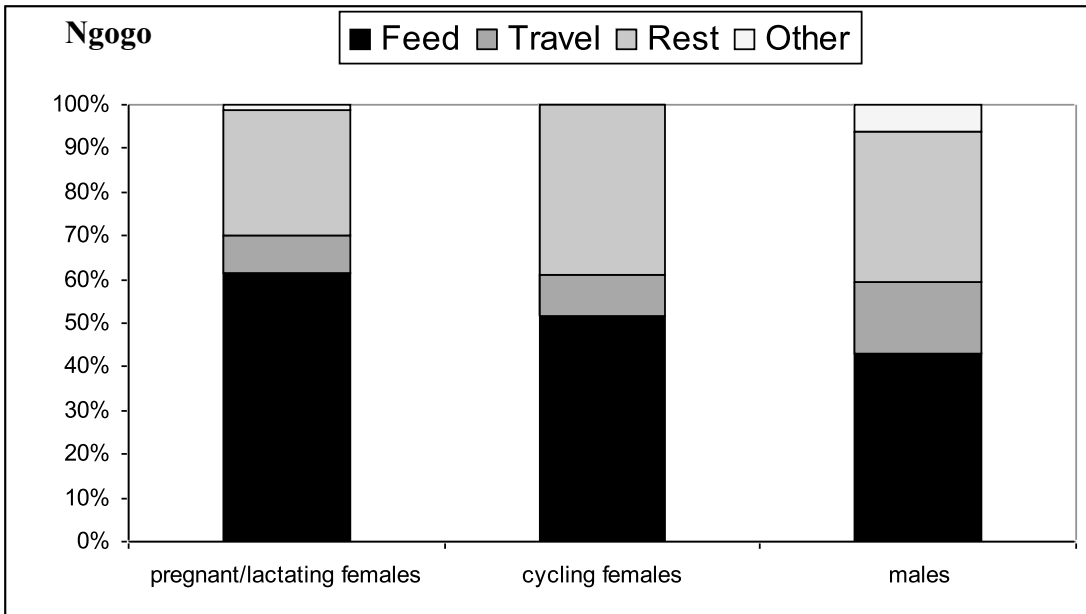


Figure 3

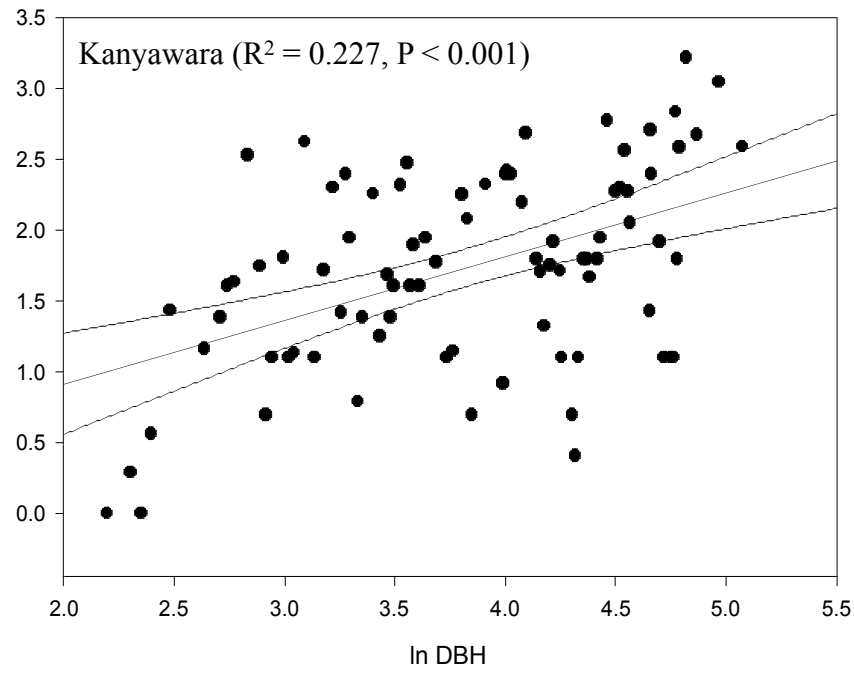
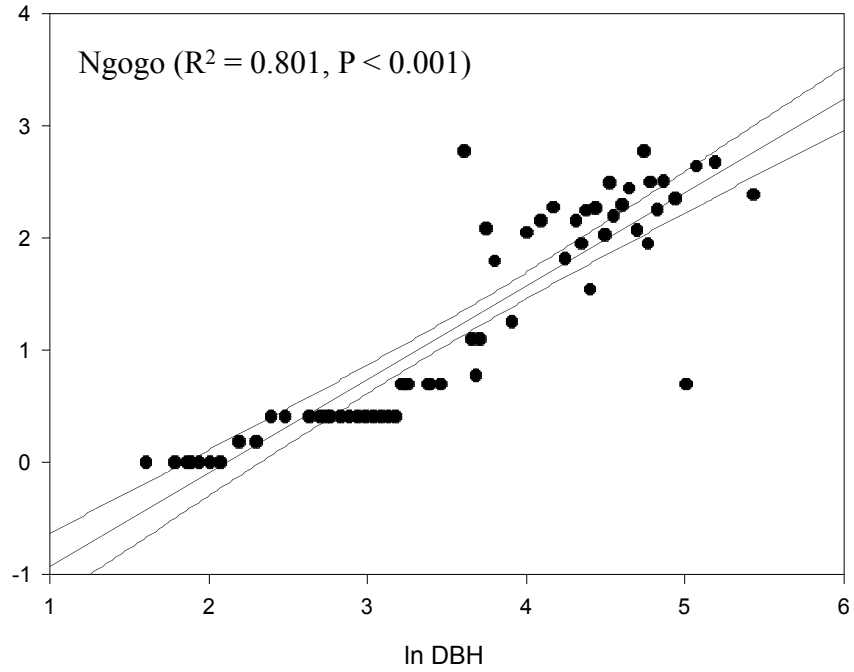


