Feeding ecology of a highland population of hamadryas baboons (*Papio hamadryas*) at Borena-Sayint National Park, northern Ethiopia

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Abstract

Studying the diet and feeding behavior of primates is essential to understanding their ecology and designing effective conservation plans. Despite decades of study on the hamadryas baboon (*Papio hamadryas*) in lowland habitats, little is known about the feeding ecology of this species in highland ecosystems. To address this empirical gap, we tracked temporal changes in vegetation abundance and their relation to the dietary choices of hamadryas baboons in highland habitat at Borena-Sayint National Park (BSNP) in northern Ethiopia. We performed behavioral scan sampling on a focal study band of 21-37 hamadryas baboons over a 12-month period. We found that mature and young leaves were the most abundant plant parts throughout the year while fruits and flowers were the least abundant, with significant seasonal variation that followed the bimodal pattern of rainfall characteristic of the Ethiopian highlands ecosystem. The annual diet of hamadryas baboons at BSNP consisted mostly of fruits (32.0%) and graminoid blades (21.2%), and included 52 food species across 22 families of plants and 3 families of animals. Food raided from nearby farms accounted for 8.8% of the diet. The availability of fruits and flowers was positively correlated with their consumption, suggesting these are preferred foods, whereas graminoid blades, and leaves appear to be less preferred foods. The feeding ecology of hamadryas baboons at BSNP is considerably different from that of lowland populations. The well-studied lowland hamadryas baboons in Awash National Park obtain much of their diet from *Acacia* species and palm fruit, whereas those at BSNP, where *Acacia* trees are rare and palms are absent, relied on *Olinia rochetiana* and *Rosa abyssinica* for a combined 27% of their annual diet. The reliance of hamadryas baboons on cultivated foods for nearly one-tenth of their diet indicates that conflict with humans occurs at BSNP and warrants more detailed study so that this issue can be addressed in conservation plans for the area.

Keywords Conflict, Conservation, Cultivated Crops, Diet, Hamadryas baboon, Phenology

Introduction

Primatologists have long been interested in how diet varies with spatiotemporal differences in food availability (Oates 1977, 1987; Kaplin and Moermond 2000; Lambert and Rothman 2015; Tesfaye et al. 2021). This line of inquiry provides insight into the preferred foods of primates as well as the foods they fall back on during times of scarcity (Marshall et al. 2009; Hanya and Chapman 2013). Primate diets often differ across space and time with the same species sometimes having very dissimilar diets at different locations (Richard 1974; Gathua 2000; Chapman et al. 2002; Mekonnen et al. 2018). Species occurring across a wide elevational gradient can differ in diet because of variation in the foods available at different elevations. For example, *Colobus angolensis* in montane forest at Nyungwe National Park, Rwanda rely heavily on lichens, particularly as fallback foods (Miller et al. 2020), while conspecifics in low elevation habitats do not eat lichen, but are instead largely dependent on leaves (Dunham 2017) or seeds (Maisels et al. 1994). There are also instances where altitudinal variation influences the availability of food resources and dietary composition for primate species including *Macaca fuscata* in Japan (Hanya et al. 2003), *Macaca mulatta* and *Rhinopithecus bieti* in China (Grueter et al. 2012; Zhang et al. 2022), *Mandrillus leucophaeus* in Equatorial Guinea (Owens et al. 2015), and *Papio ursinus* in South Africa (Byrne et al. 1993).

The hamadryas baboon (*Papio hamadryas*) is one of five species in the genus *Papio* and occurs mainly in the lowland habitats of the Horn of Africa, including parts of Ethiopia, Eritrea and the southwestern part of the Arabian Peninsula (Biquand et al. 1992; Al-Safadi 1994; Groves 2005; Kingdon 2015). Hamadryas baboons usually reside in arid and semi-desert areas, though they also sometimes occur in moist lowlands, including in closed canopy forests and woodlands

(Kummer 1968; Zinner et al. 2001; Swedell 2013). Several populations occupy or utilize moist highland areas as well (Hunter 2001; Ibrahim 2019). Thus, though mostly known from long-term studies in arid regions (Kummer 1968; Swedell 2013), hamadryas baboons actually occur across a wide elevational gradient.

Hamadryas baboons are considered generalist omnivores and their multi-level social organization is thought to reflect low food availability and high levels of aridity within their habitats (Kummer 1968; Dunbar 1988; Swedell 2002; Henzi and Barrett 2003; Swedell et al. 2008). Hamadryas baboons rely mainly on the flowers, seeds, leaves and fresh shoots from *Acacia* (Fabaceae) trees as well as a wide array of semi-desert plants such as *Grewia* spp. (Malvaceae), *Dobera glabra* (Salvadoraceae) and *Hyphaene thebaica* (Arecaceae) (Kummer 1968; Nagel 1973; Al-Safadi 1994; Swedell et al. 2008; Schreier 2010; Admassu 2012). Studies suggest that fruits and flowers are preferred foods across their range in lowland habitats of Ethiopia (Swedell et al. 2008; Schreier 2010). Like other baboons, they also feed opportunistically on invertebrates and small mammals such as hares (*Lepus* spp.) (Swedell 2013). Some hamadryas baboons also supplement their diet with human foods, via direct provisioning (Boug et al. 2017) or by consuming refuse from garbage dumps (Swedell 2013). Additionally, hamadryas baboons are known to occasionally raid crops and are considered pests in some areas (Nagel 1973; Admassu 2012; Abdela 2019).

Though the hamadryas baboon is classified as Least Concern overall in the IUCN Red List, the species is locally threatened as a result of agricultural land and human settlement expansion as well as hunting in response to crop raiding and small domestic animal depredation (Admassu 2012; Gippoliti 2019). Unfortunately, the dietary requirements of hamadryas baboons have only been studied in a small proportion of the habitats where they occur, making it difficult to critically assess any dietary issues impacting the conservation prospects of the species across its range in Ethiopia and more widely across its distribution into Eritrea and the Arabian peninsula (Swedell 2013). For example, although the feeding ecology of hamadryas baboons has been studied extensively in dry lowland habitat at Awash National Park (~900 m a.s.l.) in eastern Ethiopia (Swedell et al. 2008; Schreier 2010; Admassu 2012), little is known about hamadryas baboon populations residing in highland ecosystems.

In this study, we aimed to assess the feeding ecology of hamadryas baboons in and around Borena-Sayint National Park (BSNP) in the highlands of northern Ethiopia. Given the higher plant species diversity and composition in BSNP compared to the arid lowland Awash National Park (Friis et al. 2010; Adal 2014), we hypothesized that the diet of hamadryas baboons at BSNP would be more diverse and contain a different profile of plants than the diet reported for hamadryas baboons in the lowland ecosystem at Awash National Park. In addition, due to the strong seasonality of rainfall in the Ethiopian highland ecosystem, we predicted seasonal differences in the consumption of the major food plant species and food items. By analyzing the consumption of food types in relation to their abundance, we also aimed to identify the preferred and fallback foods of hamadryas baboons at BSNP (Marshall and Wrangham 2007; Marshall et al. 2009). Given the proximity of BSNP to farms, we also anticipated hamadryas baboons there would engage in crop raiding and sought to quantify the percentage contribution of crops to their diet.

Methods

Description of the Study Area

BSNP is located in the South Wollo Zone of Amhara Regional State, northern Ethiopia, and covers an area of 4,375 ha (10^{0}50'45.4" 10^{0}53'58.3", and 38^{0}40'28.4" 38^{0}54'49", Fig. 1). Established as a National Park in 2009, BSNP is bordered by three districts: Borena and Sayint to the north and Mehal Sayint to the east. The study area consists of rough topography, gorges, deeply incised valleys, steep escarpments, and strips of plateaus and cliffs (Ayalew et al. 2006) across a wide altitudinal range (2,188 - 3,732 m asl). BSNP is part of the Eastern Afromontane Biodiversity Hotspot which is characterized by remarkable species richness and endemism but also high human population density (Williams et al. 2005; Fashing et al. 2022).

BSNP extends across two broad, agro-climatic zones known as Weina-dega (cool, sub-humid) and Dega (cold, cold humid) as classified based on ambient heat intensity and moisture regimes (Adal 2014). Temperature and rainfall data (from 1998 to 2018) for the study area were collected from Mekaneselam Meteorological Station (NMSA 2019), which is 16 km away from the National Park. The study area is characterized by a distinctive bimodal rainfall pattern, usually with a short rainy season from April to May and a main wet season from June to September (Ibrahim 2019). The average amount of rainfall per annum was 917 mm (SD ± 39.78, range: 655 to 1,165 mm). The mean annual temperature was 16.7°C SD ± 1.05. The mean monthly minimum temperature ranges from 10.1ºC SD ± 0.85 (November) to 12.4ºC SD ± 1.74 (May), while the mean monthly maximum temperature ranges from 17.9ºC SD ± 0.67 (August) to 24.8ºC SD ± 0.79 (February) (Fig. 2).

The study area consists of large areas of both natural forest and high altitude grassland, both containing rich floral and faunal communities (Adal 2014). The floristic composition of BSNP consists of 354 plant species belonging to 265 genera and 95 families that are classified in the categories of trees, shrubs, graminoids and forbs (Adal 2014). In addition to containing a high diversity of plant species, BSNP also harbors many animal species. In particular, 23 species of medium- to large-sized mammals have been identified and recorded at BSNP, including the following nonhuman primates: hamadryas baboons, geladas, guerezas and grivet monkeys (Chane 2010). BSNP is surrounded by human settlements and agrarian landscapes with little or no buffer zone (H. Ibrahim, pers. observ.).

Study Subjects

From January to May 2016, we habituated a band of hamadryas baboons for study by following them from dawn, when they left their sleeping site, to dusk, when they returned to their sleeping site. Band size was small for the species (Kummer 1968; Schreier and Swedell 2012) and fluctuated between 21 to 37 individuals. Within the band, 4-7 individuals were adult males, 6-15 were adult females and 11-15 were immatures. We identified the study band by individual members that had unique natural markings, coat colour, or other identifiable features. During daily travel, the band sometimes separated into smaller foraging groups (i.e., one-male units of at least five individuals) (Kummer 1968; Swedell et al. 2008). On such occasions, we typically followed the subgrouping with the largest number of individuals. During our study, the study band ranged across elevations of 2341-3016 m (Ibrahim 2019).

