Diet and activity patterns of Arsi geladas in low-elevation disturbed habitat south of the Rift Valley at Indetu, Ethiopia

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Abstract Understanding the basic natural history of threatened primate taxa is crucial to developing and implementing successful conservation strategies for them. Data on feeding ecology and activity patterns are particularly important for identifying the strategies through which primates invest time and foraging effort towards survival and reproduction at a given locale. Here, we report the results of the first study of the diet and activity budget of Arsi geladas, a population of <1000 individuals endemic to a heavily disturbed region of the southern Ethiopian Highlands and believed to represent a new taxon of geladas. We conducted our research on a band of 34 individuals belonging to 5 one-male units at Indetu, eastern Arsi, Ethiopia from August 2010 to May 2011 (excluding March 2011). Feeding accounted for 41.7% of total scans, followed by moving (20.3%), resting (19.0%), and social behavior (19.0%). Feeding and moving increased and resting and socializing decreased during the dry season when food availability was probably lower than during the wet season. Geladas ate mostly graminoid leaves (51.7% of feeding scans) though they also consumed graminoid rhizomes (24.4%), forb tubers (7.1%), forb leaves (7.1%), cactus, shrub, and tree fruits (3.6%), graminoid corms (1.7%), forb roots (1.6%), and unidentified items (3.0%). Underground foods (corms, rhizomes, roots, and tubers) accounted for 22%-47% (mean = 35%) of the monthly (n=9) diet and were eaten slightly more during the wet season than during the dry season. Contributions of human crops to the gelada diet could not be quantified without creating conflict between farmers and researchers, though we did note that geladas visited farms on 5-10% of study days. Threats from farmers, children, and dogs limited the geladas' access to crops once they entered the farms. Further research involving questionnaire surveys of farmers, direct observation of crop damage by geladas, and DNA

metabarcoding of gelada feces are crucial to the development of strategies to mitigate human-gelada conflict in the densely populated Arsi Zone of Ethiopia.

Keywords Activity budget, anthropogenic disturbance, crop raiding, diet, Ethiopian Highlands

Introduction

As primate habitats become increasingly fragmented by humans and their activities, the study of isolated populations takes on increasing importance (Chapman et al. 2006; Irwin 2016). Such studies are especially crucial when these isolated populations are taxonomically unique (Oates et al. 2002; Fan et al. 2011). Understanding the basic natural history of all primate taxa should be a fundamental goal of primatology, yet many of the rarest species and subspecies remain largely unstudied (Rowe and Myers 2016). Data on the diet and activity patterns of these little-known species are particularly important to understanding the nutritional and energetic challenges they face, information that can contribute to the development of more informed conservation strategies for them (Struhsaker 2010; Lambert 2011).

The country of Ethiopia is characterized by unusually high endemism, including for primates (Yalden and Largen 1992). Despite facing high levels of habitat destruction and degradation due to Ethiopia's rapidly growing human and livestock populations (Williams et al. 2005), most of Ethiopia's unique primates remain little-studied. For example, two taxa, Bale monkeys (*Chlorocebus djamdjamensis*) and Boutourlini's blue monkeys (*Cercopithecus mitis boutourlini*), were only recently studied for the first time (Mekonnen et al. 2010, 2012; Tesfaye et al. 2013). Of Ethiopia's endemic primates, only the gelada (*Theropithecus gelada*) has been the subject of detailed research at multiple study sites (e.g., Dunbar and Dunbar 1975; Kawai 1979; Beehner and Bergman 2008; Nguyen et al. 2015).

Even among geladas, however, there is a rare, isolated, and little-studied population known colloquially as the Arsi gelada, that represents the only gelada found south of the Rift Valley. Recent genetic evidence suggests that Arsi geladas are different enough from their northern counterparts (common and dusky geladas) to warrant their own taxonomic status (Shotake et al. 2016) though it remains unresolved whether the different gelada clades deserve subspecies (*T. gelada gelada*; *T. gelada obscurus*; Arsi gelada - proposed nomenclature: *T. gelada arsi*: Shotake et al. 2016) or species status (C. Groves, pers. comm.), an issue that requires further study. Though some details are known about its genetic composition (Belay and Mori 2006; Shotake et al. 2016) and social structure (Mori et al. 1999, 2003), no studies of the Arsi gelada's basic natural history, including diet and activity patterns, have been conducted. With fewer than 1000 individuals remaining and their Afroalpine habitat experiencing intense disturbance (Belay and Shotake 1998; Abu 2011), there is an urgent need for empirical data on their behavior and ecology, information that will be useful to the development and implementation of a management plan for the Arsi gelada.

