ZOOLOGICAL RESEARCH

Preliminary study on dietary selection in Shortridge's langurs (*Trachypithecus shortridgei*) from China

DEAR EDITOR,

Understanding dietary selection and feeding strategies is important for the conservation and management of endangered primate species. Here, we conducted a preliminary study on the diet and feeding behavior of endangered Shortridge's langurs (*Trachypithecus shortridgei*) within the Drung River Valley (Dulongjiang) in southwestern China. The study site lies at a high latitude (N27°47.5′) and elevation (1 900 m a.s.l.) and is characterized by substantial annual rainfall (2 745.1 mm). From August 2012 to September 2013, we observed five groups of langurs and analyzed their overall food composition and dietary variation in spring and autumn. To understand their dietary adaptations to the distinctive habitat of the Drung River Valley, we also compared the diet of Shortridge's langurs to that of other *Trachypithecus* species inhabiting different environments. Results indicated that *T. shortridgei* fed on 52 plant species, 23 of which each accounted for ≥1% of their annual feeding time. Their primary dietary components included leaves (46.2%, young, mature, and petioles), fruits (28.7%, unripe 17.6%, ripe 11.1%), and mosses (10.2%). The langurs mainly consumed mature (34.2%) and young leaves (27.5%) in spring and ripe fruits (39.4%) and mature leaves (24.7%) in autumn. Two species of moss (*Macrothamnium macrocarpum* and *Scapania verrucosa*, 21.2% of annual feeding time), which are usually found growing together on cliffs, played a relatively important role in the diet of *T. shortridgei*. The langurs mainly consumed ripe fruits of *Saurauia napaulensis* (7.1%) and *Dendropanax burmanicus* (7.1%), which were abundant at lower elevations. *Trachypithecus* species in temperate forests consumed more fruits and seeds but fewer leaves (similar mature leaves but fewer young leaves) than those species in tropical forests, which may be related to their availability and abundance. Compared to *Trachypithecus* species in temperate forests, the higher proportion of mosses and mature leaves but fewer young leaves in the annual diet of *T. shortridgei* are likely a response to the distinctive Drung River Valley habitat. Therefore, conservation of the main food plants of this threatened species could be vital for its survival and conservation management.

Dietary traits among and within primate species are shaped by both phylogenetic and environmental factors, as well as the nutritional and physical properties of foods (Lambert, 2011). Environmental and climatic conditions can affect food availability and impact dietary diversity and composition (Hill & Dunbar, 2002). An animal's foraging strategy is an adaptive response to dietary constraints, such as food abundance, availability, and quality (Sundell et al., 2003). The spatiotemporal distribution and abundance of food resources also influence foraging behavior in primates (Grueter et al., 2009; Hanya et al., 2013; Tsuji et al., 2013).

Latitude can exert a strong influence on various ecological phenomena; for example, species biodiversity decreases with increasing latitude (Badgley & Fox, 2000; Hillebrand, 2004; Stevens & Willig, 2002). In temperate forests, the availability of fruit and young leaves is lower than that in tropical forests in terms of biomass, species composition, and seasonality of flushing and fruiting (Hanya et al., 2013). Fruiting seasonality is more predictable in temperate forests than in tropical forests (Hanya et al., 2013). In response to this variation, temperate-living primates rely less on fruits and more on leaves (especially mature leaves) and other vegetative matter with a high fiber content (Hemingway & Bynum, 2005; Tsuji et al., 2013).