Vegetation Composition and Food Availability

Vegetation composition: We examined the vegetation composition of the study area by sampling plots/vegetation quadrats in the home range of the study band (e.g., Mekonnen et al. 2018; Tesfaye et al. 2021). Since deeply incised gorges and sharp cliffs posed obstacles to performing long transects, we employed a combination of stratified and systematic random sampling to select study plots. In particular, we sampled a total of 29 (20 x 20 m) vegetation quadrats in the range of the study band. Once we established the first sampling plot randomly, we laid subsequent independent sampling plots sideways ~0.5 km apart on a baseline projected along the long axis of the home range of the study band. We selected representative sampling plots on the basis of homogeneity of vegetation and visually checked for uniformity in floristic composition (Adal 2014).

In each quadrat, we counted trees ≥10 cm DBH and measured and identified them to species (Swedell et al. 2008; Schreier 2010; Boug et al. 2017). Within these quadrats, we recorded all sampled plants, including the species and number of individuals. In addition, within each of the above quadrats, we randomly placed one 5×5 m and one 1×1 m quadrat to quantify the available shrubs and forbs/graminoids, respectively. Considering the overall uniformity of the ground layer, we only placed and sampled one 1x1 m subplot in each nested plot where the vegetation appeared representative (Adal 2014). We collected, pressed, and dried unidentified plant species using a plant press. These samples were later identified to species level by professional botanists at the National Herbarium, Addis Ababa University.

Phenology: We carried out phenological assessment of the trees in the home range of our hamadryas baboon study band to evaluate monthly changes in the availability of potential food resources (Mekonnen et al. 2018; Tesfaye et al. 2021). We collected phenological data on plant parts from 10 randomly selected trees per species on a monthly basis. We chose and marked only trees ≥10 cm DBH for this monthly phenological monitoring (Mekonnen et al. 2018). We measured GBH as circumference (in cm at a height of 1.3 to 1.4 m) and later changed this value into DBH using the standard conversion formula DBH = Circumference/π. We collected phenological data for seven tree species frequently consumed by the study species during the habituation period, including *Olinia rochetiana* (Oliniaceae), *Dombeya torrida* (Sterculiaceae), *Olea europaea* subsp. *cuspidata* (Oleaceae), *Myrica salicifolia* (Myricaceae), *Nuxia congesta* (Loganiaceae), *Scolopia theifolia* (Flacourtiaceae) and *Myrsine melanophloeos* (Myrsinaceae).

We inspected the availability of food items from the marked trees monthly for 1 or 2 days after completing the behavioral ecology data collection. We assessed each marked tree for the relative abundance score of potential food resources (mature leaves, young leaves, flowers, and fruits) by visual inspection and using binoculars with a relative abundance score ranging from 0 to 8 at intervals of 1. A value of 0 corresponds to a complete absence of that plant part, and a value of 8 corresponds to the plant part encompassing >87.5% of the crown (Twinomugisha and Chapman 2008; Mekonnen et al. 2018). We calculated the proportion of monitored trees bearing each of the phenophases every month for each study species. We calculated the monthly and seasonal variability in the availability of the different potential food resources as in Mekonnen et al. (2017).

We also monitored the phenology of common and/or dietarily important species of graminoids and forbs every month from the randomly selected permanent plots (each 1x1 m) in the home range area of the study band throughout the study period (Fashing et al. 2014; Jarvey et al. 2018). We monitored a total of 35 plots to assess the percentage of greenness and desiccation of graminoids and forbs. We selected and tagged these graminoid and forb plots at random. Depending upon their temporal greenness changes, we assigned each plot with a score from 0-3 at intervals of 1; where 0 (0%) = no graminoids or forbs in plot, 1 (1-25 %) = graminoids and forbs in plots that are entirely brown (DGP), 2 (26 - 50%) = graminoids and forbs in plots that are mixed green and brown (MGGP), and 3 (>50%) = graminoids and forbs in plots that are mostly or entirely green (GGP) using visual inspection (Moges 2018).

Feeding ecology

For 8 consecutive days per month from June 2016 to May 2017, we used the instantaneous scan sampling method (Altmann 1974) at 30-min intervals for up to 5 min duration (06:00 to 18:30) to record the activities of hamadryas baboons. Activities were categorized as feeding, moving, resting, socializing and others (Ibrahim 2019). We recorded feeding when the baboons manipulated, masticated, or ingested a food item (food handling and processing) (Schreier 2010). During activity scans, when the baboons were feeding, we recorded the type of food item (as graminoids, roots, fruits, leaves, flowers, stem, bark, animal prey or unidentified items) and species consumed

(Swedell et al. 2008; Schreier 2010). We identified and recorded most of the plant species consumed by hamadryas baboons in the field. However, for plant species we were unable to identify, we recorded their local name (where possible), pressed them and transported them to the National Herbarium for taxonomic identification. We collected a total of 5293 individual behavioral records during 837 h of observation (Ibrahim 2019). Feeding accounted for 1807 (or 34.1%) of these records.

Data Analyses

Vegetation composition and phenology: From the data collected on vegetation composition, we calculated the density of each plant species as the total number of each plant species divided by the total number of all plant species sampled per hectare in the home range of the study band (Mekonnen et al. 2010). We calculated plant species diversity in the home range of the study band using the Shannon-Wiener diversity index, H' and evenness using the evenness index, J (Krebs 1999) to determine whether or not the dietary species are evenly distributed in the study band's home range. We calculated the basal area (BA) of each tree species to estimate the biomass of each tree within the home range of hamadryas baboons band and to determine dominant tree species in the home range of the monkeys (Fashing 2001; Felton et al. 2008). BA for each tree was calculated from the measured DBH value using the formula, $BA = [0.5 \times DBH]^2 \times \pi$ (Fashing 2001).

We obtained food availability index (FAI) (units per hectare) for young leaves, mature leaves, flowers and fruits from the monthly average phenology scores and the basal area per hectare value for trees in the vegetation sampling plots (Dasilva 1994). We computed FAI using the following formula: FAIi = PISpi x BAi, where; FAIi is the food availability index of species i, PISpi is the monthly phenological index for species *i*, and BAi is the basal area (cm^2/ha) of species i obtained by the vegetation survey data (Fashing 2001). The monthly total FAI for each phenophase was calculated by adding FAIi indices across plant food species (Fashing 2001).

We added the level of greenness of graminoids and forbs in each month to determine phenology and availability of graminoid blades and forb leaves in the home range of the study band and to estimate the availability of graminoid blades and forb leaves in each area. We calculated the proportion of greenness score of each month in each site by dividing the number of each plot assigned to the particular score to the total number of plots and then multiplied by 100.

Feeding ecology: The number of individuals we spotted in each scan was limited by the movement of the band amidst rough topography (mean: 3.14; range: 1–5). We divided the number of individuals feeding on a particular food item for each scan by the total number of individuals observed in the scan to prevent the over-representation of highly visible foods (Hanya and Bernard 2012). Using the proportion of the total number of feeding records spent on each diet category, we determined the contribution of each food item and species to the total diet consumption. We summed the daily food item consumptions within each month to construct the monthly proportion of diet item composition. We then calculated mean seasonal and overall dietary composition by averaging the monthly percentage proportions (Mekonnen et al. 2018; Kifle and Bekele 2021). To estimate the overall plant species richness of the diet, we pooled the data from all sampling months within the band. We calculated within-month and overall dietary diversity indices for the study band using the Shannon–Wiener index (H′) and evenness index (J) (Krebs 1999) using the software PAST (Hammer et al. 2009).

We measured dietary selection ratio (relative dietary preferences) for different food species in the study band's diet by dividing the annual percentage of time spent feeding on species *i* by the percentage of the stem density that species *i* contributes to the total stem density in the study band's home range (Tesfaye et al. 2021). We could not include forbs and graminoids in this analysis given that they lack a comparably quantifiable stem density. A selected food species is consumed more frequently than expected based on its proportional representation in the home range of the study band. A selection ratio of 1 indicates no selectivity for that food plant species by baboons, < 1 indicates a food species is avoided by baboons and > 1 indicates a food species is selected for.

Statistical Analyses

We mainly analyzed the data using SPSS 23.0 Software for Windows Evaluation Version. We used two-tailed statistical tests with 95% confidence intervals (the significance level was set at 0.05). We assumed that each of the observations was independent. We tested the data for normality using the Shapiro-Wilk test, and tested homogeneity of variances using the Levene test ($P > 0.05$). We compared phenological and feeding ecology data among seasons and months using statistical tests such as t-tests, one way ANOVAs, Mann-Whitney U tests or Kruskal-Wallis H tests. Following an analysis of variance, we used the post-hoc Tukey test to determine the difference between pairwise comparisons of overall food consumption. In addition, we computed Pearson rank correlation coefficients to determine the relationship between the availability of young leaves, mature leaves, flowers and fruits and their consumption.

Results

Vegetation Composition and Phenology

Our analysis of vegetation composition in the home range of the hamadryas baboon study band revealed a total of 18 tree, 27 shrub, 43 forb, 9 graminoid, 3 liana and 1 fern species (Table S1). The stem densities for the tree, shrub and liana species and basal areas of tree species sampled in the home range of the study band are provided in Table S2. Plant species taller than 2 m in the home range of the study band occurred at a density of 610 stems/ha. The Shannon-Wiener diversity index (H') of plant species in the home range of the study band was 2.94 and the plant species evenness index (J) was 0.85. In addition, the mean number of plant species per hectare was 27.59. Mature leaves were the most abundant plant parts and were available in large quantities throughout the year followed by young leaves (Table S3). However, a Pearson rank test revealed that there was no significant correlation in the FAI between young leaf and mature leaf availability (r_p= 0.52, $P > 0.05$).