To address the paucity of knowledge about this taxon, we carried out the first study of the diet and activity patterns of Arsi geladas. From August 2010-May 2011 (excluding March), we studied a band of 34 individuals belonging to 5 one-male units at Indetu, a heavily disturbed site in eastern Arsi. Here, we report our findings on the diet and activity patterns of Arsi geladas and compare them with those from previous studies of *T. g. gelada* and *T. g. obscurus* in northern and central Ethiopia, respectively. We also briefly discuss the conservation implications of our results and suggest directions for further research on Arsi geladas.

Methods

Study site

We carried out this study at Indetu (7°31'N, 39°60'E), an unprotected area experiencing heavy usage by humans and their livestock, in Robe District, eastern Arsi, Ethiopia. Indetu occurs at elevations ranging from 1180-2434 m asl and consists of ~30 km^2 of mixed grassland, bushland, agricultural areas and forest near steep cliffs bisected by the Wabi River (Mori et al. 1997; Abu 2011). Annual rainfall (~800 mm per year) at the nearest weather station (50 km away at Robe) is only about half the amounts typical of gelada study sites north of the Rift Valley (Hunter 2001; Fashing et al. 2014; Mekonnen et al. 2010; Abu 2011). Rainfall in Arsi is seasonal with the wet season lasting from July-October (Abu 2011). The short rainy season, low overall rainfall levels, and low elevation at Indetu result in there being longer and more intense periods of drought and higher temperatures at Indetu (Abu 2011) than at gelada study sites north of the Rift Valley (Hunter 2001; Fashing et al. 2014). Primates present at Indetu include geladas (*Theropithecus gelada*), anubis baboons (*Papio anubis*), hamadryas baboons (*Papio hamadryas*), and grivet monkeys (*Chlorocebus aethiops*). Predators of geladas occurring at Indetu include leopards (*Panthera pardus*) and domestic dogs (*Canis familiaris*) (Iwamoto et al. 1996; Mori et al. 1999; Abu 2011).

Study animals

We carried out our research on a gelada band of 34 individuals belonging to five one-male units that often traveled together and shared a common home range (Abu 2011). Members of the band were habituated to within 10 m of human observers. Several members of the study band were easily identifiable by distinctive natural markings, coat colors, or facial features though most members were not individually recognized. The study band occupied a W-shaped valley with steep cliff faces descending to the east. During this study, they ranged at elevations from 1800-2320 m asl (Abu 2011), at the low end of the elevational range for *T. gelada* (1800-4400 m asl; Fashing and Nguyen 2016). Because of the challenging terrain and tendency of geladas to spend much of their time on cliffsides at Indetu, many observations had to be made through a telescope from near a cliff edge.

Behavioral observation

Activity patterns

Habituation of the study band was carried out for two months from June - July 2010. Over 9 of the next 10 months (August 2010 - May 2011, excluding March 2011), K.A. collected data on activity budget and feeding ecology using instantaneous scan sampling (Altmann 1974) at 15-minute intervals from 0700 to 1730 on an average of 10 consecutive days per month. During each scan sample, the first activity that lasted for $\geq$3 seconds was recorded for up to five adults, subadults or juveniles. Study animals were scanned consistently from left to right to avoid biases towards eye-catching activities (Mekonnen et al 2010). Activities recorded during scans consisted of ‘feeding’, ‘moving’, ‘resting’, or ‘social’. Feeding was recorded when a gelada manipulated or masticated a particular item of food. Moving was recorded when a gelada changed its spatial position through locomotor behavior, including walking, jumping or running. Resting was recorded when a gelada was inactive in a sitting or lying position. Social was recorded when a gelada participated in grooming, play, sexual, or agonistic behavior with another individual.