Asian colobines are typically regarded as leaf-eating

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monkeys. In general, leaves constitute 51.0% of their diet (33.8% young and 16.7% mature) and seeds and fruits account for 36.8% of their diet (Kirkpatrick, 2011). Asian colobines in temperate-alpine forests feed more on lichens and less on flowers, whereas populations in tropical-lowland forests feed more on fruit and foliage but consume fewer fruits and flowers with increasing altitude (Tsuji et al., 2013). Members of the genus *Trachypithecus* are also considered heavy folivores (Kirkpatrick, 2011). In temperate forests, *Trachypithecus* species, on average, consume more plant species (81.4% vs. 75.4%), more fruits and seeds (32.7% vs. 20.8%), and less young leaves (37.8% vs. 55.2%) than those in tropical forests (Supplementary Table S1). They also show interspecific and intraspecific variation in the degree of dietary plasticity. Compared with tropical-living *Trachypithecus* species, temperate-living species show a smaller coefficient of variation (CV) (Hemingway & Bynum, 2005) of plant species (160 vs. 380) but larger CV of leaf feeding (610 vs. 520) and fruit and seed consumption (304 vs 190) (Supplementary Table S1). In temperate-living colobines, *Trachypithecus* species consume, on average, more fruit (32.5% vs. 11.1%) and foliage (59.5% vs. 32.7%) than other non-*Trachypithecus* species. In addition, compared with non-*Trachypithecus* species in temperate forests, *Trachypithecus* species display less plasticity in fruit (CV: 360 vs. 120), foliage (710 vs. 130), and flower feeding (140 vs. 40) (calculated by data in Tsuji et al., 2013 and on species in Supplementary Table S1). Obvious variations also exist in diet composition in populations of *Trachypithecus* species in temperate forests; for instance, *T. pileatus* groups in the Pakhui Wildlife Sanctuary of India consume more leaves (68% vs. 48%) but less fruits and seeds (16% vs. 32%) than *T. pileatus* groups in the Madhupur National Park of Bangladesh (Monirujjaman & Khan, 2017; Solanki et al., 2008). Moreover, the diet of temperate-living *Trachypithecus* species is marked by seasonal variation and switching between food items (Kirkpatrick, 2011). For example, in the Mayanghe Nature Reserve, China, *T. francoisi* groups rely heavily on foliage (≥79% of feeding time) in spring and summer, but consume more fruits (≥53%) in autumn and winter (Hu, 2011).

Shortridge's langurs (*Trachypithecus shortridgei*) (Wroughton, 1915) are native to the western side of the Hengduan Mountains and southeast side of the Himalayas. They are distributed in southwestern China (Drung River Valley, northwest Yunnan) (Cui et al., 2016) and northeastern Myanmar (Htun et al., 2008), with 4 951.8 km^2 of highly suitable habitat (Yang et al., 2019b). The species is categorized as Endangered on the IUCN Red List (Htun et al., 2008) and is listed in CITES Appendix I (CITES, 2014). In China, Shortridge's langurs are considered as Category I protected species under Chinese animal conservation law and are protected under the National Wildlife Protection Law in Myanmar (Htun et al., 2008). At present, we have very limited information on the feeding behavior, home range, and time budget of *T. shortridgei*. Previous research has established that this species occurs primarily in evergreen and semi-evergreen forests, and is largely arboreal (sometimes terrestrial) and folivorous (Htun et al., 2008; Li, 2015).

Compared to other *Trachypithecus* species, the study groups of *T. shortridgei* from Drung River Valley live at higher latitude (N27°47.5′) and elevation (average 1 900 m a.s.l.), with lower mean annual temperature (14.5 °C) (Htun et al., 2008; Li et al., 2015). These environmental and climatic conditions are similar to those experienced by some populations of *T. phayrei* (Ma et al., 2017), although annual precipitation in the Drung River Valley is higher (2 745.1 mm). Here, we present some preliminary information on the diet of Shortridge's langurs and their distinctive feeding strategies, i.e., feeding on "unusual" food items in response to their distinctive living environments, and place these findings within the broader context of the genus *Trachypithecus*.

In total, the langur groups were observed for 270 h over 63 d (mean±*SD*: 67.5±36.6 h per season, range: 33–116.4 h, *n*=4), resulting in 1 026 feeding records (256.5±157.3 records per season, range: 102–397 records, *n*=4), which included 679 (66.2%), plant-species-identified records (169.8±111.7 records per season, range: 57–275 records, *n*=4) and 907 (88.4%) plant-part-identified records (226.8±138.2 records per season, range: 91–358 records, *n*=4) and 119 (11.6%) unidentified food parts (29.8±20.4 records per season, range: 11–54 records, *n*=4). Only species- and part-identified records were used to calculate dietary composition. On average, we observed 2.9 individuals (*SD*=1.5, range: 1–9) per scan.