Flowers and fruits were the least abundant plant parts (Table S3). Flowers were most abundant from November 2016 to January 2017 and higher availability scores for fruits were recorded from June to September 2016. The Kruskal–Wallis H test revealed that there was a statistically significant difference ($P < 0.001$) across months in the FAI scores of young leaves, mature leaves, flowers and fruits. Seasonal food item availability scores showed that young leaves ($Z = -2.24$, $P < 0.05$), mature leaves and fruits ($Z = -2.25$, $P < 0.05$) were more abundant during the wet season than the dry season (Fig. 3). On the other hand, FAI for flowers was significantly higher during the dry season than the wet season ($Z=-2.25$, $P < 0.05$). Green graminoid/forb availability peaked from April-October (Table S4). In the study plots, percentage of green graminoids/forbs was higher during the wet season than the dry season (Fig. 4).

Feeding Ecology

Overall, we observed hamadryas baboons consume a total of 52 food species (including cultivated foods) grouped in 22 families of plants and three families of animals (Table 1). The 49 plant species that were eaten included 12 species of trees, 13 species of shrubs, 14 species of graminoids and 10 species of forbs (Table 1). Hamadryas baboons included in their diet five cultivated plants, wheat

(*Triticum spp.*), maize (*Zea mays*), barley (*Hordeum vulgare*), sellalie (*Avena abyssinica*), and potatoes (*Solanum tuberosum*), from farmlands which cumulatively accounted for 8.8% of their annual diet (Table 1). Hamadryas baboons were also observed to consume lichens by scraping them from the surface of rocks. Fruits were the largest contributors (32.0%) to the diet of hamadryas baboons followed by graminoid blades (21.2%), young leaves (13.2%) and cereals (8.8%), respectively (Fig. 5).

Other less often consumed food items included flowers, forb leaves, stems, mature leaves, animal prey, graminoid roots, forb roots, bark and vegetables (Fig. 5). The proportion of time devoted to feeding on these food items differed significantly (Kruskal Wallis test, $\chi^2 = 97.51$, df = 12, $P < 0.05$). Follow-up post hoc tests of pairwise comparisons indicated that significant differences were observed in the consumption of fruits compared with cereals (P = 0.025), flowers (P = 0.006), and forb leaves (P = 0.005); and graminoid blades with forb leaves (P = 0.004) and cereals (P = 0.02). However, there were no significant differences in the consumption of fruits with young leaves (P = 0.176), graminoid blades (P = 0.934), and forb leaves (P = 0.417). In addition, we found that the availability of fruits was not correlated with the consumption of graminoid blades (r =-0.028, N = 12, P = 0.931), young leaves (r =-0.473, N = 12, P = 0.121), forb leaves (r =-0.241, N = 12, P = 0.45), and mature leaves (r =-0.131, N = 12, P = 0.686). However, there were significant positive correlations between the availability of flowers and fruits and consumption of flowers (r = 0.743, N = 12, P = 0.006) and fruits (r = 0.583, N = 12, P = 0.047). We found that the availability of green graminoid plots correlated negatively with the consumption of graminoid blades (r =-0.669, N = 12, P = 0.030). We also found that consumption of young leaves correlated negatively with their availability (r =-0.626, N = 12, P = 0.029).

Monthly consumption of fruits ranged from 1.4% in November 2016 to 58.3% in March 2017 (Table S5). Kruskal-Wallis H tests revealed that there were significant differences across months in percentage of time devoted to feeding on all of the seven main food items: fruits ($\chi^2 = 66.78$, df = 11, $P < 0.05$), graminoid blades ($\chi^2 = 30.12$, df = 11, $P < 0.05$), young leaves ($\chi^2 = 26.59$, df = 11, $P < 0.05$), cereals ($\chi^2 = 50.33$, df = 11, $P < 0.05$), flowers ($\chi^2 = 48.55$, df = 11, $P < 0.05$), forb leaves ($\chi^2 = 42.17$, df = 11, $P < 0.05$), and stems ($\chi^2 = 22.67$, df = 11, $P < 0.05$).

Fruits were the most consumed food items during both the wet (38.3%) and dry seasons (25.6%), followed by graminoid blades (wet: 16.4%; dry 22.8%) (Table 2). We found that there were no statistically significant differences between seasons in the time spent feeding on flowers (Students t-test, t = -2.06, df = 10, P = 0.066), fruits (t = 1.167, df = 10, P = 0.27), graminoid blades (t = -0.72, df = 10, P = 0.48), young leaves (t = -1.176, df = 10, P = 0.267), mature leaves (t = 0.443, df = 10, P = 0.667), stems (t = 0.82, df = 10, P = 0.432), cereals (t = -0.739, df = 10, P = 0.477), and forb leaves (t = 1.74, df = 10, P = 0.112).

The 20 most frequently consumed plant species cumulatively comprised 79.2% of the overall diet. Each of these plant species accounted for >1% of the diet except *Ficus sur*, which accounted for 0.9%. Out of the top 20 diet species, five species were trees accounting for 23.1% of the overall diet, six were shrubs (29.1%), four were forbs (6.8%) and five were graminoids (20.3%).

The monthly consumption of each plant species in the diet is listed in Table S6. Mean monthly food plant species richness was 16.75 (range: 6 – 30 species) (Table S7). We recorded the highest dietary diversity during June and July 2016 (Shannon-Wiener diversity index H' = 2.84 for both months) and the lowest in March 2017 (H' = 1.27). We found that the mean monthly dietary evenness index (J) was 0.59. Dietary evenness was highest in January 2017 (J = 0.78) and lowest in October 2016 (J = 0.42). There were significant differences across months in the food plant species diversity ($F = 23.9$, $df = 11$, $P < 0.05$) and evenness indices ($F = 3.7$, $df = 11$, $P < 0.05$).

Hamadryas baboons consumed a higher mean number of food plant species per month during the wet season (n = 19.67) than the dry season (n = 13.83) though the difference did not reach significance (t-test: $t = 1.429$, $df = 10$, $P = 0.184$). We found that there was a higher diversity of food plant species during the wet season (H' = 2.30) compared to the dry season (H' = 2.05) but this difference was not significant (t-test: $t = 0.942$, $df = 10$, $P = 0.368$). Mean dietary evenness index was higher during the dry season (J = 0.63) than the wet season (J = 0.55), though this difference was also not significant (t-test: $t = -1.347$, $df = 10$, $P = 0.208$). We found that *Scolopia theifolia* was by far the most selected for food plant species with a selection ratio of 11.88. *Olinia rochetiana*, and *Dombeya torrida* had the second and third highest selection ratios at 1.79 and 1.75, respectively (Table 3).

Discussion

We conducted the first study on the feeding ecology of hamadryas baboons at a high-elevation site, Borena Sayint National Park (BSNP) in northern Ethiopia. The highland habitat of BSNP has a different ecological composition than the arid lowland field sites where hamadryas baboons have been studied, including at Awash [Filoha, Ethiopia (Swedell et al. 2008; Schreier 2010), Erer-Gota, Ethiopia (Kummer 1968)] and in Saudi Arabia and Yemen (Biquand et al. 1992; Al-Safadi 1994; Boug et al. 2017). Generally, young leaves and fruits were more prevalent during the wet season than the dry season at BSNP. These plant parts were also more abundant during wetter months at hamadryas baboon study sites in Saudi Arabia (Boug et al. 2017) and Yemen (Al-Safadi 1994). Scarcity of fruits occurred from November to January, which were among the drier months at

BSNP. Shrubs such as *Myrsine africana*, *Clutia lanceolata*, *Acanthus sennii*, *Rosa abyssinica*, *Discopodium penninervium* and *Rubus steudneri* were common in the home range of the study group, in addition to many species of trees, forbs and graminoids. In other parts of Ethiopia (Erer-Gota and Awash National Park), *Acacia* species are common trees in the habitat of hamadryas baboons (Kummer 1968; Sigg and Stolba 1981; Schreier 2010), but were rare in the highland environment at BSNP. Saudi Arabian hamadryas baboons mainly relied on wadi vegetation and figs (*Ficus* sp.) because they were abundant in the area (Biquand et al. 1992). In their survey in Eritrea, Zinner et al. (2001) reported the exotic succulent *Opuntia ficus-indica* as a dominant plant species in the range of hamadryas baboons there. Taken together, these patterns indicate that hamadryas baboons inhabit varied habitats across a large geographic area and wide elevational gradient.

We documented several qualitatively similar patterns of feeding ecology for hamadryas baboons at BSNP and the Filoha site at Awash National Park, where the most extensive research on hamadryas baboons has been conducted to date (Swedell et al. 2008; Schreier 2010; Admassu 2012; Swedell 2013). Hamadryas baboons at BSNP largely relied on fruits, similar to what studies found at Filoha (Swedell et al. 2008; Schreier 2010). Given the significant positive correlation between the availability and consumption of fruits and its disproportionate consumption compared to other food items, we suggest that fruits are a preferred food item for the hamadryas baboons at BSNP (Fashing et al. 2007; Marshall and Wrangham 2007; Mekonnen et al. 2018). However, the absence of correlations between the availability of fruits and consumption of graminoid leaves, young leaves, and mature leaves suggests that these are not fallback foods (Marshall and Wrangham 2007; Marshall et al. 2009), but rather less preferred food items for hamadryas baboons at BSNP.

In contrast to results from Filoha (Swedell et al. 2008; Schreier 2010), hamadryas baboons at BSNP do not exhibit major dietary changes between seasons. Moreover, hamadryas baboons at BSNP and Filoha consumed different profiles of plant species (Swedell et al. 2008; Schreier 2010; Admassu 2012) in line with our hypothesis that dietary strategies would differ among populations of hamadryas baboons inhabiting lowland versus highland habitats though both populations consumed cultivated crops (Admassu 2012; Ibrahim et al. 2023). In addition, hamadryas baboons in BSNP were unusual in their frequent consumption of graminoid blades (21.2% of annual diet), a food item rarely consumed by conspecifics in the lowlands of Awash (Swedell et al. 2008; Shreier 2010). Highland graminoids are considered of higher nutritional quality than those in the lowlands of Ethiopia (Dunbar and Bose 1991), and represent the main food item of geladas (Fashing et al. 2014; Jarvey et al. 2018; Kifle and Bekele 2021). The potential for feeding competition between hamadryas baboons and geladas where they co-occur, like at BSNP, is a topic worthy of investigation. Hamadryas baboons at BSNP showed significant variation across months in the consumption of their major food items, similar to Awash National Park (Swedell et al. 2008; Shreier 2010). For instance, the low consumption of fruits from November to January (Table S5) coincides with the scarcity of fruits (Table S3) and the high consumption of cultivated crops (Table S5). This indicates that the diet of hamadryas baboons at BSNP changes over short time scales.