To calculate the proportion of time the study animals spent engaged in each activity, we divided the number of records for each activity category by the total number of activity records. We used the behavioral records of the group to calculate the activity budget for each day and then averaged the daily values within each month to construct monthly activity budgets. The grand mean proportions of the monthly budgets provided the overall activity budgets for the entire study period (cf., Mekonnen et al. 2010).

Feeding ecology

During activity scan sampling, when an individual gelada was observed feeding, we recorded the type of food item – graminoid leaves (i.e., grass or sedge blades), forb leaves, graminoid corms, graminoid rhizomes, forb roots, forb tubers, fruits from cacti, shrubs, or trees, or unidentified - as well as the species consumed, if possible. Voucher specimens of species consumed were collected for later taxonomic identification by a botanist in the National Herbarium, Addis Ababa University. However, it was not possible to collect and identify all the graminoid and forb species consumed by geladas because of the difficult terrain and large distances from which geladas were observed when they occupied cliff sides. Geladas at Indetu also raided the crops of local people on 5-10% of study days but we were unable to follow them onto the farms because farmers were upset about these incursions and, in some cases, believed researchers were leading geladas to the farms. Therefore, data on the contribution of crops to gelada diets - and gelada activity patterns - while on the farms are not available for this study. However, we should note here that several previous studies of geladas have also described gelada crop raiding while also proving unable to collect data on percentage crop consumption to incorporate into their estimates of overall gelada diet (e.g., Dunbar 1977; Hunter 2001).

We evaluated the diet of geladas by calculating the proportion of different food items consumed by the geladas. We summed the daily food items consumed by geladas within each month to construct a monthly proportion of food items consumed. We summarized the monthly proportion of each food item in the scans by dividing the total number of monthly individual scans for each food item by the total number of individual scans for all food items. We then used the grand means of the monthly proportions of food items consumed to calculate the overall diets of geladas for the entire study period (cf., Mekonnen et al., 2010).

Results

Activity budget

A total of 6,152 individual activity records were obtained during 1521 scans conducted on 87 study days. In these scans, geladas spent 41.7% (SD±5.3%) of their time feeding, 20.3% (SD±5.5%) moving, 19.0% (SD±3.3%) resting, and 19.0% (SD±7.4) engaging in social activities. Percentage of time devoted to feeding (9.0% increase in dry season), moving (4.3%

increase in dry season), and socializing (12.3% increase in wet season) all differed markedly between seasons (Figure 2). However, percentage of time spent resting (0.9% increase in wet season) was relatively invariable between seasons (Fig. 2).

Feeding ecology

Diet Composition During scans, graminoid leaves accounted for 51.7% (SD ± 12.5%) of the overall diet (n=2481 feeding records). Graminoid rhizomes made the second largest contribution to the diet at 24.4% (SD ± 5.7%). Geladas also consumed forb tubers 7.1% (SD ± 5.8%), forb leaves 7.1% (SD ± 7.0), fruit from cacti 2.0% (SD ± 3.8%), fruit from shrubs and trees 1.6% (SD ± 2.2%), graminoid corms 1.7% (SD ± 3.3), forb roots 1.6% (SD ± 3.3), and unidentified items 2.7% (SD ± 5.3%). Geladas were never observed eating animal matter.

Graminoid leaves were the top food item during all months contributing between 38.1-71.4% of the monthly diet (Table 1). Graminoid rhizomes were also consumed during all months (range 16.9-32.4%). Forb tubers (0.0-17.1%) and forb roots (0.0-5.9%) were each eaten in all but one month, as were forb leaves (0.0-15.0%). When combined into a single category, underground foods (corms, rhizomes, roots, and tubers) accounted for 21.6-46.6% of the monthly diet (mean=34.8%). Graminoid leaf consumption peaked towards the end of the wet season (October) and the months immediately following it (November-January). Underground items were eaten slightly more during the wet season (37.8%±4.6) than during the dry season (33.3%±10.0).