Results showed that the diet of *T. shortridgei* was composed of leaves (46.2%), fruits (28.7%), mosses (10.2%), flowers (7.4%), herbs and ferns (5.6%), buds (1.5%), and bamboo shoots (0.4%). Mature leaves accounted for 25.2%, young leaves for 15.2%, and petioles for 5.8%; unripe fruits accounted for 17.6% and ripe fruits accounted for 11.1% (Supplementary Table S2). In some cases, the langurs were observed licking rocky surfaces, possibly for mineral acquisition, and occasionally foraging for earthworms.

The Shortridge's langurs foraged on 52 plant species belonging to 39 families, including 18 tree species (accounting for 42.7% of all records), 12 shrubs (14.5%), 10 vines (9.5%), seven herbs (5.4%), three ferns (6.6%), and two mosses (21.2%). In total, 23 plant species each comprised ≥1% of annual feeding records and cumulatively accounted for 88.2% of total feeding records and were thus regarded as annual main foods. Of the annual main food plants, 14 species accounted for more than 75% of the total feeding records, and seven species accounted for more than 50% of the total records. Two species of mosses (*Macrothamnium macrocarpum* and *Scapania verrucosa*), which are often found growing together on rocks, were difficult to distinguish from one another, and therefore were combined during data collection. These two mosses were eaten in eight of the 12 months. The next most frequently consumed species was *Saurauia napaulensis*, which accounted for 11.5% of all feeding records and was consumed in seven months of the year, and *Dendropanax burmanicus* (7.1%), which was eaten over one month of the year. In addition to the above-

mentioned species, the remaining 19 (48.4%) of the 23 consumed plant species were eaten for nine months of the year. The top 10 species cumulatively accounted for 43.2% of all feeding records (Supplementary Table S3).

In spring, the langurs consumed more mature leaves (34.2%) and young leaves (27.5%) and less moss (18.6%); in autumn, they consumed more fruits (47.5%, ripe fruits 39.4%, unripe fruits 8.1%) and fewer mature leaves (24.7%).

Mature leaves were available all year, but young leaves were available mainly from March to June, peaking in May. Flowers, which were also available all year, except in January and February, gradually increased in terms of phenological availability from March to July before rapidly decreasing to their lowest availability in August. Buds were present from January to May, with a peak in March. Fruits were primarily available from July to November, with a peak in September (Figure 1). The langurs increased their feeding on buds (Spearman rank correlation test: r_s=0.82, n=10, P=0.004) and young leaves (r_s=0.86, n=10, P=0.002) when these food parts were abundant. No correlations were found between the percentages of feeding on fruits and mature leaves and their availability in the plots (r_s<|0.32|, n=10, P<0.05).

This study presents the first documentation of the diet of Shortridge's langurs. Results indicated that this species foraged on 52 plant species belonging to 39 families. Annual diet was mainly composed of leaves (47.7%) and fruits (28.7%), which is within the range of other *Trachypithecus* species (Kirkpatrick, 2011; Tsuji et al., 2013) (Supplementary Table S1).

Compared with *T. phayrei* (China, N24°48', 2 000 m a.s.l.) (Ma et al., 2017), the Shortridge's langurs in the current study spent similar time feeding on leaves (47.7% vs. 52.6%), but consumed more mature leaves (25.2% vs. 4.1%), slightly more fruit (28.7% vs. 22.2%), and fewer young leaves and buds (16.7% vs. 41.5%). Of note, while seeds account for 18.7% of the annual diet of *T. phayrei*, Shortridge's langurs were not observed foraging on seeds during the study period. In China, the majority of seeds consumed by *T. phayrei* are from one of the most abundant tree species (*Castanopsis echidnocarpa*) which provides plentiful seeds from September to November. *Trachypithecus phayrei* also forage on *Lindera caudata* fruit in March to October when it is abundant. For at least three months, when other fruits and seeds are not available, they also descend to the ground to feed on slowly decomposing seeds of several highly productive Fagaceae species (Ma et al., 2017). Shortridge's langurs appear to selectively consume fruits as the percentage in their diet was not correlated with their availability in the experimental plots. Although *T. shortridgei* and *T. phayrei* mainly forage on young leaves or buds from March to August, *T. shortridgei* consumed fewer young leaves and buds than *T. phayrei* (Ma et al., 2017; this study). This may relate to differences in availability and abundances of food species between the two areas (Ma et al., 2017; Xiang et al., 2007).