Seasonality is an important factor that influences the dietary composition of many baboons (Hill and Dunbar 2002) and other primates (Brockman and van Schaik 2005). When the most preferred food items of baboons are scarce, they typically shift their diet to eat other food sources (Kummer 1968; Whiten et al. 1987; Hill and Dunbar 2002). Hamadryas baboons at Erer-Gota and Filoha consumed fruits, flowers and young leaves when they were available, but switched to less preferred items like roots and stems during the dry season (Kummer 1968; Swedell et al. 2008; Schreier 2010). Conversely, although hamadryas baboons at BSNP spent somewhat more time feeding on fruit during the wet season and on graminoid blades during the dry season, significant seasonal differences in the consumption of food items existed only for forb leaves, a relatively small contributor to the annual diet. Fruits, which were the most often consumed and most preferred food items in BSNP, were fed on throughout the year. For instance, *Olinia rochetiana* largely bear fruit during the wet season. On the other hand, *Rosa abyssinica*, *Rubus steudneri* and *Discopodium penninervium* bear fruit during a few months in both the wet and dry seasons.

Fruits are the most important contributors to the diet of baboons across their ranges (Kummer 1968; Dunbar and Dunbar 1974; Davidge 1978; Sharman 1981; Norton et al., 1987). Leaves contributed 24% of the diet of hamadryas baboons in BSNP. Leaves are also important contributors in the diet of hamadryas baboons at Erer-Gota (28%: Kummer 1968) and in the diets of some populations of *Papio anubis* (41%: Dunbar and Dunbar 1974) and *Papio ursinus* (25%: Davidge 1978). Hamadryas baboons in BSNP also consumed flowers and subterranean items, consistent with reports for hamadryas baboons at Erer-Gota (Kummer 1968) and Filoha (Swedell et al. 2008; Schreier 2010). Like many other baboon populations (Biquand et al. 1992; Al-Safadi 1994; Admassu 2012; Bough et al. 2017; Abdela 2019), hamadryas baboons in BSNP supplement their diet by consuming cultivated crops which are available from farms near their habitat.

Hamadryas baboons in BSNP obtained food from 49 plant species, a value within the range of the number of species of plants consumed by hamadryas baboons at Filoha in Awash National Park (40: Schreier 2010; 45: Swedell et al. 2008; 73: Admassu 2012) and Alhada in Saudi Arabia (42: Boug et al. 2017). Whereas five *Acacia* species combined contributed 39% of the diet of hamadryas baboons at Filoha (Schreier 2010), hamadryas baboons at BSNP exploited only one species of *Acacia* (*Acacia decurrens*), which contributed <1% to the total diet. *Acacia* species are also major contributors to the diets of several other hamadryas populations as well as other baboons (Norton et al. 1987; Barton et al. 1993; Al-Safadi 1994; Swedell et al. 2008; Boug et al. 2017).

Acacia has a very limited distribution and low abundance in BSNP, however, which may be due to the higher elevation and different climatic patterns of the area. The incorporation of animals (*Tragelaphus scriptus*, *Lepus starcki*, and one species of ants) in the diet of hamadryas baboons at BSNP is consistent with some other populations of hamadryas baboons which also exploit mammals and invertebrates (Admassu 2012; Schreier et al. 2019).

The top three plant food species combined accounted for 36.8% of the diet of hamadryas baboons and the top 20 species of plants accounted for 79.2% of their feeding time at BSNP. In comparison, just 3 plant species consumed by Band 1 of hamadryas baboons at Filoha accounted for 50.3% of their annual feeding budget (Schreier 2010). Band 1 relied most frequently on the fruit of *Hyphaene thebaica* (doum palm) and the seeds, leaves and flowers of *Acacia senegal* (Schreier 2010). Additionally, Band 3 at Filoha spent 47.4% of their total annual feeding time eating *H. thebaica* fruits and 11.6% on the leaves, flowers and seeds of *A. senegal* (Swedell et al. 2008). Notably, the baboons at Filoha focused intensively on the fruits of *H. thebaica* when they were available (Swedell et al. 2008; Schreier 2010). The high energy density of this fruit apparently enabled the baboons at Filoha to devote a relatively low percentage of their activity budget to feeding (Swedell et al. 2008; Schreier 2010). There was no such highly prized food item for the hamadryas baboons in our study at BSNP. Taken together, these comparisons suggest that hamadryas baboons at BSNP have a more eclectic diet than at lowland sites where single or a few prized food items comprise larger proportions of the diet.

In BSNP, there was no single food plant species that was consumed throughout the year. Still, the top ranked food plant species (*Olinia rochetiana*) was consumed during all months except March. This absence of *Olinia rochetiana* during March might be related to the high consumption of *R. abyssinica* during the same month. On the other hand, Band 3 at Filoha consumed *H. thebaica* and *A. senegal* during every month of the year (Swedell et al. 2008). In addition, Band 1 in Filoha consumed food items from *A. senegal*, *Tribulus cistoides*, *A. tortilis* and *A. mellifera* throughout the year (Schreier 2010). These patterns suggest that hamadryas baboons in BSNP did not rely on specific plant species throughout the year like those at Filoha. Like Band 3 at Filoha (Swedell et al. 2008), hamadryas baboons in BSNP consumed more food plant species during the wet season than the dry season.

The availability of cultivated foods along protected area boundaries often compels primates to forage outside the boundaries (Seiler and Robbins 2016; Mekonnen et al. 2020; Kifle 2021). Crop foraging behavior is a common response by some primates to the reduction of their preferred wild food resources (McLennan et al. 2017; Mekonnen et al. 2020). Hamadryas baboons in BSNP spent more time feeding on cultivated foods, particularly during November and December when there was low availability of fruits (the preferred food item). Similar tendencies have been observed in hamadryas baboons at Awash National Park (Admassu 2012) as well as several other primates, including ring-tailed lemurs (*Lemur catta*; LaFleur and Gould 2009), chimpanzees (*Pan troglodytes*; McLennan, 2013), tufted capuchin monkeys (*Sapajus nigritus*; Mikich and Liebsch, 2014), Bale monkeys (*Chlorocebus djadjamensis*; Mekonnen et al. 2020), and olive baboons (*Papio anubis*; Kifle 2021).

At BSNP, the crop foraging behavior of hamadryas baboons elicited some retaliation from local people, posing a risk to their survival (Ibrahim et al. 2023). In some instances, people caused injury or death to the hamadryas baboons by throwing spears, stones, sticks, and long knives (Ibrahim et al. 2023), as reported previously for olive baboons in Wollo area, Ethiopia (Kifle 2021). To ensure the long-term survival of hamadryas baboons in habitats like BSNP where conflict is occurring with human communities nearby, it is essential to include nearby farmlands in management plans. For example, the locals should grow a monoculture of unpalatable plant species in a buffer zone to discourage crop foraging by hamadryas baboons (Ibrahim et al. 2023). The role of local peoples is crucial in such participatory conservation programs, as we cannot hope to conserve primates without considering the wider political, socio-economic, ecological, and cultural conditions under which coexistence with humans is possible (McLennan et al. 2017).

Conclusion

Our results show that the diet and feeding behavior of hamadryas baboons in highland habitat at BSNP differs from the well-studied bands in lowland habitat at Filoha. Still, at both locations, fruits were the largest contributor to the diet of hamadryas baboons. Contrary to our prediction, there was no significant difference between seasons in the consumption of the major food items and food plant species. However, the baboons preferred fruits and flowers when these food items were available in the habitat. Hamadryas baboons raided cultivated lands throughout the year and cultivated foods accounted for 8.8% of the annual diet at BSNP. This crop foraging behavior creates conflict with the surrounding local community (who are subsistence farmers) posing a future conservation issue for the species that should be addressed in the development of conservation and management plans for BSNP.

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Approval

Permission to conduct this research project was granted by the Ethiopian Wildlife Conservation Authority. This project also adhered to the legal requirements of Ethiopia and complied with the American Society of Primatologists’ Principles for the Ethical Treatment of Non-human Primates.

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Table 1 Food species included in the diet of our study band of hamadryas baboons at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017. (AP=animal prey, B=bark, CER= cereals, FL=flowers, FR=fruits, GB=graminoids blade, GR=graminoids root, HL=forbs leaves, HR=forbs root, ML=mature leaves, S=stem, YL=young leaves, and V=vegetables).