Figure 4

Table 1 – Plant items in the diet of chimpanzees at Ngogo and Kanyawara, and the percent contribution of each item (abbreviations: “RF” = Ripe Fruit, “UF” = Unripe Fruit, “SD” = Seed, “YL” = Young Leaves, “LB” = Leaf Buds).

Ngogo			Kanyawara		
Species	Part	% feeding time	Species	Part	% feeding time
<i>Ficus mucoso</i>	RF	34.11	<i>Ficus natalensis</i>	RF	17.90
<i>Uvariopsis congensis</i>	RF	11.16	<i>Ficus sansibarica</i>	RF	13.75
<i>Chrysophyllum albidum</i>	RF	9.84	<i>Mimusops bagshawei</i>	RF	8.31
<i>Pterygota mildbraedii</i>	UF/SD	5.91	unk spp.	PITH/STEMS/YL	5.42
<i>Teclea nobilis</i>	RF	5.46	<i>Acanthus arborescens</i>	PITH	5.33
<i>Mimusops bagshawei</i>	RF	5.05	<i>Ficus capensis</i>	RF	4.94
<i>Ficus sauseureana</i>	RF	3.68	<i>Celtis africana</i>	YL	4.88
<i>Morus mesozygia</i>	RF	2.62	<i>Ficus exasperata</i>	RF	4.62
<i>Pouteria altissima</i>	RF	2.16	<i>Uvariopsis congensis</i>	RF	3.94
<i>Ficus sansibarica</i>	RF	1.77	<i>Aframomum spp.</i>	PITH	2.87
<i>Treculia africana</i>	RF	1.24	<i>Ficus exasperata</i>	YL	2.07
<i>Pseudospondias microcarpa</i>	RF	1.16	<i>Celtis africana</i>	LB	2.00
<i>Pterygota mildbraedii</i>	YL	1.07	<i>Lepistemon spp.</i>	PITH	1.80
<i>Cassine buchananii</i>	RF	1.03	<i>Pennisetum purpureum</i>	PITH	1.62
<i>Ficus exasperata</i>	YL	0.98	<i>Ensete spp.</i>	PITH	1.27
<i>Cordia millenii</i>	RF	0.98	<i>Cordia abyssinica</i>	RF	1.17
<i>Ficus natalensis</i>	RF	0.96	<i>Ficus sauseureana</i>	RF	1.39
<i>Monodora myristica</i>	RF	0.95	<i>Pseudospondias microcarpa</i>	RF	1.14
<i>Ficus capensis</i>	RF	0.72	<i>Linociera johnsonii</i>	RF	1.04
<i>Cola gigantea</i>	RF	0.68	<i>Cyperus papyrus</i>	PITH	0.96
<i>Neoboutonia macrocalyx</i>	ROOTS	0.60	<i>Ficus exasperata</i>	UF	0.95
<i>Celtis africana</i>	YL	0.46	<i>Brilliantasia spp.</i>	SEEDS	0.80
<i>Ficus variifolia</i>	RF	0.46	unk Ulmaceae	YL	0.70
<i>Ficus exasperata</i>	UF	0.41	<i>Phytolacca dodecandra</i>	RF	0.62
<i>Aframomum spp.</i>	PITH	0.38	<i>Marantochloa leucantha</i>	PITH	0.60
<i>Acanthus arborescens</i>	PITH	0.36	<i>Prunus africana</i>	RF	0.58
<i>Ficus cyathistipula</i>	UF	0.35	<i>Ficus urceolaris</i>	YL	0.57
<i>Morus mesozygia</i>	FL	0.35	<i>Ficus cyathistipula</i>	RF	0.52
<i>Celtis durandii</i>	RF	0.35	<i>Ficus thoningii</i>	RF	0.50
<i>Iligera pentaphylla</i>	FL	0.34	<i>Monodora myristica</i>	RF	0.48
<i>Warburgia ugandensis</i>	RF	0.34	<i>Rubia cordifolia</i>	YL	0.46
<i>Antiaris toxicaria</i>	UF	0.29	<i>Chaetacme aristata</i>	YL	0.44
unk spp. bark	CAMBIUM	0.29	<i>Triumphetta spp.</i>	PITH	0.37
<i>Ficus variifolia</i>	YL	0.23	unk climber	UF	0.36
<i>Baquertiodendron oblancoelatum</i>	RF	0.20	<i>Uretia spp.</i>	RF	0.30
<i>Pseudospondias microcarpa</i>	UF	0.20	<i>Acalypha spp.</i>	PITH	0.28
<i>Cyperus papyrus</i>	PITH	0.18	<i>Treculia africana</i>	RF	0.25
<i>Phytolacca dodecandra</i>	RF	0.17	<i>Todaria spp.</i>	RF	0.25
<i>Hoslundia opposita</i>	RF	0.15	<i>Trichilia drageana</i>	YL	0.24

