Blue monkeys' utilization of five tree species in relation to abundance of each tree species: *Diospyros abyssinica*, *Euclea divinorum*, *Turraea robusta*, *Warburgia ugandensis* and *Ficus lutea*

Blå markattors utnyttjande av fem trädarter i relation till varje trädarts förekomst: Diospyros abyssinica*,* Euclea divinorum*,*Turraea robusta*,* Warburgia ugandensis *och* Ficus lutea

Vendela Kempe

Sveriges Lantbruksuniversitet **Skara 2008** **Studentarbete 212**
Institutionen för husdjurens miljö och hälsa
Avdelningen för etologi och djurskydd

Swedish University of Agricultural Sciences ***Student report 212***
Department of Animal Environment and Health
Section of Ethology and Animal Welfare

ISSN 1652-280X

Blue monkeys' utilization of five tree species in relation to abundance of each tree species: *Diospyros abyssinica*, *Euclea divinorum*, *Turraea robusta*, *Warburgia ugandensis* and *Ficus lutea*

Blå markattors utnyttjande av fem trädarter i relation till varje trädarts förekomst: Diospyros abyssinica*,* Euclea divinorum*,* Turraea robusta, Warburgia ugandensis *och* Ficus lutea

Vendela Kempe

Examensarbete, C-nivå, 15 hp, Biologi

Handledare: Jens Jung
Inst för husdjurens miljö och hälsa
BOX 234
532 23 SKARA

Abstract

This study was carried out in the Sabaringo forest outside the Masai Mara National Reserve in Kenya in order to obtain knowledge about the dietary preferences of the blue monkey *Cercopithecus mitis stuhlmanni*. Previous studies of foraging behaviour of lactating and non-lactating females in this forest have investigated the monkeys' preferences of tree species to foraging of and being positioned in. To relate the monkeys' preferences of each tree species to the abundance of the tree species we made a total inventory of the trees in the forest. This was done by identifying species and size of each tree, as well as GPS position in order to create maps of the area. For the ten most popular tree species displayed in the previous study, comparisons were then made between the monkeys' use of the species and the abundance of these species (measured by number of trees, number of branches and stem area). The observations displayed in this thesis are based on the analysis of five of the ten most popular tree species; *Diospyros abyssinica* (Giant Diospyros), *Euclea divinorum* (Diamond-leaved Euclea), *Turraea robusta* (Honeysuckle tree), *Warburgia ugandensis* (East African Greenheart) and *Ficus lutea* (Giant-leaved Fig). The remaining five tree species are analysed in a corresponding thesis by Ahlbäck.

F. lutea was despite of its low frequency in the area the clearly most popular tree species, mainly for foraging of but also for being positioned in. It was used 28 times its abundance for foraging and 10.2 times its abundance for positioning, concerning its number of trees. Both lactating and non-lactating females showed this preference, even though the trend was stronger among the latter. The second most popular tree species for foraging was *W. Ugandensis* and *D. Abyssinica.* Both *E. divinorum* and *T. robusta* were utilized for foraging with same or less frequency than their abundance. When looking at the tree species used for positioning, the most popular species after *F. lutea* was *W. Ugandensis, E. divinorum* and *D. abyssinica*. The least popular species was *T. robusta*.

Keywords: *Cercopithecus mitis stuhlmanni*; lactating females; *Diospyros abyssinica*; *Euclea divinorum*; *Turraea robusta*; *Warburgia ugandensis*; *Ficus lutea*; tree abundance; foraging; positioning

Sammanfattning

Denna studie gjordes i Sabaringoskogen utanför Masai Mara National Reserve i Kenya med syfte att undersöka födopreferenserna hos den blå markattan *Cercopithecus mitis stuhlmanni*. Artens användning av trädarterna som föda och för att vistas i hade tidigare studerats hos lakterande och icke-lakterande honor i samma område. För att förstå apornas preferenser gällande trädarter att äta respektive vistas i genomförde vi en totalinventering av trädarterna i området. Detta gjordes genom att bestämma art och storlek för varje träd, samt även GPS-position för att kunna göra kartor över området. Jämförelser gjordes sedan för de tio populäraste trädarterna i den tidigare studien, gällande apornas användning av arterna samt arternas förekomst (mätt som antal träd, antal grenar och stamarea). Observationerna i denna uppsats bygger på analyser av fem av de tio populäraste trädarterna; *Diospyros abyssinica* (Giant Diospyros), *Euclea divinorum* (Diamond-leaved Euclea), *Turraea robusta* (Honeysuckle tree), *Warburgia ugandensis* (East African Greenheart) och *Ficus lutea* (Giant-leaved Fig). Användningen av de resterande fem analyseras i en motsvarande uppsats av Ahlbäck.

Trots dess låga förekomst i området var *F. lutea* den klart populäraste trädarten, främst vad gäller att äta i men även att vistas i. Arten användes 28 gånger sin förekomst för att äta i och 10,2 gånger sin förekomst för att vistas i, gällande dess antal träd. Denna preferens delades av både lakterande och icke-lakterande honor, men trenden var tydligare bland de senare. De näst populäraste trädarterna att äta i var *W. Ugandensis* och *D. abyssinica.* Både *E. divinorum* och *T. robusta* användes i samma eller mindre utsträckning för att äta i än de förekom. Vad gäller användningen av trädarterna för att sitta i var *W. Ugandensis, E. divinorum* och *D. abyssinica,* efter *F. lutea,* populärast. Den minst populära arten var *T. robusta*.

Nyckelord: *Cercopithecus mitis stuhlmanni*; lakterande honor; *Diospyros abyssinica*; *Euclea divinorum*; *Turraea robusta*; *Warburgia ugandensis*; *Ficus lutea*; trädförekomst; födosök; vistelse

Table of Contents

1 Introduction

In East Africa only 28 % of the original forests remain, and it is estimated that Africa is deforested at a rate of 0.4-0.5 % each year. This process is mainly caused by commercial timber cutting and clearings on behalf of agriculture, small-scale slash-and-burn-agriculture and gathering of natural resources by local human communities. Of the frugivore biomass in tropical forests, primates compose between 25 and 40 % (Chapman *et al.* 2006), which makes them sensitive to forest clearings as it may reduce the availability of food (Cordeiro *et al.* 2004). Different frugivores are more or less specialized on eating fruits from different plant species (Chapman *et al*. 2002), which means that some plants are being used more frequently than other. To ensure efficiency in possible future conservation programs, it is therefore important with basic research in foraging ecology concerning the animal species of interest.

1.1 Blue monkeys

The blue monkey, *Cercopithecus mitis stuhlmanni,* is a subspecies to *Cercopithecus mitis* which is an Old World monkey and a member of the genus Guenons, with species most abundant in the equatorial forests (Cords 1986). *C. mitis* is arboreal, but can occasionally be found foraging on the ground and moving across open areas (Stuart 1997). It occurs in rain forests and montane bamboo forests in Angola, Burundi, The Democratic Republic of Congo, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Somalia, South Africa, Sudan, Swaziland, United Republic of Tanzania, Uganda, Zambia and Zimbabwe, while the subspecies *C. mitis stuhlmanni* only occurs in Kenya and Uganda (IUCN Red List 2007).

C. mitis lives in matriarchal groups of 20-40 individuals, often with one adult male that can stay up to three years in the group. The female becomes sexual mature when she is 5-6 years old and the males when they are somewhat older (Rowell 1984). The mating season is influenced by nutritional availability, which corresponds to the rain seasons (Swart & Lawes 1996). In the southern range areas the females give birth during the summer months, while the reproduction is aseasonal in the equatorial belt (Stuart 1997). Hybridizations producing fertile offspring have been observed between *C. mitis* males and females of its smaller relative, the red-tail monkey (*C. ascanius*), in areas where the two species' distributions overlap. The mothers of all known hybrid offspring were of the latter species (Rowell 1984).

A male of *C. mitis* weighs 8-10 kg and a female 4-5 kg, and the species have a total length of 1.2 to1.4 m with the tail making up over half of it (Stuart 1997). The species has a long, dense and silky fur with a mottled grey body colour and a dark face and pale diadem. Cheek pouches extends from the lower jaw down along the neck, in which the monkeys can press down and store food in case of danger or competition. These pouches can hold as much as the stomach and are easily emptied with the hands by pressing the food upwards towards the mouth. *C. mitis* is adapted to a life in the canopy with both thumb and hallox turning away from the other fingers and toes, long muscular back legs and shorter fore legs, and a long tail which improves its balance (Rowell 1984).

Tashiro (2006) has reported that the species *C. mitis* uses the strata at around 20 m above ground for foraging. The species is considered to have a very flexible diet, as shown by various studies (Butynski 1990; Chapman *et al.* 2002; Lawes *et al.* 1990; Twinomugisha *et al.* 2006). *C. mitis* is mainly a frugivore but can also eat larger amounts of leaves, flowers and insects depending on the food supply (Cords 2002; Fairgrieve & Muhumuza 2003). This flexibility is based on its large hindgut and substantial gut surface area as well as a specialized intestine micro flora (Twinomugisha *et al*. 2006).