Scientific name	Vernacular name (Amharic)	Family	Category	Food Item (% contribution)	Frequency (%)
Olinia rochetiana	Tife	Oliniaceae	Tree	FL (0.15), FR (13.07), ML (0.37), YL (1.41)	15.00
Rosa abyssinica	Kega	Rosaceae	Shrub	FL (1.78), FR (10.59), YL (0.06)	12.43
Andropogon abyssinicus	Balamie	Poaceae	Graminoids	FL (0.04), GB (8.60), GR (0.75)	9.39
Unidentified species	Fura*		Graminoids	GB (8.87), GR (0.09)	8.96
*Triticum spp.***	Sinde	Poaceae	Graminoids	CER (5.09)	5.09
Acanthus sennii	Shekori	Acanthaceae	Shrub	B (0.03), FL (1.09), ML (0.31), S (1.92), YL (1.39)	4.74
Discopodium penninervium	Ameraro	Solanaceae	Shrub	B (0.55), FR (0.25), ML (0.9), S (0.72), YL (2.1)	4.52
Rubus steudneri	Gurarba	Rosaceae	Shrub	FL (0.07), FR (4.15), ML (0.29)	4.51
Dombeya torrida	Wulkefa	Sterculiaceae	Tree	FL (1.44), ML (0.40), YL (1.89)	3.73
*Zea mays***	Bekolo	Poaceae	Graminoids	CER (3.1)	3.10
Haplocarpha schimperi	Getn	Asteraceae	Forbs	HL (2.82), HR (0.25)	3.07
Scolopia theifolia	Wanaye	Flacourtiaceae	Tree	FR (1.87), YL (0.03)	1.90
Rumex nervosus	Embuacho	Polygonaceae	Shrub	FL (0.15), ML (0.29), S (0.62), YL (0.58)	1.64
Nuxia congesta	Askuar	Loganiaceae	Tree	FL (0.16), ML (0.38), YL (1.03)	1.57
Ant	Chichuan	Formicidae	Invertebrates	AP (1.51)	1.51
Andropogon distachyos	Gaja	Poaceae	Graminoids	FL (0.04), GB (0.49), GR (0.83), S (0.04)	1.40
Trifolium polystachyum	Maget	Fabaceae	Forbs	HL (1.20), HR (0.11)	1.31

Cynodon aethiopicus	Serdo	Poaceae	Graminoids	GB (1.22), GR (0.07)	1.29
Cyperus sesquiflorus	Gicha	Cyperaceae	Graminoids	GB (1.29)	1.29
Urera hypselodendron	Lakuso	Urticaceae	Shrub	ML (0.2), YL (1.07)	1.27
Bidens prestinaria	Adey Abeba	Asteraceae	Forbs	FL (0.76), HL (0.27), HR (0.08)	1.11
Ficus sur	Shola	Moraceae	Tree	FR (0.88)	0.88
Acacia decurrens	Dikerens	Fabaceae	Tree	ML (0.23), YL (0.63)	0.86
Vernonia myriantha	Buyte	Asteraceae	Shrub	FR (0.10), ML (0.26), YL (0.46)	0.82
Olea europaea subsp. cuspidate	Woira	Oleaceae	Tree	FR (0.56), ML (0.10), YL (0.13)	0.79
Maesa lanceolata	Akelaho	Myrsinaceae	Shrub	FL (0.32), FR (0.18), ML (0.04), YL (0.21)	0.75
Cyperus fischerianus	Gramta	Cyperaceae	Graminoids	GB (0.73)	0.73
*Hordeum vulgare***	Gebs	Poaceae	Graminoids	CER (0.58)	0.58
Solanum dennekense	Emburi	Solanaceae	Shrub	S (0.52)	0.52
Dovyalis abyssinica	Koshim	Flacourtiaceae	Shrub	FR (0.51)	0.51
Phaulopsis imbricata	Derg	Acanthaceae	Forbs	HL (0.51)	0.51
Myrica salicifolia	Shinet	Myricaceae	Tree	B (0.03), FL (0.03), ML (0.14), YL (0.25)	0.45
Commelina benghalensis	Lalinch	Commelinaceae	Forbs	HL (0.42)	0.42
Myrsine melanophloeos	Gewra	Myrsinaceae	Tree	ML (0.10), YL (0.3)	0.40
Trifolium semipilosum	Chemekot	Fabaceae	Forbs	HL (0.4)	0.40
Arisaema schimperanum	Amoch	Araceae	Forbs	HR (04)	0.40
Hypericum revolutum	Amja	Hypericaceae	Shrub	FL (0.27), YL (0.13)	0.40
Prunus Africana	Anje	Rosaceae	Tree	FR (0.37), ML (0.03)	0.38
Kalanchoe petitiana	Endawula	Crassulaceae	Forbs	S (0.23)	0.23
Carex bequaertii	Filla	Cyperaceae	Graminoids	GB (0.22)	0.22

Rumex abyssinicus	Mokmoko	Polygonaceae	Forbs	S (0.18)	0.18
Tragelaphus scriptus	Dekula	Bovidae	Vertebrates	AP (0.17)	0.17
Apodytes dimidiate	Dong	Icacinaceae	Tree	YL (0.16)	0.16
Schefflera abyssinica	Getem	Araliaceae	Tree	FR (0.13)	0.13
Laggera tomentosa	Alashume	Asteraceae	Shrub	YL (0.11)	0.11
Eleusine floccifolia	Akrma	Poaceae	Graminoids	GB (0.10)	0.10
Solanecio gigas	Yeshikoko Gomen	Asteraceae	Shrub	S (0.08)	0.08
Hyparrhenia dichroa	Senbelet	Poaceae	Graminoids	GR (0.08)	0.08
Oplismenus compositus	Yekok sar	Poaceae	Graminoids	GB (0.07)	0.07
Lepus starcki	Tenchel	Leporidae	Vertebrates	AP (0.05)	0.05
*Avena abyssinica***	Sellalie	Poaceae	Graminoids	CER (0.05)	0.05
*Solanum tuberosum***	Dench	Solanaceae	Forbs	V (0.03)	0.03

* - Represents unidentified graminoid species.

** Cultivated foods

Table 2 Seasonal variation in the diet of hamadryas baboons at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

	Seasonal food items contribution (%)		
Food items	Wet season	Dry season	Average
Fruits	38.32	25.64	31.98
Graminoid blades	19.64	22.76	21.20
Young leaves	10.65	15.74	13.20
Cereals	6.97	10.67	8.82
Forb leaves	8.04	3.50	5.77
Flowers	2.34	10.36	6.35
Stem	5.86	4.16	5.01
Mature leaves	3.23	2.30	2.77
Animal prey	2.11	1.35	1.73
Graminoid roots	1.00	2.24	1.62
Forb roots	1.01	0.28	0.64
Bark	0.78	0.23	0.51
Vegetables	0.05	0.00	0.03

Table 3 Dietary preference of hamadryas baboons based on stem density and percentage of feeding time for plant species consumed at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

Scientific name	Family	Habit	Stem density (%)	Annual diet (%)	Selection ratio
Olinia rochetiana	Oliniaceae	Tree	8.36	15.00	1.79
Rosa abyssinica	Rosaceae	Shrub	8.2	12.43	1.52
Acanthus sennii	Acanthaceae	Shrub	10.16	4.74	0.47
Discopodium penninervium	Solanaceae	Shrub	7.05	4.52	0.64
Rubus steudneri	Rosaceae	Shrub	5.08	4.51	0.89
Dombeya torrida	Sterculiaceae	Tree	2.13	3.73	1.75
Scolopia theifolia	Flacourtiaceae	Tree	0.16	1.90	11.88
Rumex nervosus	Polygonaceae	Shrub	4.26	1.64	0.38
Nuxia congesta	Loganiaceae	Tree	1.48	1.57	1.06
Urera hypselodendron	Urticaceae	Shrub	1.97	1.27	0.64
Vernonia myriantha	Asteraceae	Shrub	5.74	0.82	0.14
Olea europaea subsp. Cuspidate	Oleaceae	Tree	3.11	0.79	0.25
Maesa lanceolate	Myrsinaceae	Shrub	2.62	0.75	0.28
Dovyalis abyssinica	Flacourtiaceae	Shrub	0.49	0.51	1.03
Myrica salicifolia	Myricaceae	Tree	0.33	0.45	1.36
Myrsine melanophloeos	Myrsinaceae	Tree	0.49	0.40	0.82
Prunus Africana	Rosaceae	Tree	0.98	0.38	0.38
Apodytes dimidiate	Icacinaceae	Tree	0.82	0.16	0.19
Solanecio gigas	Asteraceae	Shrub	1.64	0.08	0.05

Figure Legends

Fig. 1 Map of the study site, Borena-Sayint National Park in northern Ethiopia.

Fig. 2 Mean monthly temperature (mean, mean minimum and mean maximum) and rainfall patterns at Mekaneselam town, 16 km south-east of the BSNP in northern Ethiopia, 1998 to 2018.

Fig. 3 Seasonal FAI values of food items in the home range of the study band (FAI units/ha) at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

Fig. 4 Percentage of graminoids/forbs phenology during the wet and dry seasons at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

Fig. 5 The overall percentage consumption of food items by hamadryas baboons at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

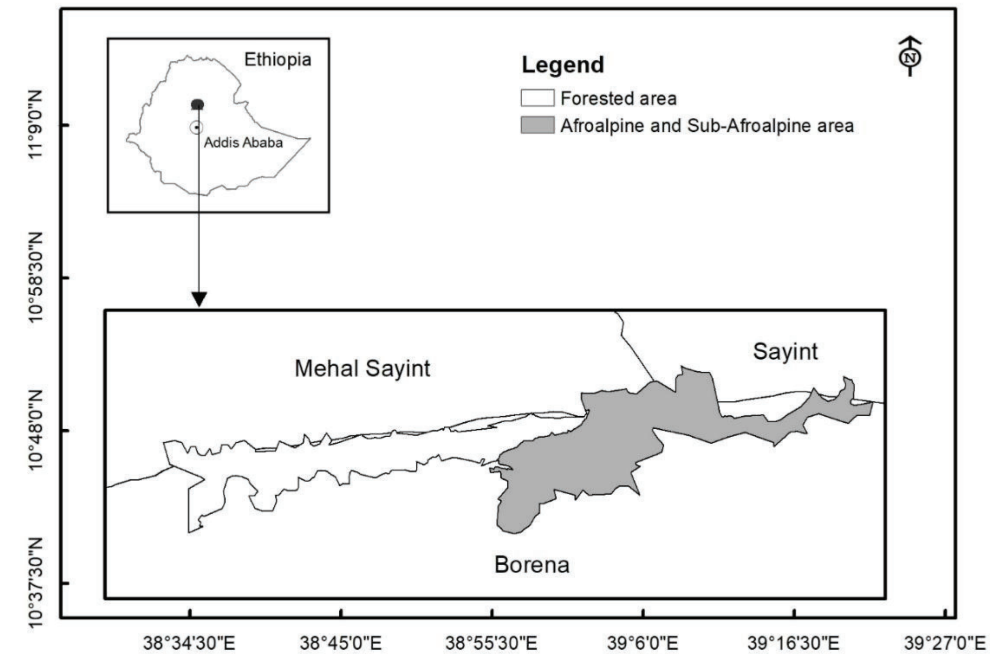

Fig. 1 Map of the study site, Borena-Sayint National Park in northern Ethiopia.