Compared with *T. phayrei* in China, Shortridge's langurs consumed more mature leaves. This may be due to having no choice but to forage on mature leaves when their preferred food, e.g., fruit, is scarce. Moreover, *T. shortridgei* consumed young leaves and buds when these foods were most abundant. This is consistent with reports on other *Trachypithecus* species (Fan et al., 2015; Ma et al., 2017; Zhou et al., 2009, 2018) and colobines (Ehlers Smith et al.,

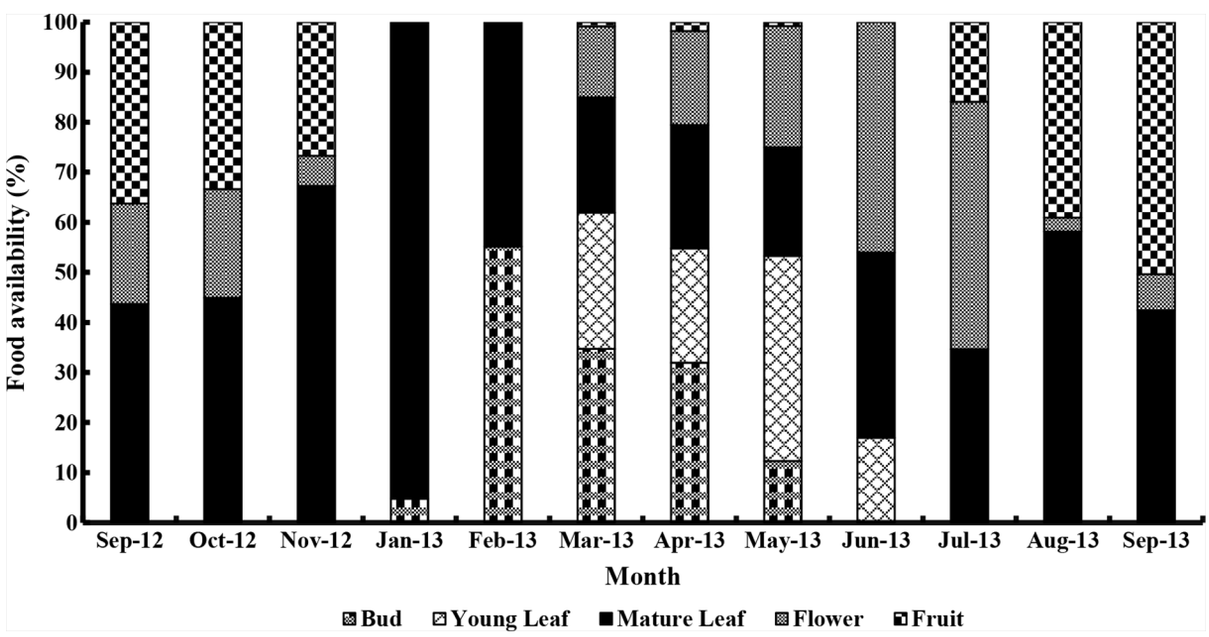

Figure 1 Monthly variation in food availability for *Trachypithecus shortridgei* between August 2012 and September 2013 (excluding December 2012 and July 2013)

2013; Kirkpatrick, 2011; Xiang et al., 2012).

The langurs in our study relied mainly on leaves and mosses in the spring, but more heavily on ripe fruit and mature leaves in the autumn. In China, *T. phayrei* relies heavily on fruits and seeds (>60%) during autumn (September to November) when they are highly abundant, whereas *T. shortridgei* fed on fruits for five months (June and August to November).