Large variations in diet between different groups of *C. mitis* have been reported. In Kakamega, Kenya, the monkeys spent 54 % of their foraging time on fruit, 16 % on leaves and 17 % on insects, while for an Ugandian population in Kibale the same numbers were 33 % for fruits, 24 % for leaves and 30 % for insects (Chapman *et al*. 2002). Data from the Kalinzu forest in Uganda showed that 50 % of the species' foraging time was spent on insectivory with fruit only second in place (Tashiro 2006), while data from Kenya showed fruit to be the first choice and insects only to be consumed as a last resort (Cords 2002). The limiting feature for frugivorous primates in general is considered to be the access of fruit during the lowest seasonal level. This is because fruit often serves as the primary energy source for these populations (Twinomugisha *et al*. 2006).

Seasonality in the consumption of different food items has been observed among *C. mitis stuhlmanni* in the Kakamega forests in Kenya, where the highest intake of fruit was in the middle of the rainy and dry seasons. When fruit was less available, the proportion of leaves in the diet increased. Differences in food choice were also observed among lactating and non-lactating females. The first ones have been shown to eat more insects and less fruit, due to their greater need of food of high nutritional value, compared to non-lactating. Smaller juveniles ate more fruit, in expense to leaves, than larger juveniles (Cords 1986).

The seasonality in food consumption observed in the subspecies can be attributable to the high variation in nutritional quality of fruits over the year. Worman & Chapman (2005) has for example found a positive correlation between the lipid content of ripe fruit and the amount of fruit that *C. mitis* included in the diet.

A variation in the diet of *C. mitis stuhlmanni* has also been observed between logged and unlogged forests in the Budongo Forest Reserve in Uganda. In the logged forest the monkeys consumed a higher proportion of immature fruit than the ones in the unlogged, who ate more ripe fruit. The ones in the latter habitat included a higher proportion of seeds, young leaves and invertebrates in their diet than the monkeys in logged areas, who also consumed more bark. These results are an effect of the tree species presence and abundance in the different areas, which leads to different availabilities of food items. It is suggested that the fruit availability is scarcer in unlogged forests, which drives the monkeys to consume more seeds, leaves, and invertebrates as a complement (Fairgrieve & Muhumuza 2003). Logged areas have been showed to harbour higher primate densities in general (Plumptre & Reynolds 1994), and the group sizes of *C. mitis stuhlmanni* are also smaller in those habitats in comparison to unlogged areas (Fairgrieve & Muhumuza 2003).

Despite the above mentioned variations in diet, human disturbance seems to have a substantial impact on the foraging behaviour of *C. mitis*. Different groups can show dissimilar preferences depending on their habitats' distance to settlements (Tashiro 2006; Linderoth in prep.). Monkeys that live close to human communities often include trash and crops in their diets and when food is arriving to a place at certain times, such as at disposal sites, the monkeys adjust their visits to these moments (Linderoth in prep.).

The primary predators of *C. mitis* are eagles, but they are also threatened by other primate species, leopards and snakes. Human activities impose negative effects on the species by decimating and fragmenting its habitat. In some areas it is also hunted as a vermin for destroying crops and debarking trees in plantations while foraging (Rowell 1984).

C. mitis stuhlmanni is classed as threatened at a low risk and at the least concern since 1996. The taxa do, however, not qualify as near threatened and is not dependent on conservation (IUCN 2007).

1.2 Studied tree species

Diospyros abyssinica
Common names: Giant Diospyros (Eng.); Mdaa-mwitu (Swahili)
D. abyssinica grows in evergreen forests. It is a large tree, 9 to 30 meters high with a relatively sparse and shortly branched crown and glossy dark green (Flora of Zimbabwe 2007), 11 cm long leaves (Chapman *et al.* 1999). The bole is straight and long with rough bark that scales off in fibrous strips from old trees (Dharani 2002). The species flowers from October to January with solitary or few-flowered clusters that develops into fleshy spherical fruits, up to 1.5 cm across (Flora of Zimbabwe 2007) with 0.9 cm long seeds inside (Chapman *et al.* 1999).

Euclea divinorum
Common names: Diamond-leaved Euclea (Eng.); Magic gwarra (Eng.); Mdaa (Swahili)
E. divinorum grows in rocky places in dry forest margins, wooded grasslands and evergreen bush lands, at altitudes up to 2 400 m.a.s.l. It is a richly branched, small tree or shrub up to 10 meters high with a rough bark that cracks and scales off with age and dull green stiff leaves (Flora of Zimbabwe 2007) that are browsed by e.g. giraffes and grey duiker (World Agroforestry Centre 2007). It flowers between August and January (Flora of Zimbabwe 2007) with short-lived fragrant flowers in small sprays that develop into round thinly fleshy fruits, 0.5 cm in diameter (Dharani 2002).

Turraea robusta
Common names: Honeysuckle tree (Eng.); Ol-burobinik (Maa)
T. robusta grows in wooded grasslands, bush lands and in riverine forests, at altitudes up to 2 000 m.a.s.l. It is 9 to 15 meters high with a rough bark and glossy leaves that are softly haired below. The flowers are found in dense fragrant clusters, developing into round flattened capsules, 1.5 cm across (Dharani 2002).

Warburgia ugandensis
Common names: East African greenheart (Eng.); Ol-msogoni (Maa)
W. ugandensis grows in lower rain forests and more arid highland forests at altitudes from 1 000 to 2 000 m.a.s.l. It is a large tree up to 42 metres high (Flora Zambesiaca 2007) with a spreading crown of shiny leaves (Dharani 2002), which are used as livestock food (World Agroforestry Centre 2007). It has a rough bark that cracks and scales off and all parts of the tree have an aromatic hot taste (Dharani 2002). In Kenya, *W. ugandensis* flowers between December and January (World Agroforestry Centre 2007) with solitary flowers or in few-flowered cymes (Flora Zambesiaca 2007). The fruits develop in May in the end of the rainy season (World Agroforestry Centre 2007) into 3 to 5 cm long, hard spherical bodies with a waxy surface (Dharani 2002), which can remain on the tree for a longer period (World Agroforestry Centre 2007) until they are dispersed by animals (Chapman *et al.* 1999). The fruits contain several edible seeds (Dharani 2002) which are flat and 1 to 1.5 cm long with an oily endosperm (World Agroforestry Centre 2007).

Ficus lutea
Common names: Giant-leaved fig (Eng.); Reuseblaarvy (Afrikaans)
F. lutea grows in evergreen and riverine forests at altitudes up to 1 800 m.a.s.l. It is a hemi-epiphytic or secondarily terrestrial tree (Flora Zambesiaca 2007) up to 25 meters high with a spreading crown of glossy leaves. The species produces fleshy sessile figs that are 1.5 to 3 cm in size, which attracts insects, birds and mammals (PlantZAfrica.com 2007). The genus Ficus produces figs all year around due to its unique relation to the seed predator wasps that pollinate the genus. Ficus is the most important plant genus for fruit eating animals in the tropics, with *Cercopithecidae* known as one of the major frugivorous mammal families (Shanahan *et al.* 2001).

1.3 Aim of the study

The aim of this thesis is to relate the data from Hansson (in prep.) of utilization of tree species among a group of blue monkeys in the Sabaringo forest, Kenya, with the abundance of the same tree species. The hypothesis I am intending to test is that there is a difference between the abundance of the tree species and the extent to which they are used by the blue monkeys. This knowledge would be useful to have if conservation actions are to be carried out for the species, in order to focus on the maintenance of the most important tree species. Another hypothesis is that lactating and non lactating females show different preferences for tree species, based on their different nutritional needs. Since lactating females are crucial for the survival of the entire population, it is important to know if they prefer specific tree species that may otherwise be underrepresented when looking at the tree utilization of the species as a whole.

The tree species analyzed in this thesis are *Diospyros abyssinica*, (Giant Diospyros), *Euclea divinorum* (Diamond-leaved Euclea), *Turraea robusta* (Honeysuckle tree), *Warburgia ugandensis* (East African Greenheart) and *Ficus lutea* (Giant-leaved Fig). These are selected randomly from the ten most popular tree species used by the monkeys in the previous study (Hansson, in preparation). The usage of the remaining five species is analyzed in the corresponding thesis “Blue monkeys’ utilization of five tree species in relation to the abundance of each tree species: *Teclea nobilis*, *Elaeodendron buchananii*, Species 1, *Grewia bicolor* and *Ficus sycomorus*” (Ahlbäck, in press).