Geladas consumed a minimum of 12 plant species during the study period, though this number is undoubtedly an underestimate. The graminoids and forbs consumed by geladas often could not be identified confidently to species because of the challenges inherent in identifying these taxa from a distance. Geladas clearly fed on at least two species of graminoid, *Hyparrhenia hirta* and *Hyparrhenia* sp. (Poaceae), and three species of forbs, *Dodonaea angustifolia* (Sapindaceae, forb), *Euclea racemosa* (Ebenaceae, forb), and *Ipomoea hildebrandtii* (Convolvulaceae). In addition, they fed on three species of shrubs, *Balanites aegyptica* (Balanitaceae), *Rhus glutinosa* (Anacardiaceae), and *Opuntia stricta* (Cactaceae) - the latter a cactus (i.e., an exotic succulent) - as well as on two species of trees, *Ficus vasta* (Moraceae), and *Olea europaea* (Oleaceae). Lastly, geladas also consumed two human crops, barley (*Hordeum vulgare*) and wheat (*Triticum* sp.), during their visits to nearby farms on 5-10% of study days. However, threats from farmers, children, and dogs undoubtedly limited gelada foraging on these crops.

Discussion

Here, we report the results of the first ever study of the feeding ecology and activity budget of Arsi geladas south of the Rift Valley. Based on our research at Indetu, we found that Arsi geladas fed mostly, but not exclusively, on graminoid parts to meet their daily energy needs. Underground items from graminoids and forbs were substantial contributors (22%-47%) to the monthly diet throughout the study. Geladas at Indetu increased time spent feeding and moving in the dry season, perhaps to cope with reduced availability of preferred foods during this time. The low elevation and intensive anthropogenic disturbance make Indetu the most marginal habitat in which geladas have been studied to date. Given the taxonomic uniqueness, restricted range, and small population size of Arsi geladas as well as the anthropogenic threats they face, this little-known monkey urgently requires more detailed study and the development and implementation of empirically-based conservation strategies to improve its chances of long-term survival.

Activity budget

Animals occupying high elevation habitats typically have elevated energy requirements because of the thermoregulatory demands of cold climates (Kleiber 1961; Grow et al. 2014). As a result, Iwamoto and Dunbar (1983) predicted that, among geladas, percentage of time spent feeding should be correlated with elevation. They described the activity budgets from three gelada study sites at elevations ranging from 2300 m asl (Bole) to 3300 m asl (Sankaber) to 3900 m asl (Gich) which fit this pattern. Geladas at Gich devoted a remarkable 62% of their time to feeding while those at Bole only spent 36% of their time feeding (Iwamoto and Dunbar 1983). Here, we add comparative data from a fourth site, Indetu (1800-2320 m asl), at the lower elevational limit for geladas (Table 2). Though still lower than at the high elevation sites of Gich (62%) and Sankaber (45%), percentage time spent feeding was higher at Indetu (42%) than at Bole (36%) with a concomitant reduction in percentage time spent resting at Indetu (19%) relative to Bole (26%). Thus, while the general pattern described by Iwamoto and Dunbar (1983) seems robust, we suggest that the unexpected activity budget differences between Indetu and Bole may result from the extremely degraded nature of Indetu where human and livestock activity have made it an especially marginal site for occupancy by geladas.

Geladas at Indetu also exhibited striking seasonal differences in activity patterns. Increases in time spent feeding (9.0% increase) and moving (4.3% increase) during the dry season are probably related to the lower availability of food for geladas at that time of year. Studies of geladas at other sites have found that food availability, particularly of green graminoids, is driven by rainfall (Iwamoto 1979; Hunter 2001; Fashing et al. 2014). Not only is rainfall also strongly seasonal at Indetu, but annual rainfall totals in the region are half those typical for geladas at study sites north of the Rift Valley (Hunter 2001; Mekonnen et al. 2010; Fashing et al. 2014). Thus, a few months into the dry season at Indetu, most graminoids have already turned brown and water sources have become scarce (K. Abu, pers. observ.), compelling geladas to increase time spent feeding and traveling. Substantial increases in feeding time during the dry season have also been noted for geladas at the high elevation sites of Sankaber and Gich (Dunbar 1977; Iwamoto 1979, 1993), suggesting this is a pattern that holds for geladas across sites and subspecies. It is also known to occur in some baboon (*Papio* spp.) populations, particularly those that experience long dry seasons (Dunbar 1992).