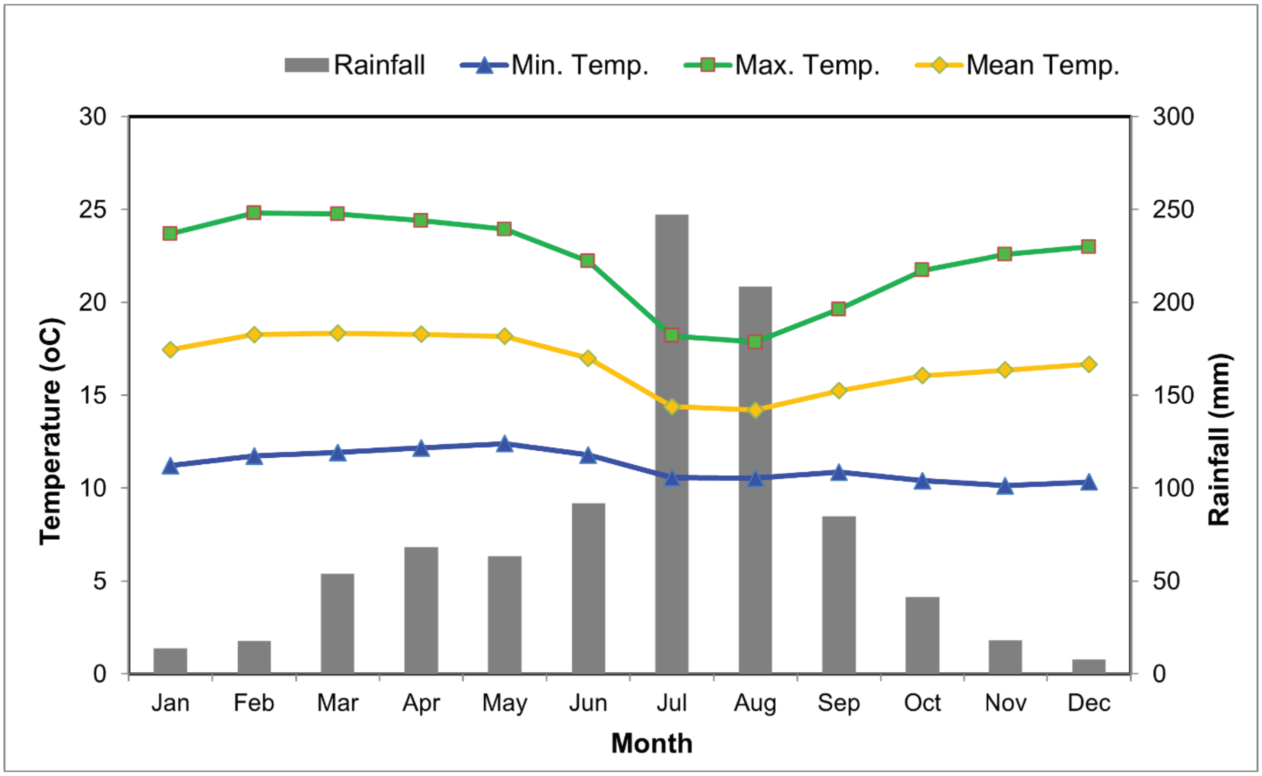

Fig. 2 Mean monthly temperature (mean, mean minimum and mean maximum) and rainfall patterns at Mekaneselam town, 16 km south-east of the BSNP in northern Ethiopia, 1998 to 2018.

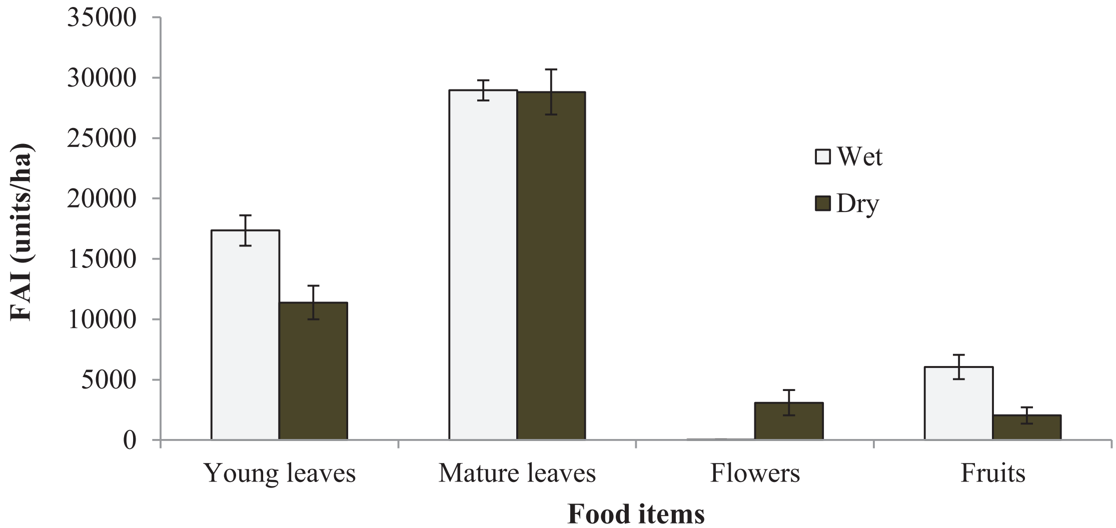

Fig. 3 Seasonal FAI values of food items in the home range of the study band (FAI units/ha) at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

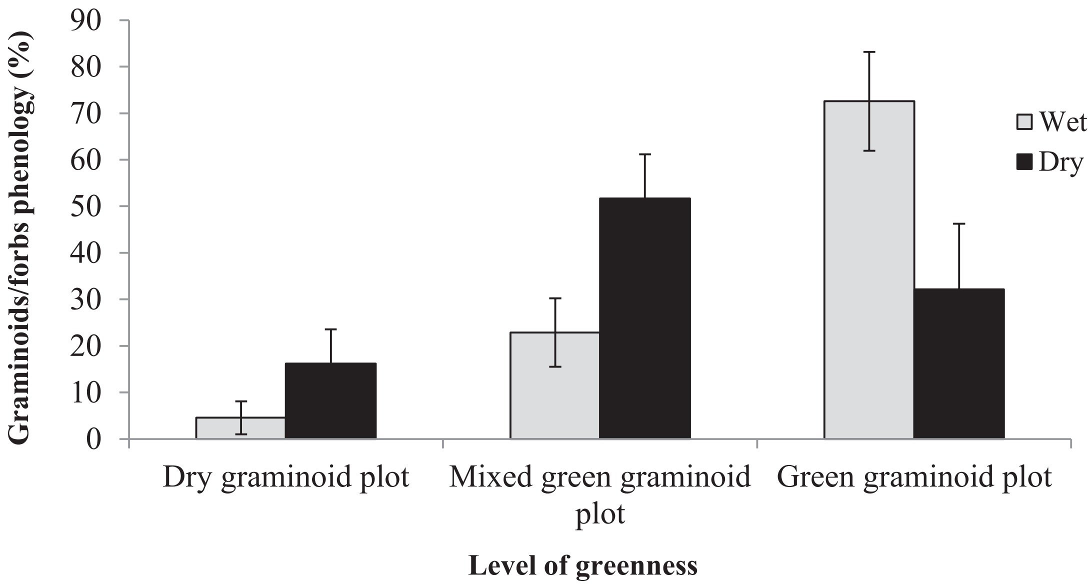

Fig. 4 Percentage of graminoids/forbs phenology during the wet and dry seasons at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

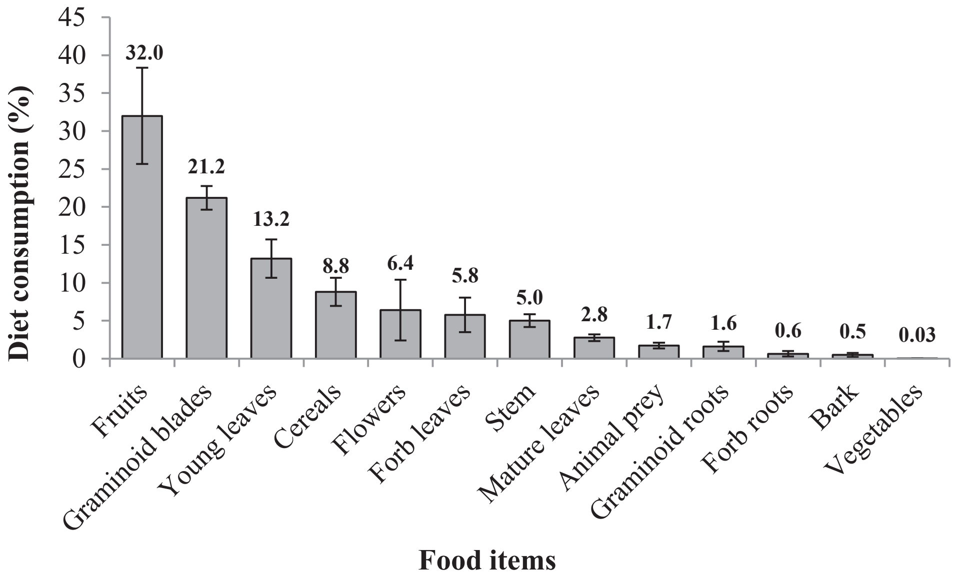

Fig. 5 The overall percentage consumption of food items by hamadryas baboons at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

Table S1. Plant species identified in the home range of the study group.