2 Methods

2.1 Study site

The Masai Mara National Reserve in southern Kenya lays on the edge of the Great Rift Valley, a few degrees below the equator. It is an extension of the vast Serengeti ecosystem in Tanzania consisting of open plains divided by the Mara River and its influents, forest patches and marshes. The reserve receives an annual rainfall of around 1 000 millimetres which is mainly concentrated to two rain seasons, although rain may fall throughout the year. The long rains come between March and June, and the short rains between mid-October and December. The mean altitude is 1 600 metres above sea level which gives the area a minimum temperature of 11°C and a maximum of 30°C, with December to March being the warmest months (Butchart 1997). The forests in the reserve and the surrounding areas function as dispersal zones for wildlife populations moving in and out of the reserve, but a progressive decline in vegetation diversity is observed in the ecosystem. The Maasai communities living in the surroundings of the reserve have traditionally used the area for herding cattle, but the land use of areas around the reserve has in recent years been shifting towards crop production. Hence, forests and grazing areas around the reserve are now being cleared on behalf of agriculture (Legilisho-Kiyiapi 1998).

This study was carried out in the Sabaringo Forest, a few kilometres outside the northern border of the Masai Mara at the base of the Oloololo escarpment. The forest covers an area of 24 ha which is divided by the Sabaringo River, and in the centre lays the lodge Kichwa Tembo Tented Camp. The forested area is dominated by tall trees with a thick floor vegetation of shrubs, herbs and vines. Due to an electric fence surrounding the lodge and most of the forest, it is protected from elephants pushing over trees and presumably also from larger carnivores (Butchart 1997). Within the lodge area lies 49 safari tents and thatched rondavels, a bar and a restaurant with adherent kitchen, a reception, a few tourist houses, a pool, the main office, two management houses, a staff quarter and a football field. The area is evidentially affected by human disturbance with garbage left around the staff quarter, and waste disposal sites which are either being burned or covered under a shallow layer of soil. Leftovers from the restaurant and the staff quarters are found in open trash cans, from which the monkeys sometimes feed (Hansson in prep.; Linderoth in prep.).

2.2 Data collection

The inventory of the trees surrounding the Kichwa Tembo Tented Camp was conducted in March 2007 by two teams, each with one Swedish student recording data and two local Maasai field workers with knowledge of the tree species. The study was conducted by dividing the forest with ropes, creating separated fields in order to exclude double recording of trees. Within these created patches we defined the species of each tree and measured their diameter with a diameter admeasure at a height of 1.30 m. Each tree's location was also marked with a GPS (VENTURE Cx GARMIN) and the information was used to make maps in ArcGIS 9.1. The borders of the area included in the study were determined by the fence around Kichwa Tembo in July 2006. An area belonging to a luxury part of the lodge, the Bateleur Camp, was not included since we had no access to that area. A smaller area consisting of an old covered disposal site was excluded, since it was considered as too dangerous to walk in.

A tree was defined as a lignified plant with a diameter of at least 5 cm at a height of 1.30 m. Dead and fallen branches or trees were not included, neither were vines. If a tree was surrounding another tree or if it was hollow, the measured diameter was divided by two to get a more accurate calculation of the tree's biomass. If a tree was divided into several branches below 1.30 m, each branch was measured separately but were all counted as a single tree with the same GPS position.

2.3 Data treatment

The measured diameter was used to calculate the surface area in diameter of each branch with the formula $\pi * r^2$. By adding these values we received the total surface area in diameter of each tree (stem area) and hence of each tree species in the forest. By using the total stem surface area in diameter, the total number of trees and the total number of branches for each tree species, we received three biomass estimations of the trees in the area. These tree data were compared with utilization data for *C. mitis stuhlmanni*, collected in the same area in July 2006 by Nilsson, Linderoth and Hansson together with their field workers. Those data describe the percentage of each tree species in the diet of the monkeys, e.g. % of food intake of the tree species respectively (“foraging”) and the time monkeys spent in each tree species (“positioning”). For details, see Hansson (in prep.).

In this descriptive study, no statistical analysis has been made.

3 Results

3.1 The most common tree species in the area

The total number of trees in the investigated area was 10 260, which belonged to 51 identified and 17 unidentified tree species. For most of these species only a few specimens were found; the area was dominated by 15 species that made up 96 % of all counted trees (Fig. 1).

Fig. 1 shows the relative abundance of the 15 most common species in the area; *Acacia aristida,* unidentified species 1*, Croton dichogamus, Diospyros abyssinica, Eleadendron buchananii, Euclea divinorum, Euphorbia candelabrum, Ficus lutea, Ficus sycomorus, Ficus thoningii, Grewia bicolour, Teclea nobilis, Turraea robusta, Warburgia ugandensis* and the unidentified species 2. The abundance is illustrated by the three biomass estimates; the surface area in diameter (stem area), the total number of trees, and the total number of branches.

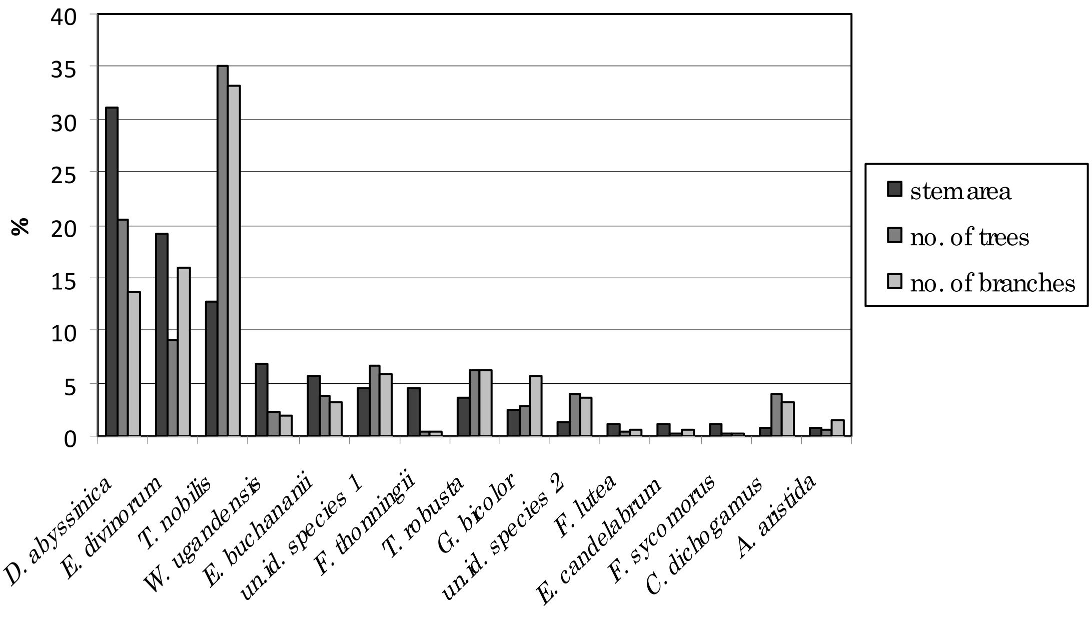


Fig. 1. The relative abundance of the 15 most common tree species, illustrated by three different biomass estimates.

The distribution of the 10 most popular tree species among the monkeys is shown in Fig. 2. Due to problems with the GPS, approximately 2000 trees' locations are missing, which results in seemingly non-forested areas where there in reality was tree cover.