Feeding ecology

The diet of geladas at Indetu was consistent with those of geladas studied at most other sites (Table 3). For example, graminoid parts accounted for an average of 80% of the diet at other sites and 78% of the diet at Indetu, supporting the long-held notion that geladas are mostly graminivorous wherever they occur (Crook and Aldrich-Blake 1968; Iwamoto 1993; Swedell 2011; Bergman and Beehner 2013; Fashing and Nguyen, 2016). Further, forb parts contributed an average of 17% of the diet at other sites versus 16% of the diet at Indetu. Invertebrates were never consumed at Indetu, consistent with reports from other sites, where invertebrates consistently account for ≤0.1% of the diet with one exception (2.8% of the diet at the most ecologically intact site, Guassa: Fashing et al. 2010, 2014).

On the other hand, reliance on underground foods (from both graminoids and forbs) was higher at Indetu (35% of the diet) than elsewhere, with only geladas at Sankaber relying on underground items nearly as much (32%: Hunter 2001; 26% Dunbar 1977). Furthermore, whereas geladas elsewhere mostly consumed underground items during the dry season when above-ground biomass was lower (Iwamoto 1979; Hunter 2001; Fashing et al. 2014), geladas at Indetu consumed underground items consistently over time (never less than 22% of the monthly diet), even eating them slightly more during the wet season (mean=38%) than during the dry season (mean=33%). This result is consistent with our suggestion that Indetu is a marginal habitat for geladas, where they must resort to excavating underground items across all seasons to survive. The low overall species richness (n=12) of the gelada diet at Indetu, though likely an underestimate, is also suggestive of a limited array of potential food species being available there.

Conservation implications and recommendations for future research

First discovered by scientists only three decades ago (Mori and Belay 1990) and identified as genetically distinct from other geladas in 2016 (Shotake et al. 2016), Arsi geladas are among the world’s least known primates. Their extremely restricted distribution, small remaining numbers (<1000 individuals), occurrence at the lower elevational limit for geladas, and heavily anthropogenically-degraded habitat (Belay and Shotake 1998; Abu 2011; Fashing and Nguyen 2016) may ultimately warrant listing them among the world's most endangered primates (i.e., Schwitzer et al. 2015; IUCN 2017).

Future research that will be crucial to both filling a gap in our dietary study as well as to the conservation of geladas involves quantifying levels and impacts of crop raiding by geladas in Arsi. This research will require sustained efforts to gain the trust of local farmers, questionnaire surveys of the farmers, and direct observation of crop damage by geladas (c.f., Yihune et al. 2009; Wallace and Hill 2012). The additional application of the more indirect technique of conducting DNA metabarcoding analyses on feces (e.g., Kartzinel et al. 2015) would also provide a thorough accounting of which crops are being eaten by geladas and in what quantities. The issue of crop raiding at Indetu must be solved, not only to minimize the potential for conflict between Arsi geladas and humans, but also because crop raiding by local wildlife is a major factor driving human populations towards illegal resource exploitation in natural environments (Harrison et al. 2015).

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Figure Legends

Fig. 1 The locations of *Theropithecus gelada* study sites across the Ethiopian Highlands, including our site, Indetu, where the rare Arsi gelada is found.

Fig. 2 Comparison of the activity budgets of Arsi geladas during the dry season and the wet season at Indetu, Ethiopia.