Compared with other *Trachypithecus* species, the studied langurs exhibited distinctive feeding strategies, reflecting a potential dietary response to living in subtropical evergreen broadleaf forests at a high latitude and with high rainfall. First, although *T. shortridgei* spent a similar amount of time (annually) consuming leaves as other temperate-living *Trachypithecus* species, they consumed more mature leaves (25.2% vs. 9.3%) and fewer young leaves (15.2% vs. 49.1%) (Supplementary Table S1). Second, compared to the mean annual feeding time, other *Trachypithecus* species spent consuming fruits and seeds (33.4%) (Supplementary Table S1), the langurs were only observed feeding on fruit (including seeds). Third, the *T. shortridgei* study groups spent 10.2% of their annual feeding time consuming two moss species (*Macrothamnium macrocarpum* and *Scapania verrucosa*). Previous research has reported that *T. crepusculus* consumes moss, although it only accounts for <1.6% of their diet (Fan et al., 2015). Several populations of *T. phayrei* in the Tongbiguan Provincial Nature Reserve Yunnan, China, have also been observed consuming unidentified moss species (Pen-Fei Fan and Chi Ma, personal communications). The high proportion of mosses in the diet of *T. shortridgei* suggests the presence of a distinct dietary strategy for this species in the Drung River Valley. This may be related to the unique environment of the region and usually high level of annual precipitation (2 745.1 mm), resulting in many cliffs bearing mosses, and/or the nutrient content of the two moss species. The consumption of "unusual" food items has also been reported in other primates inhabiting the margins of their ranges, particularly latitudinal or elevational extremes, and include bark (*Macaca thibetana*: Zhao, 1996), conifer needles (*Macaca*: Goldstein & Richard, 1989; *Rhinopithecus bieti*: Yang & Zhao, 2001), lichen (*Rhinopithecus*: Yang et al., 2019a), and bromeliad leaves (*Cebus*: Brown & Zunino, 1990; Hemingway & Bynum, 2005). Thus, more attention should be paid to these mosses in future dietary studies.

Trachypithecus colobines are traditionally referred to as leaf-eating monkeys (Kirkpatrick, 2011), but tend to exhibit dietary diversity and variability. The number of plant species consumed ranges from 50 in *T. leucocephalus* and *T. phayrei* (Ma et al., 2017 Zhang et al., 2020) to 164 in *T. crepusculus* (Hu, 2011). Moreover, the time spent feeding on leaves varies from 43.8% in *T. geei* in India (23.7°N) to 87.9% in *T. leucocephalus* in China (22.5°N) (Gupta & Chivers, 2000; Li et al., 2003). Similarly, the proportion of fruit in the annual diets of *Trachypithecus* species shows marked variations, with values ranging from 6.6% (*T. leucocephalus*) to 39.5% (*T. phayrei*) (Suarez, 2013; Zhang et al., 2020) (Supplementary Table S1). Primate dietary diversity and variability are determined by various factors such as habitat type, floristic composition, food plants, and phenological stages (Solanki et al., 2008), which are related to environmental variables including latitude, elevation, and precipitation. For example, northern gibbons in temperate forests consume less fruit than gibbons in tropical forests (Guan et al., 2018; Fan et al., 2013), which may be related to the decrease in fleshy fruit productivity with increasing elevation in northern gibbon habitats (Marshall et al., 2009; Guan et al., 2018). Compared with tropical forests, temperate forests are characterized by a lower fruit fall biomass, fewer fleshy food plants, and greater predictability and shorter duration of the fruiting season (Hanya et al., 2013). However, *Trachypithecus* species in temperate forests consume, on average, more fruits and seeds and fewer young leaves than those species in tropical forests (Supplementary Table S1). This may be related to the increased fruits and seeds (*T. phayrei*: Ma et al., 2017, Monirujjaman & Khan, 2017; This study) and/or less competition for such foods in temperate-living *Trachypithecus* species. However, further details on fruit (and/or seed) distribution, availability, biomass, and duration, as well as information on feeding competition, are required to clarify dietary patterns.

Consistent with other *Trachypithecus* species, the studied langurs mainly consumed leaves. They foraged heavily on leaves and mosses in spring, and more on ripe fruits and mature leaves in autumn. However, due to the limited observation hours caused by rough terrain, heavy rainfall, and long rainy season, more field surveys and observations are required in the future.

SCIENTIFIC FIELD SURVEY PERMISSION INFORMATION

Permission to conduct field work in the Drung River Valley was granted by the Gongshan Bureau of the Gaoligongshan National Nature Reserve.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

L.W.C. and W.X. designed the study. Y.G., J.F.H., Y.C.L., X.Y.H., and J.S. performed the study. Z.P.H., Y.P.L., and F.Y. conducted literature research. Y.G., J.F.H., Y.C.L., and Z.H.G. analyzed the data. Y.G., Y.C.L., J.F.H., and L.W.C. wrote the paper. All authors read and approved the final version of the manuscript.

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