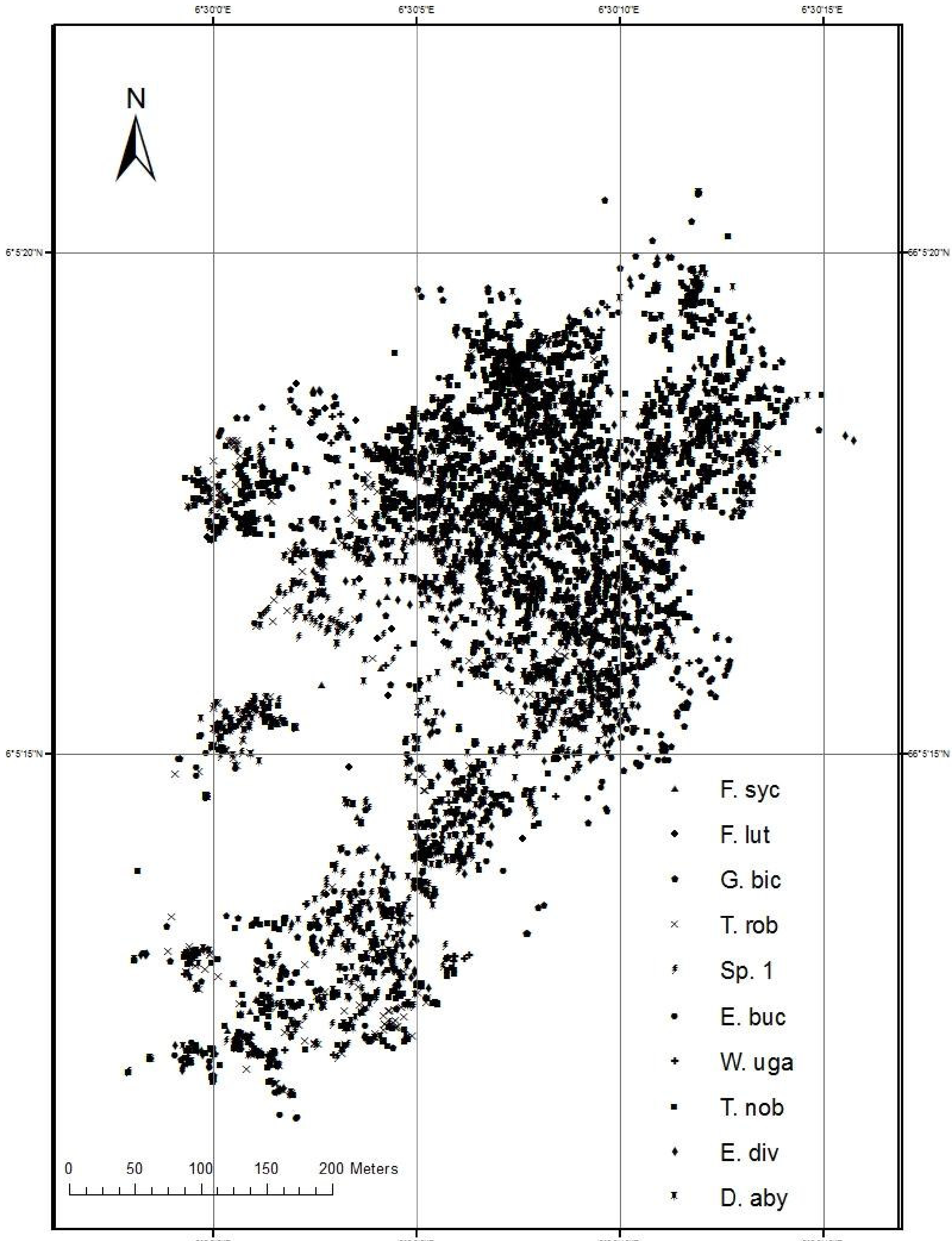


Fig. 2. The forested investigated area, visualized by the distributions of Diospyros abyssinica, Euclea divinorum, Teclea nobilis, Warburgia ugandensis, Eleadendron buchananii, *Species 1*, Turraea robusta, Grewia bicolour, Ficus lutea *and* Ficus sycomorus. *Geographic Coordinate System: WGS 1984. Projected Coordinate System: Mercator.*

3.2 Tree species used by all females for foraging and positioning

The results from the inventory concerning the five species are in part 3.2, 3.3 and 3.4 compared with the earlier collected monkey data.

Figure 3 compares the three different biomass estimates of the five focal tree species with the monkeys' utilization of each tree species for foraging and for positioning. In relation to its abundance, *F. lutea* was used at a much higher extent than it occurs in the area. It was used more for foraging than for positioning, which was also the case for *D. abyssinica*. *E. divinorum* and *T. robusta* were on the other hand used more as position trees, while the species *W. ugandensis* seemed to have a more general function for the monkeys and was used at similar extent both for foraging and positioning.

The stem area measurement is the biomass estimation that best matches the foraging utilization for *D. abyssinica, W. ugandensis, T. robusta* and *F. lutea.* For *E. Divinorum*, the best measurement is the number of trees. For the utilization of tree species for positioning, the stem area measurement is also the best matching estimation concerning the species *D. abyssinica*, *E. divinorum*, *W. ugandensis* and *F. lutea*. For *T. robusta*, both the stem area measurement and the number of stems are the best matching estimates.

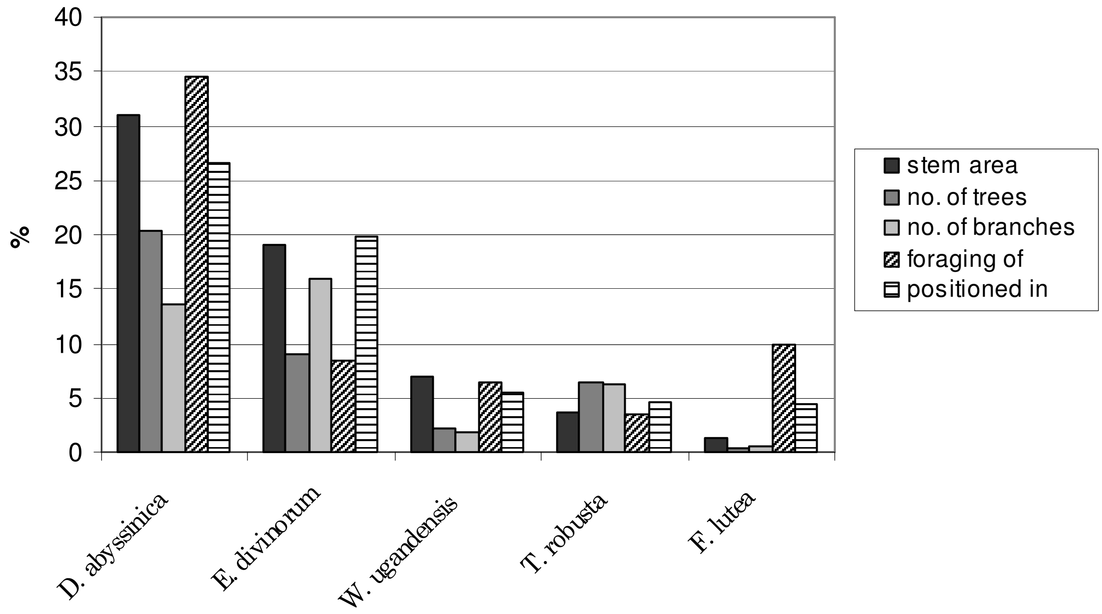
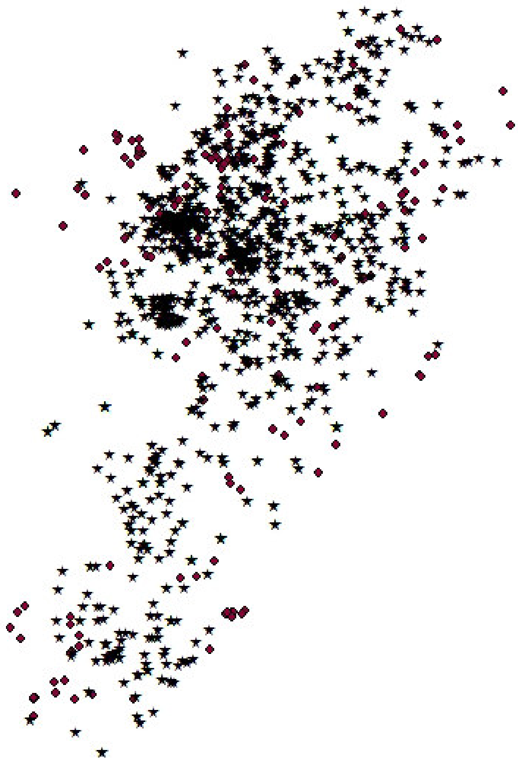


Fig. 3. Tree species used by all females for foraging and positioning.

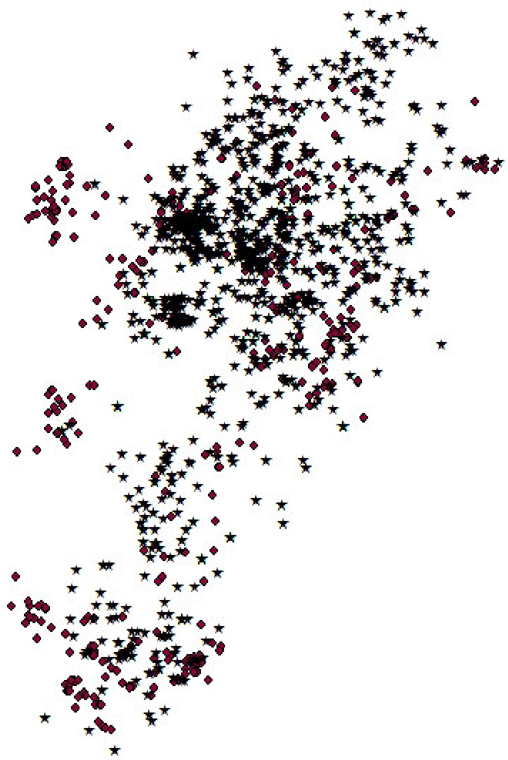
Maps showing the distribution of the five tree species in the investigated area can be seen in Fig. 4. Each map also displays the sites where the female blue monkeys were observed by Nilsson, Linderoth and Hansson in 2006.