Roll no.	Local Name	Scientific Name	Family	Habit
1	Anje	*Prunus africana*	Rosaceae	Tree
2	Askuar	*Nuxia congesta*	Loganiaceae	Tree
3	Azamir	*Bersama abyssinica*	Melianthaceae	Tree
4	Barimbes	*Allophyllus abyssinicus*	Sapindaceae	Tree
5	Dikerens	*Acacia decurrens*	Fabaceae	Tree
6	Dong	*Apodytes dimidiata*	Icacinaceae	Tree
7	Getem	*Schefflera abyssinica*	Araliaceae	Tree
8	Gewra	*Myrsine melanophloeos*	Myrsinaceae	Tree
9	Girar nech	*Acacia abyssinica*	Fabaceae	Tree
10	Koso	*Hagenia abyssinica*	Rosaceae	Tree
11	Sembo	*Ekebergia capensis*	Meliaceae	Tree
12	Shinet	*Myrica salicifolia*	Myricaceae	Tree
13	Shola	*Ficus sur*	Moraceae	Tree
14	Tife	*Olinia rochetiana*	Oliniaceae	Tree
15	Wanaye	*Scolopia theifolia*	Flacourtiaceae	Tree
16	Woira	*Olea europaea subsp. cuspidata*	Oleaceae	Tree
17	Wulkfa	*Dombeya torrida*	Sterculiaceae	Tree
18	Yabesha Tsid	*Juniperus procera*	Cuppressaceae	Tree
19	Akelaho	*Maesa lanceolata*	Myrsinaceae	Shrub
20	Alashume	*Laggera tomentosa*	Asteraceae	Shrub
21	Ameraro	*Discopodium penninervium*	Solanaceae	Shrub
22	Amja	*Hypericum revolutum*	Hypericaceae	Shrub
23	Antafulasa	*Maytenus senegalensis*	Celastraceae	Shrub
24	Asta	*Erica arborea*	Ericaceae	Shrub
25	Atat	*Maytenus gracilipes*	Celastraceae	Shrub
26	Kombel	*Maytenus arbutifolia*	Celastraceae	Shrub
27	Beles	*Opuntia ficus-indica*	Cactaceae	Shrub
28	Buyte	*Vernonia myriantha*	Asteraceae	Shrub
29	Damakesie	*Ocimum lamiifolium*	Lamiaceae	Shrub
30	Digta	*Calpurnia aurea*	Fabaceae	Shrub
31	Embuacho	*Rumex nervosus*	Polygonaceae	Shrub
32	Embuay	*Solanum dennekense*	Solanaceae	Shrub
33	Endod	*Phytolacca dodecandra*	Phytolaccaceae	Shrub
34	Fyelfeji	*Clutia lanceolata*	Euphorbiaceae	Shrub
35	Gurarba	*Rubus steudneri*	Rosaceae	Shrub
36	Kechemo	*Myrsine africana*	Myrsinaceae	Shrub
37	Kega	*Rosa abyssinica*	Rosaceae	Shrub
38	Keret	*Osyris quadripartita*	Santalaceae	Shrub
39	Koshim	*Dovyalis abyssinica*	Flacourtiaceae	Shrub
40	Kulsh	*Inula confertiflora*	Asteraceae	Shrub
41	Lakuso	*Urera hypselodendron*	Urticaceae	Shrub
42	Lomishet	*Satureja punctata*	Lamiaceae	Shrub
43	Setkest	*Asparagus setaceus*	Asparagaceae	Shrub
44	Shekori	*Acanthus sennii*	Acanthaceae	Shrub
45	Yeshikoko Gomen	*Solanecio gigas*	Asteraceae	Shrub
46	Azo Areg	*Clematis longicauda*	Ranunculaceae	Liana

47	Quande	*Tacazzea conferta*	Asclepiadaceae	Liana
48	Yayit hareg	*Convolvulus kilimandschari*	Convolvulaceae	Liana
49	Ginchire	*Festuca macrophylla*	Poaceae	Graminoid
50	Adey Abeba	*Bidens prestinaria*	Asteraceae	Forbs
51	Akenchira	*Galinsoga parviflora*	Asteraceae	Forbs
52	Akrma	*Eleusine floccifolia*	Poaceae	Graminoid
53	Amoch	*Arisaema schimperianum*	Araceae	Forbs
54	Anterfa	*Euphorbia shimperiana*	Euphorbiaceae	Forbs
55	Ashket	*Galium aparinoides*	Rubiaceae	Forbs
56	Balamie	*Andropogon abyssinicus*	Poaceae	Graminoid
57	Birkie	*Conyza tigrensis*	Asteraceae	Forbs
58	Bilikie	*Dianthoseris schimperi*	Asteraceae	Forbs
59	Chefereg	*Hibiscus macranthus*	Malvaceae	Forbs
60	Chegogit	*Torilis arvensis*	Apiaceae	Forbs
61	Chemekot	*Trifolium semipilosum*	Fabaceae	Forbs
62	Derg	*Phaulopsis imbricata*	Acanthaceae	Forbs
63	Dobi	*Girardinia bullosa*	Urticaceae	Forbs
64	Emburi	*Kniphofia foliosa*	Asphodelaceae	Forbs
65	Endawula	*Kalanchoe petitiana*	Crassulaceae	Forbs
66	Filla	*Carex bequaertii*	Cyperaceae	Forbs
67	Tef sar	*Sporobolus africanus*	Poaceae	Graminoid
68	Gemera yewrma	*Lobelia giberroa*	Lobeliaceae	Forbs
69	Anfar	*Budlejja polystachya*	Scrophulariaceae	Shrub
70	Getn	*Haplocarpha schimperi*	Asteraceae	Forbs
71	Gicha Yewrma	*Cyperus sesquiflorus*	Cyperaceae	Forbs
72	Gendero	*Echinops macrochaetus*	Asteraceae	Forbs
73	Gorteb	*Plantago lanceolata*	Plantaginaceae	Forbs
74	Gramta	*Cyperus fischerianus*	Cyperaceae	Forbs
75	Gurshit	*Impatiens tinctoria subsp. tinctoria*	Balsaminaceae	Forbs
76	Kello	*Unidentified sp1*		Forbs
77	Kelem sem	*Dipsacus pinnatifidus*	Dipsacaceae	Forbs
78	Ketetina	*Verbascum sinaiticum*	Scrophulariaceae	Forbs
79	Key Matebiya	*Hypoestes forskaolii*	Acanthaceae	Forbs
80	Kus Ayen	*Satureja paradoxa*	Lamiaceae	Forbs
81	Lalinch	*Commelina benghalensis*	Commelinaceae	Forbs
82	Maget	*Trifolium polystachyum*	Fabaceae	Forbs
83	Mech	*Guizotia scabra*	Asteraceae	Forbs
84	Mokmoko	*Rumex abyssinicus*	Polygonaceae	Forbs
85	Nechachube	*Cerastium octandrum*	Caryophyllaceae	Forbs
86	Senbelet	*Hyparrhenia dichroa*	Poaceae	Graminoid
87	Serdo	*Cynodon aethiopicus*	Poaceae	Graminoid
88	Tay matebia	*Hypoestes forskaolii*	Acanthaceae	Forbs
89	Tosign	*Thymus schimperi*	Lamiaceae	Forbs
90	Warat	*Cynodon dactylon*	Poaceae	Graminoid
91	Wof Ankur	*Commelina benghalensis*	Commelinaceae	Forbs
92	Wude Gesho	*Mikaniopsis clematoides*	Asteraceae	Forbs
93	Wulkefae	*Unidentified sp2*		Forbs
94	Yayit misir	*Argyrolobium schimperianum*	Fabaceae	Shrub

95	Yegedel Sar	*Festuca abyssinica*	Poaceae	Graminoid
96	Yebere Chew	*Anagallis serpens*	Primulaceae	Forbs
97	Yekok ras	*Campanula edulis*	Campanulaceae	Forbs
98	Yekok sar	*Oplismenus compositus*	Poaceae	Graminoid
99	Yemdir Koso	*Geranium arabicum*	Geraniaceae	Forbs
100	Yeset Afe	*Hygrophila schulii*	Acanthaceae	Forbs
101	Joroasfa	*Adiantum raddianum*	Adiantaceae	Fern

3

Table S2 Stem density of trees, shrubs and lianas > 2 m tall and basal areas of tree species sampled in the home range of the study band at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

Species name	Local name	Family name	Number of stems/ha (Density)	% of stem Density	Basal area/ha (cm^2/ha)
Myrsine africana	Kechemo	Myrsinaceae	72.00	11.80	
Clutia lanceolata	Fyelfeji	Euphorbiaceae	67.00	10.98	
Acanthus sennii	Shekori	Acanthaceae	62.00	10.16	
Olinia rochetiana	Tife	Oliniaceae	51.00	8.36	1137.57
Rosa abyssinica	Kega	Rosaceae	50.00	8.20	
Discopodium penninervium	Ameraro	Solanaceae	43.00	7.05	
Vernonia myriantha	Buyte	Asteraceae	35.00	5.74	
Rubus steudneri	Gurarba	Rosaceae	31.00	5.08	
Tacazzea conferta	Quande	Asclepiadaceae	26.00	4.07	
Rumex nervosus	Embuacho	Polygonaceae	23.00	4.26	
Olea europaea subsp. cuspidata	Woira	Oleaceae	19.00	3.11	2859.16
Maesa lanceolata	Akelaho	Myrsinaceae	16.00	2.62	
Dombeya torrida	Wulkfa	Sterculiaceae	13.00	2.13	2276.50
Urera hypselodendron	Lakuso	Urticaceae	12.00	1.97	
Maytenus arbutifolia	Kombel	Celastraceae	10.00	1.64	
Phytolacca dodecandra	Endod	Phytolaccaceae	10.00	1.64	
Solanecio gigas	Yeshikoko Gomen	Asteraceae	10.00	1.64	
Nuxia congesta	Askuar	Loganiaceae	9.00	1.48	1251.26
Hypericum revolutum	Amja	Hypericaceae	8.00	1.31	
Clematis longicauda	Azo Areg	Ranunculaceae	8.00	1.31	
Prunus africana	Anje	Rosaceae	6.00	0.98	2122.21
Apodytes dimidiata	Dong	Icacinaceae	5.00	0.82	3508.14
Acacia abyssinica	Girar nech	Fabaceae	4.00	0.66	298.44
Myrsine melanophloeos	Gewra	Myrsinaceae	3.00	0.49	828.99
Ekebergia capensis	Sembo	Meliaceae	3.00	0.49	6107.44
Juniperus procera	Yabesha Tsid	Cuppressaceae	3.00	0.49	12887.53
Dovyalis abyssinica	Koshim	Flacourtiaceae	3.00	0.49	
Osyris quadripartita	Keret	Santalaceae	3.00	0.49	
Myrica salicifolia	Shinet	Myricaceae	2.00	0.33	2198.68
Scolopia theifolia	Wanaye	Flacourtiaceae	1.00	0.16	609.05