<i>Chaetacme aristata</i>	YL	0.15	<i>Neoboutonia macrocalyx</i>	DEAD WOOD	0.24
Honeycomb	HONEY	0.15	<i>Aphania senegalensis</i>	RF	0.19
<i>Allophyllus abbyssinicus</i>	RF	0.15	<i>Ficus sansibarica</i>	UF	0.17
<i>Iligera pentaphylla</i>	SD	0.14	<i>Olea capensis</i>	RF	0.16
<i>Celtis durandii</i>	YL	0.13	<i>Ficus vallis-choudae</i>	UF	0.14
unk spp.	YL	0.13	<i>Cordia abyssinica</i>	YL	0.14
<i>Ficus thoningii</i>	RF	0.13	<i>Celtis durandii</i>	RF	0.12
<i>Cordia millenii</i>	FL	0.11	<i>Ficus natalensis</i>	UF	0.10
unk spp.	BRYOPHYTE	0.11	<i>Iligera pentaphylla</i>	SEEDS	0.10
<i>Celtis mildbraedii</i>	YL	0.11	unk vine	RF	0.09
unk spp.	WOOD	0.10	<i>Bridelia</i> spp.	RF	0.08
<i>Ficus brachylepis</i>	UF	0.10	<i>Ficus sansibarica</i>	CAMBIUM	0.08
<i>Piper capense</i>	PITH	0.10	<i>Ficus stipulifera</i>	RF	0.07
<i>Pennisetum purpureum</i>	REEDS	0.09	<i>Pancovia turbinata</i>	RF	0.06
<i>Ficus vallis-choudae</i>	RF	0.09	<i>Piper capense</i>	PITH	0.06
unk vine	YL	0.08	unk spp.	WOOD	0.06
unk spp.	LARVAE	0.06	<i>Antiaris toxicaria</i>	YL	0.06
<i>Trichilia drageana</i>	YL	0.06	Honeycomb	HONEY	0.06
<i>Zanha golungensis</i>	RF	0.06	<i>Trichilia drageana</i>	RF	0.05
<i>Ficus cyathistipula</i>	YL	0.05	<i>Markhamia platycalyx</i>	CAMBIUM	0.04
<i>Cola gigantea</i>	YL	0.05	<i>Myrianthus holstii</i>	RF	0.03
<i>Morus mesozygia</i>	YL	0.05	unk fern	YL	0.03
<i>Ficus congensis</i>	UF	0.04	<i>Bridelia</i> spp.	UF	0.02
unk spp.	PITH	0.02	<i>Jasmina</i> spp.	YL	0.01
unk spp.	WOOD	0.02	<i>Lantana</i> spp.	RF	0.01
<i>Celtis durandii</i>	CAMBIUM	0.02	Soil	SOIL	0.01
<i>Antiaris toxicaria</i>	YL	0.01	<i>Ficus urceolaris</i>	RF	0.004
<i>Phoenix reclinata</i>	FROND	0.01			
<i>Teclea nobilis</i>	YL	0.01			