D. abyssinica

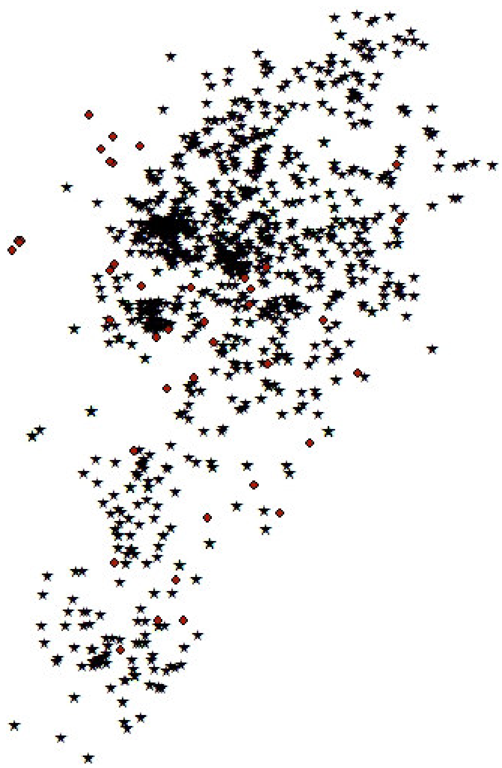
E. divinorum



W. ugandensis



T. robusta



F. lutea

Fig. 4. Each of the five tree species distribution in comparison to the sites where female blue monkeys were observed (shown as stars) in 2006.

3.3 Trees species used for foraging

3.3.1 Differences between lactating and non-lactating females

The lactating and non-lactating females' utilization of different tree species for foraging is shown in Fig. 5, as a proportion of all foraging observations. These stacks show the proportion of different food items of the foraging of each tree species (Hansson in prep.). The three types of biomass estimates for the tree species are also included in the figure.

Results from 2006 showed that there were differences in food preferences between lactating and non-lactating females. *D. abyssinica, E. divinorum* and *F. lutea* were more utilized by the non-lactating females, while *W. ugandensis* and *T. robusta* were more utilized by the lactating females.

The latter group's use of *W. ugandensis*, *T. robusta* and *F. lutea* seems to best match the stem area measurement, while the use of *E. divinorum* best matches the number of trees of the species. Concerning the use of *D. abyssinica*, both the stem area measurement and the number of trees are the best matching estimation. For the non-lactating females, the stem area measurement is the biomass estimation that best matches the utilization of *D. abyssinica*, *T. robusta* and *F. lutea.* The use of *E. divinorum* matches the species number of trees best, while both the stem area measurement and the number of trees are the best matching estimation for the use of *W. ugandensis.*

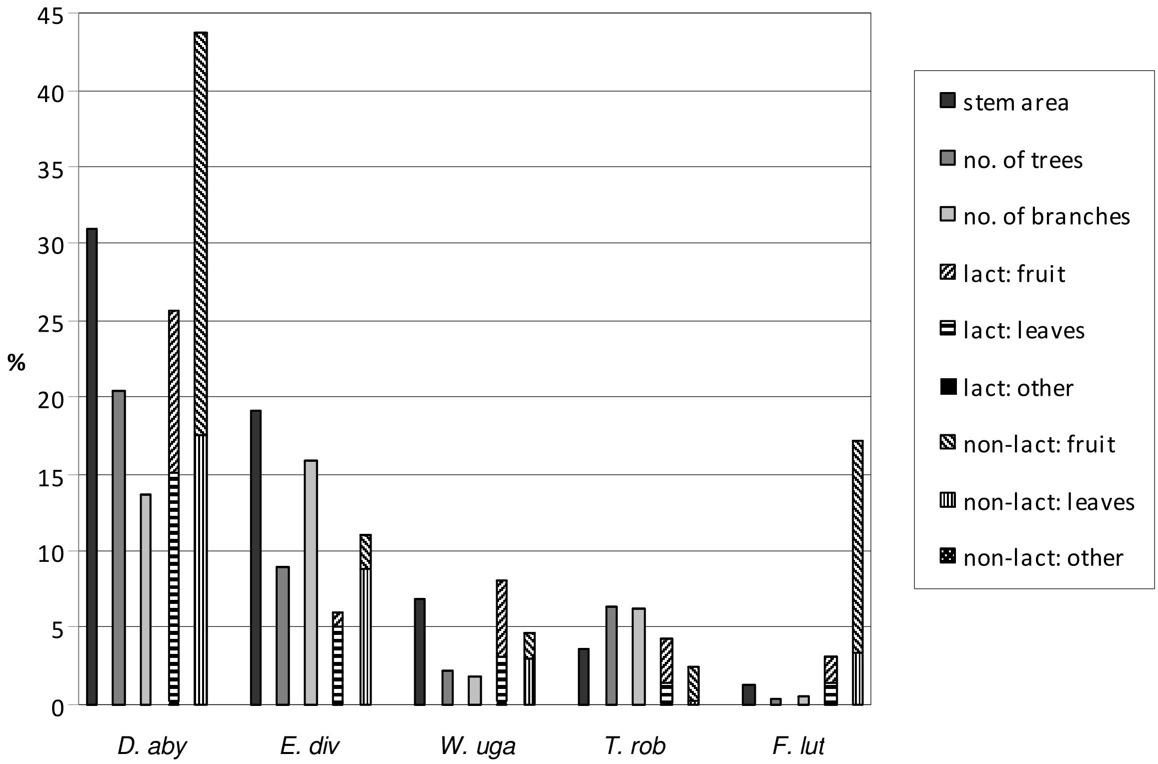


Fig. 5. Abundance of the five focal tree species and their utilization for foraging, by lactating and non-lactating females. The staples with the tree utilization show which parts of the trees that were the preferred food items.

3.3.2 The tree species' popularity

Fig. 6 shows the popularity among all female blue monkeys for foraging of the five tree species. *F. lutea* was used much more than its occurrence concerning all the biomass estimations. When not considering the stem area measurement, the use of *D. abyssinica* and *W. ugandensis* corresponded roughly with the occurrence of the two species. Both *E. divinorum* and *T. robusta* were used with less frequency than they were occurring in the area.

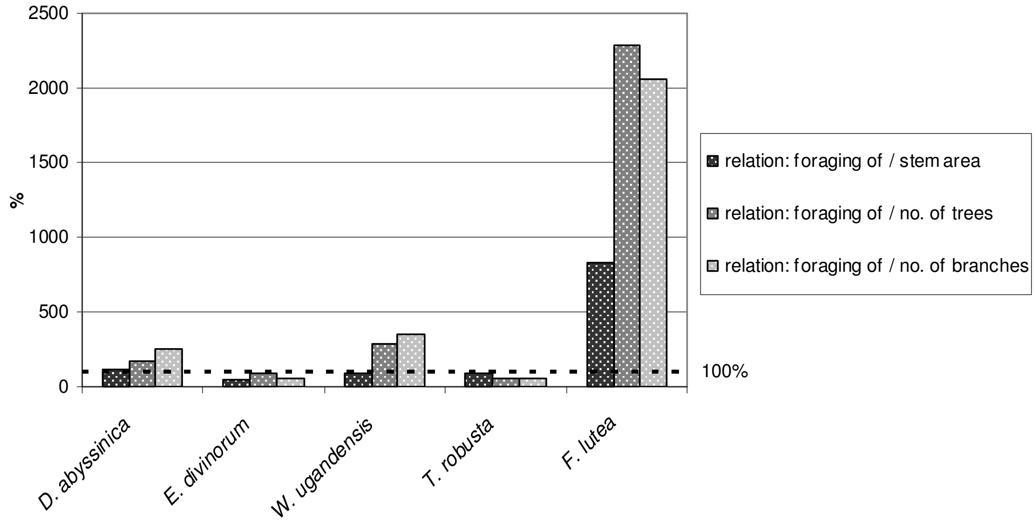


Fig. 6. The relation between all females' use of trees for foraging of and tree species abundance, based on the three biomass measurements calculated by dividing the utilization frequency with the species' occurrence frequency. A value over 100 % indicates utilization greater than the species occurrence.

3.4 Tree species used for positioning

3.4.1 Differences between lactating and non-lactating females

The lactating and non-lactating females' utilization of the different tree species for being positioned in is shown in Fig. 7 as a proportion of all recorded observations of their positioning in trees (Hansson, in prep.). The three types of biomass estimates for the tree species are also included in the figure.

Results from 2006 shows that *E. divinorum, T. robusta* and *F. lutea* were used more by non-lactating than by lactating females. The species *D. abyssinica* and *W. ugandensis* seemed to be used at quite similar extents by both lactating and non-lactating females.

The lactating females' use of tree species matches the stem area measurement best for *D. abyssinica, W. ugandensis, T. robusta* and *F. lutea.* The use of *E. divinorum* is best matched by the species' number of stems. The non-lactating females' use of tree species also best matches the stem area measurement for *D. abyssinica, W. ugandensis* and *F. lutea,* as well as for *E. divinorum.* For *T. robusta,* the use is best matched by the species number of stems.