Table 1 Monthly variation in percentage contribution of different food items to the diet of geladas at Indetu

Months	% of diet							
	Graminoid leaves	Graminoid rhizomes	Graminoid corms	Forb leaves	Forb roots	Forb tubers	Fruit	Unidentified
Aug	39.1	16.9	0.8	1.5	1.5	15.0	12.0	13.2
Sept	38.1	32.4	0.0	0.4	0.0	10.6	7.8	10.7
Oct	63.2	23.7	0.0	0.0	0.5	12.2	0.0	0.5
Nov	71.4	25.5	0.0	0.5	0.8	1.3	0.5	0.0
Dec	65.2	17.8	0.0	8.1	1.2	2.8	4.9	0.0
Jan	56.1	19.3	0.0	13.2	0.5	4.7	6.1	0.0
Feb	44.6	26.5	0.0	7.4	5.9	14.2	1.5	0.0
Apr	40.8	25.2	9.5	18.4	2.7	3.4	0.0	0.0
May	46.8	32.2	4.7	14.6	1.8	0.0	0.0	0.0
Mean	51.7	24.4	1.7	7.1	1.6	7.1	3.6	2.7

Table 2 Activity budgets of geladas at different study sites across Ethiopia

Subspecies	Study site	Elevation (m)	Activity budget (%)					Reference
			F	M	R	S	O	
Arsi gelada	Indetu	2060	41.7	20.3	19.0	19.0	0.0	This study
T. g. gelada	Bole	2300	35.7	17.4	26.3	18.5	2.1	Iwamoto and Dunbar 1983
T. g. gelada	Sankaber	3250	45.2	20.4	13.8	20.5	0.0	Iwamoto and Dunbar 1983
T. g. gelada	Gich	3900	62.3	14.7	5.2	16.0	1.8	Iwamoto and Dunbar 1983

F feeding and foraging, *M* moving, *R* resting; *S* socializing *O* other

Table 3 Comparison of gelada diets across study sites in Ethiopia

Subspecies	Site	Elevation (m)	Study length (month)	% of diet									# of species	Reference
				GLV	GUG	GS	FLV	FUG	FLO	FR	IN	OT		
Arsi gelada	Indetu, Arsi	2060	9[a]	51.7	26.1	0.0	7.1	8.7	0.0	3.6	0.0	3.0	≥10	This study
T. g. obscurus	Bole, Debre Libanos	2300	6[b]	91.4	0.5	5.0	0.3	0.0	0.3	2.0	0.0	0.5	≥14	Dunbar and Dunbar (1974)
T. g. gelada	Sankaber, Simien Mts.	3300	6[c]	55.2	11.9	1.8	5.6	20.5	0.6	3.3	0.1	1.1	---	Hunter (2001)
T. g. gelada	Sankaber, Simien Mts.	3300	5[d]	45.0	24.5	23.2	1.4	1.4	1.1	1.0	0.1	2.3	---	Dunbar (1977)
T. g. obscurus	Guassa, Menz	3450	15[e]	50.6	4.0	2.2	28.7	7.5	0.4	0.0	2.8	3.8	≥78[g]	Fashing et al. (2014)
T. g. gelada	Gich, Simien Mts.	3900	3[f]	68.8	8.0	5.1	15.7	2.5	0.0	0.0	0.0	0.0	≥35[h]	Iwamoto (1979, 1993)

GLV Graminoid leaves, *GUG* Graminoid under-ground, *GS* Graminoid seeds, *FLV* Forb leaves, *FUG* Forb under-ground, *FLO* Flowers, *FR* Fruit, *IN* Invertebrates, *OT* Other

[a] study conducted over 10-month period (Aug10-May11) though no data were collected in Mar10

[b] mean diet from 82 hours of observation during 3 non-contiguous periods of 1-3 months