Table 2 – The 20 most common items in the diet of chimpanzees at Ngogo and Kanyawara (items in bold were included in the top 20 at both sites; abbreviations: “RF” = Ripe Fruit, “UF” = Unripe Fruit, “SD” = Seed, “YL” = Young Leaves, “LB” = Leaf Buds)

Ngogo	% of feeding time		Kanyawara	% of feeding time
<i>Ficus mucuso</i> RF	34.00		<i>Ficus natalensis</i> RF	17.90
<i>Uvariopsis congensis</i> RF	11.10		<i>Ficus sansibarica</i> RF	16.10
<i>Chrysophyllum albidum</i> RF	9.80		<i>Mimusops bagshawei</i> RF	8.30
<i>Pterygota mildbraedii</i> UF/SD	5.90		<i>Celtis africana</i> YL/LB	6.90
<i>Teclea nobilis</i> RF	5.50		<i>unkTHV</i> pith/stems/YL	5.40
<i>Mimusops bagshawei</i> RF	5.10		<i>Acanthus arborescens</i> pith	5.30
<i>Ficus saussureana</i> RF	3.70		<i>Ficus capensis</i> RF	4.90
<i>Morus mesozygia</i> RF	2.60		<i>Ficus exasperata</i> RF	4.60
<i>Pouteria altissima</i> RF	2.20		<i>Uvariopsis congensis</i> RF	3.90
<i>Ficus sansibarica</i> RF	1.70		<i>Aframomum</i> spp. pith	2.90
<i>Treulia africana</i> RF	1.24		<i>Ficus exasperata</i> YL	2.07
<i>Pseudospondias microcarpa</i> RF	1.15		<i>Lepistemon</i> spp. pith/YL	1.80
<i>Pterygota mildbraedii</i> YL	1.07		<i>Pennisetum purpureum</i> reeds	1.62
<i>Cassine buchananii</i> RF	1.03		<i>Ficus saussureana</i> RF	1.40
<i>Ficus exasperata</i> YL	0.98		<i>Ensete</i> spp. pith	1.27
<i>Cordia millenii</i> RF	0.98		<i>Cordia abyssinica</i> RF	1.17
<i>Ficus natalensis</i> RF	0.96		<i>Pseudospondias microcarpa</i> RF	1.14
<i>Monodora myristica</i> RF	0.95		<i>Linociera johnsonii</i> RF	1.05
<i>Ficus capensis</i> RF	0.72		<i>Cyperus papyrus</i> pith	0.96
<i>Cola gigantea</i> RF	0.70		<i>Ficus exasperata</i> UF	0.95
Total %	91.49		Total %	89.50

Table 3 – Percentage contribution of various food patch types in the diet of chimpanzees at Ngogo and Kanyawara

Form	Ngogo	Kanyawara
Trees	58.0	29.0
Free-standing figs	14.2	17.1
Strangler figs	4.8	32.2
Herbs	2.1	13.7
Vines	1.0	1.5
Dropped fruits	8.1	0.13
Shrubs	1.1	1.2
Saplings	8.7	3.1
Other	2.0	2.1
Total non-tree or non-fig	23.0	21.6

Table 4 – Average per capita patch residency times (number of minutes spent feeding in a patch corrected for the feeding party size) at each site for the same tree species and roughly the same productivity score (phenology score multiplied by tree size [DBH]). Bold text in the last column indicates a significant difference between the sites.

	productivity score (phenology score X DBH)	Ngogo	Kanyawara	
<i>Uvariopsis congensis</i>	10-40	12	23.5	K > N (U = 667.5, P = 0.048)
	>40	3.315	3.743	K = N (U = 655.5, P = 0.232)
<i>Pseudospondias microcarpa</i>	0-200	2.77	2.07	K = N (U = 425.0, P = 0.142)
	>200	1.39	5.88	K > N (U = 100.0, P = 0.010)
<i>Ficus saussureana</i>	all	2.57	3.27	K = N (U = 440.5, P = 0.690)
<i>Ficus sansibarica</i>	all	2.27	8.27	K > N (U = 1923.5, P < 0.001)
<i>Ficus natalensis</i>	all	3.75	5.87	K > N (U = 1572.0, P = 0.048)