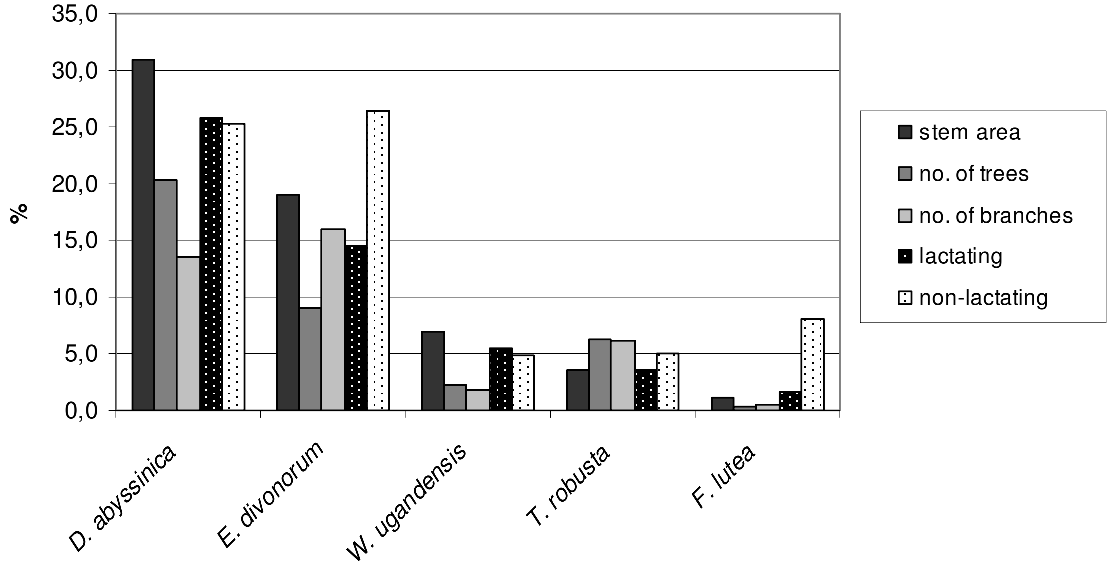


Fig. 7. Tree species used by lactating and non-lactating females for positioning.

3.4.2 The tree species' popularity

Fig. 8 shows the popularity among all females for being positioned in the five tree species. *F. lutea* and *E. divinorum* were used more than their occurrence concerning all the biomass measurements. When not looking at the stem area measurement, that was also true for *D. abyssinica* and *W. ugandensis*. *T. robusta* was used at a higher extent than the species occurred according to the stem area measurement, but when considering both its number of trees and stems it was used with less frequency.

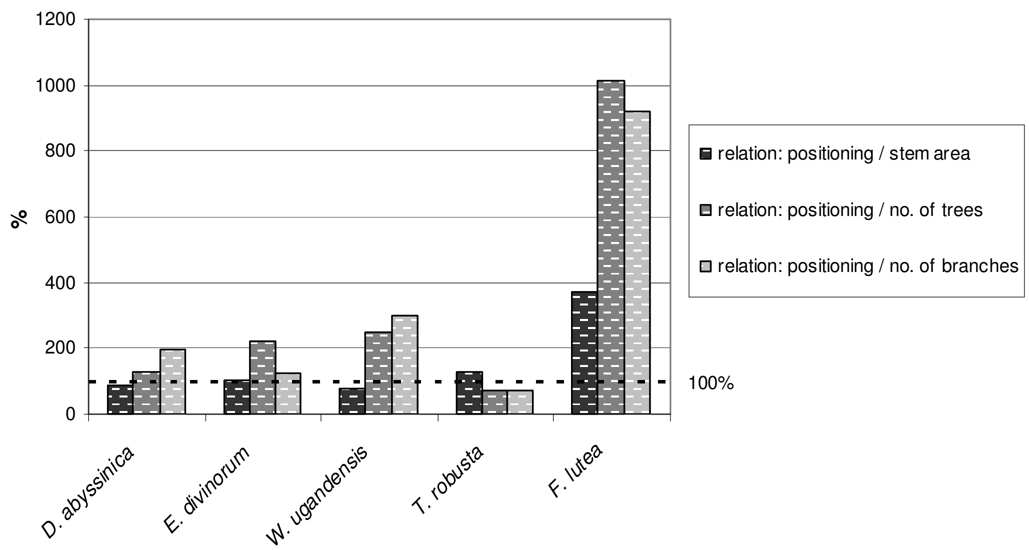


Fig. 8. The relation between all females´ use of trees for being positioned in and the species abundance, measured by the three different biomass estimates. The values were calculated by dividing the utilization frequency with the species' occurrence frequency. A value over 100 % indicates utilization greater than the species' occurrence.

4 Discussion

4.1 Tree species preferred for foraging

The diet of blue monkeys has in several studies been shown to consist mainly of elements from a few plant species (Fairgrieve & Muhumuza 2003). This is also the case in our study, where *Ficus lutea* was the undisputedly most preferred species to forage of followed by *Warburgia ugandensis* and *Diospyros abyssinica*. These results correspond with the well-known popularity of fig species as a food item among *C. mitis* (Tashiro 2006). Data from Uganda has for example showed that 30.8 % of all food eaten by C. mitis consisted of figs from the species *F. exasperata*, whilst three fig species made up 17.6 % of the food of a Kenyan population of *C. mitis* (Shanahan *et al*. 2001). In the Kanyawara area of the Kibale forest, Uganda has *C. mitis stuhlmanni* also been observed to centre their foraging activities around fruit bearing fig trees (Butynski 1990). The fact that fig species have an unsynchronized fig production makes them a reliable food source throughout the year and particularly in seasons when other fruiting trees lack fruit (Shanahan *et al*. 2001). The large utilization of *F. lutea* as a food item in our study also corresponds to the fact that fruit is thought to be the most valuable component, concerning nutritional values, in the diet of blue monkeys (Fairgrieve & Muhumuza 2003) and their primary energy source (Twinomugisha *et al*. 2006).

Although the importance of fig species as food resources mainly is due to their fruits, the leaves are also eaten and it is stated that all the large primate species consume leaves of fig species when their ordinary food items are scarce (Tweheyo & Obua 2001). Also in our blue monkey study where fig leaves eaten (Nilsson in prep**;** Linderoth in prep.) and the leaves of *F. lutea* has been proved to be a popular food item, mainly among lactating females.

The foraging behaviour of our focal group of *C. mitis stuhlmanni* was studied in July 2006. As mentioned before, *D. abyssinica* and *E. divinorum* flower in Zimbabwe between October to January and August to January respectively. *W. ugandensis* produces fruit in May and *F. lutea* is fruiting all year around. I could not find any reference for flowering or fruit bearing periods of *T. robusta*. Hence, the only tree species likely to bear fruit at the time of that study were *W. ugandensis* and *F. lutea*. The blue monkeys were however observed to eat fruits from all five tree species, but based on the known flowering periods it is still likely to assume that at least some of the studied tree species did not bear much ripe or even immature fruit at the time of the study. The fact that two observations were made of females eating flowers from *W. ugandensis* and *T. robusta* could support that theory. It should also be taken into consideration that even if some of the species had fruit at that time, as shown in Hansson (in prep.), the monkeys may still have rejected them at some extent due to the fruits non-optimal nutritional value (as showed by Worman & Chapman in 2005) and thus making the species look less attractive than they might have been during their prime fruiting time. This hypothesis may correlate with results from the Budongo Forest Reserve in Uganda showing that *Cercopithecus mitis stuhlmanni* when foraging from fig species chooses ripe fruits over young, developing and unripe fruits (Tweheyo & Obua 2001). Concerning the use of *F. lutea* however, the species has proven to be the clearly most popular tree species for foraging, so there is no evidence to the assumption that the fruits of that species may have been unripe at the time of the monkey study.

In our study area, open trash cans were situated near the restaurant and the staff quarters, often visited by the monkeys (Linderoth in prep.). Trees growing close to these areas may therefore be used rather because of their location, than due to their actual assets. The fact that *C. mitis* populations with home ranges in contact with human communities are known to learn the distinct times when leftovers are thrown and adjust their visits to these moments (Rowell 1984), may correlate with that theory. However, the map of the distribution of *F. lutea* shows that the species occurred roughly all over the investigated area, and its popularity can therefore not be attributable to the more limited distribution of trash cans.