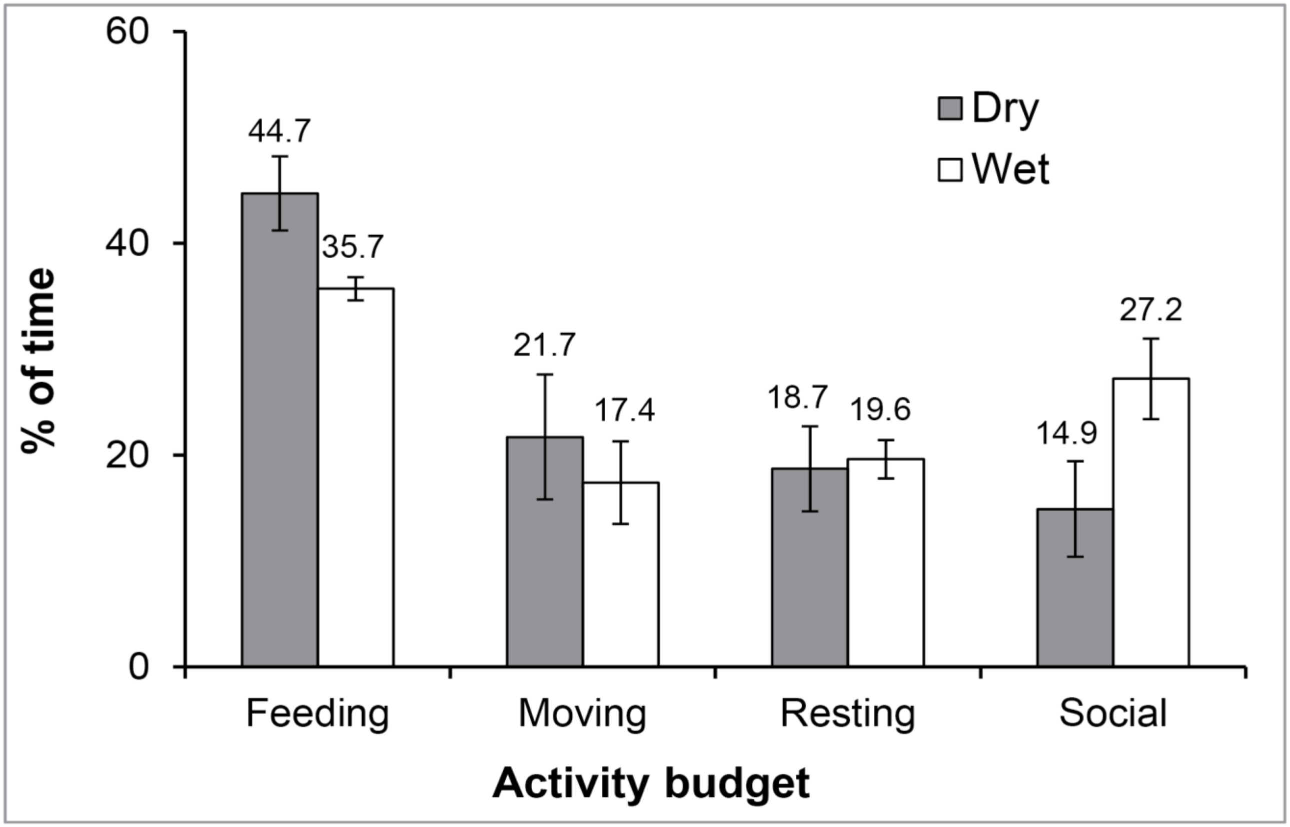
[c] mean diet from 3 wet season and 3 dry season months