Calpurnia aurea	Digta	Fabaceae	1.00	0.16
Solanum dennekense	Embuay	Solanaceae	1.00	0.16

Table S3 Monthly food availability indices of plant parts in the home range of the study band (FAI units/ha) at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

Months	Young leaves	Mature leaves	Flowers	Fruits
Jun-16	15395	27353	0	5498
Jul-16	21099	27628	0	9347
Aug-16	20343	30927	0	8522
Sep-16	18694	32164	137	6048
Oct-16	16769	28040	0	2337
Nov-16	14295	20068	3024	536
Dec-16	9622	29965	6144	275
Jan-17	8385	32714	6144	1100
Feb-17	8660	30790	1787	3849
Mar-17	10584	31339	1471	4124
Apr-17	13745	28178	0	3711
May-17	14845	27491	0	3161

Table S4 Graminoid phenological assessment in the home range of the study band (**DGP** - dry graminoids/forbs plot, **MGGP** - mixed green graminoids/forbs plot, **GGP** - green graminoids/forbs plot) at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

Month/year	DGP (%)	MGGP (%)	GGP (%)
Jun-16	2.22	30.88	66.90
Jul-16	1.23	9.46	89.31
Aug-16	0.86	8.00	91.14
Sep-16	0.88	13.53	85.58
Oct-16	0.00	10.39	89.61
Nov-16	1.97	45.33	52.71
Dec-16	8.96	55.63	35.42
Jan-17	8.37	80.37	11.26
Feb-17	36.47	63.53	0.00
Mar-17	41.52	54.68	3.80
Apr-17	22.11	55.39	22.50
May-17	0.00	20.00	80.00
Mean	10.38	37.27	52.35

Table S5 Monthly food items contribution to the diet of hamadryas baboons in BSNP (AP=animal prey, B=bark, CER= cereals, FL=flowers, FR=fruits, GB=graminoids blade, GR=graminoids root, HL=forbs leaf, HR=forbs root, ML=mature leaves, S=stem, YL=young leaves, and V=vegetables).

Months/year	AP	B	CER	FL	FR	GB	GR	HL	HR	ML	S	V	YL
Jun-16	0.87	1.92	11.85	2.11	16.86	17.87	1.81	11.41	1.05	10.28	5.47	0.00	18.53
Jul-16	1.87	0.00	11.68	3.02	34.19	6.76	3.27	12.43	3.09	5.78	9.34	0.00	8.59
Aug-16	3.27	2.75	1.24	1.76	45.32	13.99	0.00	11.28	1.89	1.95	4.16	0.33	12.08
Sep-16	2.99	0.00	0.00	5.23	48.55	13.82	0.92	17.40	0.00	1.38	3.76	0.00	5.97
Oct-16	2.14	0.00	3.42	6.83	45.52	14.89	5.10	8.96	1.70	0.00	4.26	0.00	7.21
Nov-16	4.20	1.40	25.46	19.87	1.40	11.60	7.43	7.87	0.00	1.84	3.27	0.00	15.69
Dec-16	0.85	0.00	22.22	23.93	4.27	11.97	0.00	7.69	0.00	2.56	5.98	0.00	20.51
Jan-17	0.93	0.00	5.61	6.54	9.35	28.04	0.93	0.00	0.00	8.41	9.35	0.00	30.84
Feb-17	0.00	0.00	0.00	5.00	35.00	44.00	0.00	0.00	0.00	1.00	0.00	0.00	15.00
Mar-17	0.00	0.00	7.29	0.00	58.33	26.04	0.00	1.04	0.00	0.00	2.08	0.00	5.21
Apr-17	1.92	0.00	2.88	1.92	45.19	19.23	0.00	3.85	0.00	0.00	11.54	0.00	13.46
May-17	1.77	0.00	14.16	0.00	39.82	26.55	0.00	11.50	0.00	0.00	0.88	0.00	5.31
Mean (%)	1.73	0.51	8.82	6.35	31.98	19.56	1.62	7.79	0.64	2.77	5.01	0.03	13.20

Table S6 Monthly percentage contribution of food plant species by hamadryas baboons.

Plant species consumed	Months												Average (%)
	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	
Olinia rochetiana	4.44	24.39	27.21	43.97	43.82	2.76	7.69	13.08	7.00	0.00	3.85	1.77	15.00
Rosa abyssinica	10.15	1.76	0.00	0.00	0.00	5.10	5.13	2.80	17.00	35.42	34.62	37.17	12.43
Andropogon abyssinicus	18.05	6.76	10.72	14.23	15.29	13.43	11.11	1.87	0.00	0.00	0.00	21.24	9.39
Triticum spp.	0.00	7.95	0.92	0.00	3.42	21.77	21.37	5.61	0.00	0.00	0.00	0.00	5.09
Acanthus sennii	7.92	6.00	11.10	3.76	3.84	7.86	14.53	1.87	0.00	0.00	0.00	0.00	4.74
Discopodium penninervium	8.16	3.77	6.13	2.75	0.00	3.71	10.26	4.67	0.00	6.25	7.69	0.88	4.52
Rubus steudneri	1.64	0.76	0.00	0.00	0.00	0.47	0.00	9.35	19.00	22.92	0.00	0.00	4.51
Dombeya torrida	1.17	0.25	0.65	4.59	2.97	17.52	11.11	6.54	0.00	0.00	0.00	0.00	3.73
Zea mays	9.18	3.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.29	2.88	14.16	3.10
Haplocarpha schimperi	8.85	3.23	7.70	0.92	0.85	2.75	4.27	0.00	0.00	1.04	1.92	5.31	3.07
Scolopia theifolia	0.24	4.02	12.27	4.59	1.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.90
Rumex nervosus	4.03	3.27	0.00	0.00	0.86	2.81	0.00	0.00	2.00	0.00	6.73	0.00	1.64
Nuxia congesta	1.87	0.76	0.65	0.00	0.00	0.00	0.00	5.61	8.00	1.04	0.96	0.00	1.57
Andropogon distachyos	0.00	3.27	2.75	0.51	5.56	4.68	0.00	0.00	0.00	0.00	0.00	0.00	1.40
Trifolium polystachyum	0.24	2.34	0.00	8.03	5.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.31
Cynodon aethiopicus	0.41	0.00	0.98	0.00	0.00	0.00	0.00	0.00	4.00	0.00	4.81	5.31	1.29
Cyperus sesquiflorus	1.46	3.74	0.92	1.01	0.86	1.87	0.00	0.00	0.00	0.00	3.85	1.77	1.29
Urera hypselodendron	5.36	2.45	1.30	0.00	2.54	0.00	0.00	0.00	0.00	0.00	0.00	3.54	1.27
Bidens prestinaria	0.00	0.00	0.00	8.26	5.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.11
Ficus sur	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.58	0.00	0.88
Acacia decurrens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.41	0.00	0.00	1.92	0.00	0.86
Vernonia myriantha	1.17	0.51	0.00	0.00	0.00	0.00	3.42	3.74	1.00	0.00	0.00	0.00	0.82
Olea europaea subsp. cuspidata	2.34	3.27	1.95	0.00	0.00	0.00	0.00	1.87	0.00	0.00	0.00	0.00	0.79
Maesa lanceolata	0.70	2.26	0.00	0.00	1.27	0.46	4.27	0.00	0.00	0.00	0.00	0.00	0.75
Cyperus fischerianus	1.11	1.76	3.57	0.46	0.00	1.85	0.00	0.00	0.00	0.00	0.00	0.00	0.73
Hordeum vulgare	2.44	0.00	0.00	0.00	0.00	3.69	0.85	0.00	0.00	0.00	0.00	0.00	0.58

Solanum dennekense	0.82	4.96	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52
Dovyalis abyssinica	2.04	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	2.65	0.51
Phaulopsis imbricata	0.00	0.00	0.00	0.00	0.00	0.00	3.42	0.00	0.00	0.00	0.00	2.65	0.51
Myrica salicifolia	1.17	0.00	1.30	0.00	0.00	0.92	0.00	0.00	2.00	0.00	0.00	0.00	0.45
Commelina benghalensis	0.00	0.47	0.00	1.93	2.14	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.42
Myrsine melanophloeos	0.47	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.85	0.00	0.40
Trifolium semipilosum	0.00	1.40	0.00	2.02	0.43	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.40
Prunus africana	0.00	0.00	3.57	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00	0.00	0.38
Arisaema schimperanum	0.00	2.59	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
Hypericum revolutum	0.70	0.51	0.98	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.25
Kalanchoe petitiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80	0.00	0.00	0.00	0.00	0.23
Carex bequaertii	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.77	0.22
Rumex abyssinicus	0.00	0.00	0.00	0.00	1.71	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.18
Apodytes dimidiata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.87	0.00	0.00	0.00	0.00	0.16
Schefflera abyssinica	0.00	1.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
Laggera tomentosa	0.82	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Eleusine floccifolia	1.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Solanecio gigas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00	0.00	0.08
Hyparrhenia dichroa	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Oplismenus compositus	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.07
Avena abyssinica	0.24	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Solanum tuberosum	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03

Table S7 Shannon-Wiener diversity and evenness indices of food plant species consumed by hamadryas baboons during the study period at Borena-Sayint National Park in northern Ethiopia, June 2016-May 2017.

Months/year	Observation Days	Species Consumed	Species Proportion	Shannon Wiener diversity index, *H′*	Evenness index, *J*
Jun-16	8	30	0.1493	2.84	0.57
Jul-16	8	28	0.1393	2.84	0.61
Aug-16	8	22	0.1095	2.42	0.51
Sep-16	8	14	0.0697	1.88	0.47
Oct-16	8	18	0.0896	2.02	0.42
Nov-16	8	21	0.1045	2.44	0.55
Dec-16	8	14	0.0697	2.32	0.72
Jan-17	8	16	0.0796	2.52	0.78
Feb-17	8	8	0.0398	1.72	0.70
Mar-17	8	6	0.0299	1.27	0.60
Apr-17	8	12	0.0597	1.98	0.60
May-17	8	12	0.0597	1.87	0.54
Mean/Sum	8	201	1.0000	2.18	0.59