4.2 Tree species preferred for positioning

All tree species were used both for foraging and position, although in various degrees. This may be due to time and energy saving among the monkeys, or an aversion to leave the food sources unattended. The most popular species, *Ficus lutea*, is a large tree with an extensive crown which could be desirable for the monkeys as it allows resting places high above ground protected from potential predators. Even though the forest is surrounded by an electrical fence and hence quite protected from larger predators, with exceptions from leopards and pythons, anti-predation behaviour would still be natural for the monkeys. This explanation could be supported by research from the Tana River area in Kenya, which showed that trees used for sleeping sites by both baboons and crested mangabeys shared several important features. They were generally medium to large trees, with large emerging crowns and a higher number of branches than the average trees, as well as a low leaf cover and poor to moderate accessibility. One of the tree species selected and repeatedly used by the primates in that study was *Ficus sycomorus*, which had a canopy cover between 25 and 35 %. A Diospyros species, *D. mespiliformis*, was although its large size not used by the primates, which was explained by the fact that it generally had over 85 % canopy cover and therefore had a deterrent effect on the monkeys. Also our study has showed the Ficus species to be much more utilized for positioning than the Diospyros species, and the use of sleeping trees with low canopy cover has also been observed among several Macaca species as well as *Papio ursinus* (Wahungu 2001). Observations by Treves (2002) that there is a higher risk for arboreal monkeys of being attacked when they are closer to the ground than higher up can also support the explanation of our monkeys' selection of tree species.

The only tree species except *F. lutea* that was used more than its abundance concerning all three biomass measurements was *Euclea divinorum*, which was at most used just over two times its abundance. However, when not taking the stem area measurement into account *Warburgia ugandensis* was more popular with a utilization of approximately 3 times is abundance at most. The latter species' popularity could be explained by the reasoning above, while the cause of the popularity of *E. divinorum* would be another. Treves (2002) has shown that the risk for arboreal monkeys of being attacked is higher in trees with fewer leaves and that they are not as alert when staying in dense foliage. Based on that, the richly branched i.e. richly leafed *E. Divinorum* would provide good shelter for the blue monkeys in our study, but its small size would on the other hand be negative for them by exposing them more to predators on the ground (Treves 2002). Another, and perhaps more likely, explanation for its popularity is that it could be used as a steppingstone by the monkeys between the high trees and the ground.

The reasoning regarding tree species used for foraging and their distance to the waste deposition sites can also be made, and at an even higher extent, concerning the trees used for positioning. It is likely to assume that the monkeys have learned the places and the approximate times that leftovers are thrown, and therefore tend to wait for these moments in the areas surrounding the trash cans (as stated by Rowell 1984). The popularity of *F. lutea* can however, as noted before, not be attributable to the locations of the waste deposition sites.

4.3 The future of the blue monkey

Frugivorous primates are shown to be very sensitive to forest clearings as they may reduce the populations due to scarce food availability. There is often a mutual relationship between the fruit bearing plants and the frugivors (Chapman *et al*. 2002), built on the animals' dispersal of seeds when moving around in the forest (Cordeiro *et al*. 2004). A scenario such as a forest clearing without re-planting may hence result in a negative loop, were the trees' loss of vectors create a less efficient seed dispersal, and thereby an additional decrease in plant distribution. This will eventually cause an even further decline in the frugivor populations as there will be fewer trees and thereby lower availability on fruit. This is an important aspect when dealing with conservation work, since primates are especially vulnerable to population decreases (Lambert 2003). Continuing declines in group sizes of *C. mitis* have been observed in the Kibale National Park, Uganda, even decades after large timber cuttings (Chapman *et al*. 2000). Observations from the Budongo Forest Reserve have however showed that population densities of the species are higher in logged areas than in unlogged, which indicates the difficulty of predicting the species response to habitat changes (Plumptre & Reynolds 1994).

The species' decline in areas were large timber cuttings have taken place can be related to observations that *C. mitis*, although it is considered to be the most widespread of the African guenons, has proved to be unwilling of colonizing fragmented forests. The feature emanates from the fact that the species' dispersal is male-biased, which is limiting its ability to tackle intense forestry. Although *C. mitis* still can be found in small forest fragments, these populations are mainly survival groups originating from periods with larger forests rather than newly immigrated animals. (Lawes & Chapman 2003). Forest fragments have also been showed to be poor habitats for the species because they lack sufficient fruiting trees. This is not a result of an absence of frugivores in fragmented forests, but rather due to the fact that the species' occurrence in a territory has a strong correlation to the basal area density of the important fruit producing trees in the territory. This implicates that fragments would not be used even if they have connections to larger forests by dispersal corridors, because they have too low basal area density of food trees (Worman & Chapman 2006). Although conservation and maintenance of corridors between fragmented forests may not have a direct effect on populations of *C. mitis*, it can in the long term perspective be of great importance for the survival of the species (Swart & Lawes 1996). Lawes & Chapman (2003) states that *C. mitis'* low ability to cope with fragmentation is worrying, given the deforestation occurring in Africa, and makes the species' need of careful conservation work greater than most other.

According to the IUCN redlist, *C. mitis stuhlmanni* is not dependent on any conservation work to ensure the species survival (IUCN 2007). This may however change in the future, due to the increasing pressure on unexploited areas (Legilisho-Kiyiapi 1998). In that case, focus should be on protecting the species *Ficus lutea* as well as *Warburgia ugandensis* and *Diospyros abyssinica* from forest clearings, as they are the tree species most utilized by the blue monkeys analyzed in this study.

When it is not possible to protect existing old forests, it can be of importance to preserve secondary forests on older anthropogenic grass-lands, since these have been proved able to harbour some primate species including *C. mitis* (Lwanga 2006). A sustainable land use, such as selective logging with a low intensity (Chapman *et al*. 2000), as well as protection of sufficient dispersal corridors (Swart & Lawes 1996) could also be parts of future conservation plans.

4.4 The necessity of continued research

Since the results displayed in this report are only based on one month's research, there is a need of further study seasons in the same area to ensure reliable conclusions. It is critical to understand the fruit bearing periods of all tree species in the investigated area. Knowledge of the change in nutritional content of the fruits over a season would also be valuable, in order to know why some fruits are rejected on behalf of others.

The fact that the observed group of monkeys were shown to eat from open garbage cans (Ingman in prep.) may affect the trustworthiness of the results, why it should also be preferable to repeat the study in a forest with lesser human influence, although this is difficult due to lack of habituated monkey populations. This is even more relevant since the diet of *C. mitis stuhlmanni* is known to vary a lot between groups, and therefore the results from one place may not be representative for the species in general (Tashiro 2006).

5 Acknowledgements

I am grateful for the help provided by the Maasai field workers whose knowledge of tree species was essential to the study, and for the permission from Jenny Nilsson, Emilie Linderoth and Ann-Charlotte Hansson to use their data. I would also like to thank our collective supervisor Jens Jung for his support during the field work and the writing of this thesis as well as and Nicklas Ahlm from the Swedish Forest Agency for lending us equipment and assisting us in the creation of the tree distribution maps. A special thanks goes to Lina Ahlbäck for good cooperation, company and support during the whole process, and without whom this work could not have been completed.

Bibliography

Literature and publications

Ahlbäck, L. in press. Blue monkeys' utilization of five tree species in relation to the abundance of each tree species: *Teclea nobilis*, *Elaeodendron buchananii*, Species 1, *Grewia bicolor* and *Ficus sycomorus.* Degree thesis Swedish University of Agricultural Sciences (SLU)

Butchart, D. 1997. *Kichwa Tembo Tented Camp EcoGuide*. Conservation Corporation Africa

Butynski, T.M. 1990. Comparative ecology of blue monkeys (*Cercopithecus mitis*) in high and low density subpopulations. *Ecological Monographs* **60**: 1– 26

Chapman, C.A., Chapman, L.J., Kaufman, L., Zanne, A.E. 1999. Potential causes of arrested succession in Kibale National Park, Uganda: growth and mortality of seedlings. *African Journal of Ecology* **37**: 81-92

Chapman, C.A., Balcomb, S.R., Gillespie, T.R., Skorupa, J.P., Struhsaker, T.T. 2000. Long-term effects of logging on African primate communities: a 28-year comparison from Kibale National Park, Uganda. *Conservation Biology* **14**: 207-217

Chapman, C.A., Chapman, L.J., Cords, M., Gathua, J.M., Gautier-Hion, A., Lambert, J.E., Rode, K., Tutin, C.E.G., White, L.J.T. 2002. Variation in the diets of *Cercopithecus* species: Differences within forests, among forests, and across species. In: Glenn, M.E. and Cords, M. [Editors]: *The Guenons: Diversity and Adaptation in African Monkeys.* 325-350

Chapman, C.A., Lawes, M.J., Eeley, H.A.C. 2006. What hope for African primate diversity? *African Journal of Ecology* **44**: 116-133

Cordeiro, N.J., Patrick, D.A.G., Munisi, B., Gupta, V. 2004. Role of dispersal in the invasion of an exotic tree in an East African submontane forest. *Journal of Tropical Ecology* **20**: 449-457

Cords, M. 1986. Interspecific and intraspecific variation in diet of two forest guenons, Cercopithecus ascanius and C. mitis. *Journal of animal ecology* **55**: 811-827

Cords, M. 2002. Foraging and safety in adult female blue monkeys in the Kakamega Forest, Kenya, In: Miller [Editor]; *Eat or be Eaten: Predator Sensitive Among Primates.* 205-221

Dharani, N. 2002. *Field Guide to Common Trees & Shrubs of East Africa,* Struik Publishers (ISBN: 1-86872-640-1)