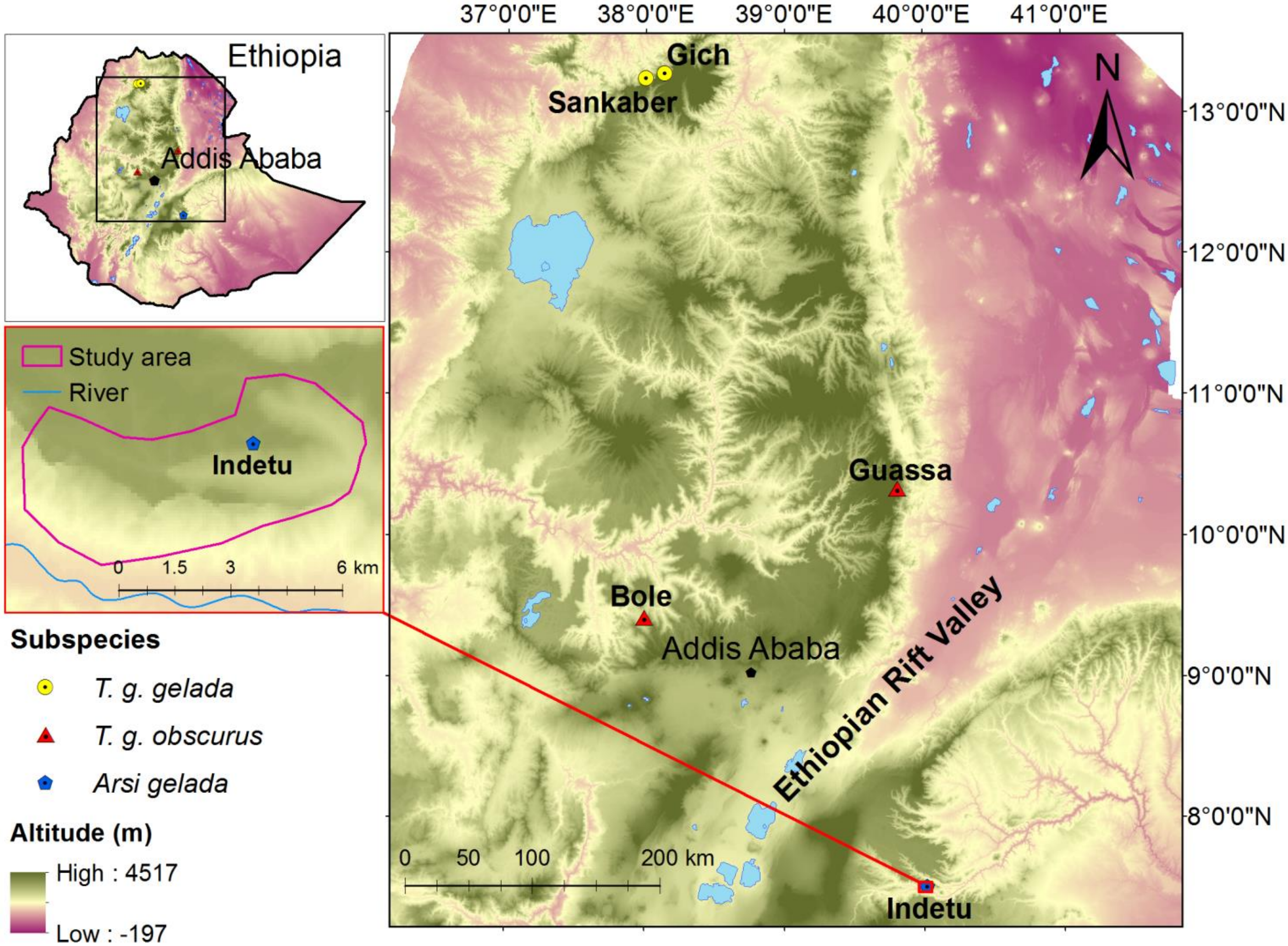
[d] mean diet from 3 several day to two-week periods during 5 months

[e] study conducted over 15 contiguous months (Feb07-Apr08), though values here represent the mean of the 4 possible annual diets (Feb 07 - Jan 08, Mar 07 - Feb 08, Apr 07 - Mar 08, May 07 - Apr 08)

[f] mean diet from 3 non-contiguous months (1 wet season and 2 dry season months)

[g] dietary species richness data collected over a 7-year period, [h] dietary species richness data collected over an 8-month period


60
40
20
0
% of time
Dry
Wet
44.7
35.7
21.7
17.4
18.7
19.6
14.9
27.2
Feeding
Moving
Resting
Social
Activity budget


Ethiopia
Addis Ababa
Study area
River
Indetu
0 1.5 3 6 km
Subspecies
T. g. gelada
T. g. obscurus
Arsi gelada
Altitude (m)
High : 4517
Low : -197
37°0'0"E
38°0'0"E
39°0'0"E
40°0'0"E
41°0'0"E
13°0'0"N
12°0'0"N
11°0'0"N
10°0'0"N
9°0'0"N
8°0'0"N
N
Gich
Sankaber
Guassa
Bole
Addis Ababa
Ethiopian Rift Valley
Indetu
0 50 100 200 km