Fairgrieve, C., Muhumuza, G. 2003. Feeding ecology and dietary differences between blue monkey (Cercopithecus mitis stuhlmanni Matschie) groups in logged and unlogged forest, Budongo Forest Reserve, Uganda. *African Journal of Ecology* **41**: 141-149

Gautier-Hion, A. 1988. The diet and dietary habits of forest guenons, In: Gautier-Hion, Bourliere, Gautier [Editors]; *A Primate Radiation: Evolutionary Biology of the African Guenons,* Cambridge University Press

Hansson, A-C. in preparation. Foraging ecology of lactating and non-lactating blue monkeys, *Cercopithecus mitis stuhlmanni.* Degree thesis Swedish University of Agricultural Sciences (SLU)

Lambert, J.E. 2003. Communities of frugivores: the relative role of anthropoids in seed dispersal. *American Journal of Physical Anthropology* **36**: 134-135. Special Issue in: Relethford [Editor]; *72nd Annual Meeting of the American Association of Physical Anthropologists*, Tempe, Arizona, April 2003. (ISSN: 0002-9483)

Lawes M.J., Henzi S., Perrin M. 1990. Diet and feeding behavior of Samango monkeys (*Cercopithecus mitis labiatus*) in Ngoye Forest, South Africa. *Folia Primatologica* **54**: 57-69

Lawes, M.J., Chapman, C.A. 2003. Determinants of patch occupancy and the distribution of blue monkey groups: lessons for conservation of guenons. *American Journal of Primatology* **60**. Special Issue: *Abstracts of Presentations Twenty-sixth Annual Meeting The American Society of Primatologists Hosted by the Department of Anthropology and the University of Calgary Alberta*, Canada, July 30th to August 2nd, 2003

Linderoth, E. in preparation. Human impact on food choice and diurnal behaviour in blue monkeys (*Cercopithecus mitis stuhlmanni*). Degree thesis Swedish University of Agricultural Sciences (SLU)

Lwanga, J.S. 2006. Spatial distribution of primates in a mosaic of colonizing and old growth forest at Ngogo, Kibale National Park, Uganda. *Primates* **47**: 230-238

Nilsson, J. 2007. Mother-young interactions and suckling behaviour in blue monkeys, *Cercopithecus mitis stuhlmanni.* Degree thesis Swedish University of Agricultural Sciences (SLU)

Plumptre, A.J., Reynolds, V. 1994. The effects of selective logging on the primate populations in the Budongo Forest Reserve, Uganda. *Journal of applied Ecology* **31**: 631– 641

Rowell, T.E. Markattor, makaker, babianer, In: Macdonald, D.W. [Editor]; *Jordens djur - Aporna*, Bonnier Fakta Bokförlag AB, 1984, 74-89 (ISBN: 91-34-50350-1)

Rudran, R. 1978. Socioecology of the blue monkeys (*Cercopithecus mitis stuhlmanni*) of the Kibale Forest, Uganda. *Smithsonian Contributions to Zoology* **249**: 1– 88

Shanahan, M., So, S., Compton, S.G., Corlett, R. 2001. Fig-eating by vertebrate frugivores: a global review. *Biological Reviews* **76**: 529-572

Stuart, C. 1997. *The larger mammals of Africa*, Struik publishers. (ISBN: 1 86825 757 6)

Swart, J., Lawes, M.J. 1996. The effect of habitat patch connectivity on samango monkey (Cercopithecus mitis) metapopulation persistence. *Ecological Modelling* **93**: 57-74

Tashiro, Y. 2006. Frequent insectivory by two guenons (Cercopithecus lhoesti and Cercopithecus mitis) in the Kalinzu Forest, Uganda. *Primates* **47**: 170-173

Treves, A. 2002. Predicting predation risk for foraging, arboreal monkeys, In: Miller [Editor]; *Eat or be Eaten: Predator Sensitive Foraging Among Primate.* 222-236. Cambridge University Press 2002 (ISBN: 0521011043)

Tweheyo, M., Obua, J. 2001. Feeding habits of chimpanzees (Pan troglodytes), red-tail monkeys (Cercopithecus ascanius schmidti) and blue monkeys (Cercopithecus mitis stuhlmanii) on figs in Budongo Forest Reserve, Uganda. *African Journal of Ecology* **39**: 133-139

Twinomugisha, D., C.A. Chapman, M.J. Lawes, C. Worman, and L. Danish. How does the golden monkey of the Virungas cope in a fruit scarce environment? In: Newton-Fisher *et al* [Editors]. *Primates of Western Uganda*. 45-60. Springer, 2006 (ISBN-10: 0387323422)

Wahungu, G.M. 2001. Common use of sleeping sites by two primate species in Tana River, Kenya. *African Journal of Ecology* **39**: 18-23

Williamson, E.A. 1993. Methods used in the evaluation of lowland gorilla habitat in the Lope Reserve, Gabon. *Tropics* **2**: 199-208

Worman, C.O'D., Chapman, C.A. 2005. Seasonal variation in the quality of a tropical ripe fruit and the response of three frugivores. *Journal of Tropical Ecology* **21**: 689-697

Worman, C.O'D., Chapman, C.A. 2006. Densities of two frugivorous primates with respect to forest and fragment tree species composition and fruit availability. *International Journal of Primatology* **27**: 203-225

Internet

Wildlife Conservation Society, WCS, (http://www.wcs.org/sw-home)

1. “ *Kenya*” Downloaded on 13 June 2007
   http://www.wcs.org/international/Africa/kenya

International Union for Conservation of Nature and Natural Resources, IUCN, Red List of Threatened Species (http://www.iucnredlist.org/)

1. "*Cercopithecus mitis* ssp. *stuhlmanni*"
   Butynski, T. & Members of the Primate Specialist Group 2000. *Cercopithecus mitis* ssp. *stuhlmanni*. In: IUCN 2007. *2007 IUCN Red List of Threatened Species.* Downloaded on 13 June 2007
   http://www.iucnredlist.org/search/details.php/39991/all
2. "*1994 Categories & Criteria (version 2.3)*" Downloaded on 13 June 2007
   http://www.iucnredlist.org/info/categories_criteria1994

African Mammals Databank, (http://www.gisbau.uniroma1.it/amd/)

1. "*Cercopithecus mitis*" Downloaded on 13 June 2007
   http://www.gisbau.uniroma1.it/amd/homespec.html

Flora of Zimbabwe, (www.zimbabweflora.co.zw)

1. "*Diospyros abyssinica*"
   Hyde, M.A. & Wursten, B. *Flora of Zimbabwe: Species information: Diospyros abyssinica.* Downloaded on 23 July 2007
   http://www.zimbabweflora.co.zw/speciesdata/species.php?species_id=143930
2. "*Euclea divinorum*"
   Hyde, M.A. & Wursten, B. *Flora of Zimbabwe: Species information: Euclea divinorum.* Downloaded on 23 July 2007
   http://www.zimbabweflora.co.zw/speciesdata/species.php?species_id=143880

World Agroforestry Centre, (http://www.worldagroforestrycentre.org)

1. "*Euclea divinorum*" Downloaded on 3 December 2007
   http://www.worldagroforestrycentre.org/sea/Products/AFDbases/af/asp/SpeciesInfo.asp?SpID=17994

2. "*Warburgia ugandensis*" Downloaded on 3 December 2007
   http://www.worldagroforestrycentre.org/sea/Products/AFDbases/af/asp/SpeciesInfo.asp?SpID=1699

Flora Zambesiaca, Royal Botanic Gardens, Kew, (http://www.kew.org/efloras/search.do)

1. "*Warburgia ugandensis*"
   FZ volume:7 part:4 (1990) Canellaceae by B. Verdcourt. Downloaded on 13 June 2007
   http://www.kew.org/efloras/namedetail.do?qry=namelist&flora=fz&taxon=5696&nameid=14460

2 "*Ficus lutea*"
   FZ volume:9 part:6 (1991) Moraceae by C. C. Berg. Downloaded on 13 June 2007
   http://www.kew.org/efloras/namedetail.do?qry=namelist&flora=fz&taxon=74&nameid=346

PlantZAfrica.com, South African National Biodiversity Institute
(http://www.plantzafrica.com/index.html)

1. "*Ficus lutea*"
   Jan-Hakon Burring, Kirstenbosch National Botanical Garden, March 2004. Downloaded on 20 July 2007
   http://www.plantzafrica.com/plantefg/ficuslutea.htm

North Central Research Station, (http://ncrs.fs.fed.us/)

1. *"Forest cover type, habitat diversity, and anthropogenic influences on forest ecosystems adjoining the Maasai Mara National Reserve, Kenya"*
   Legilisho-Kiyiapi, J. 1998. Downloaded on 6 August 2007
   http://ncrs.fs.fed.us/pubs/gtr/other/gtr_nc212/gtr_nc212ao.pdf