

Effect of habitat fragmentation on ranging behavior of white-headed langurs in limestone forests in Southwest China

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Abstract The critically endangered white-headed langur (*Trachypithecus leucocephalus*) is confined to fragmented karst forests of southwest Guangxi Province, China. A lack of information on the influence of habitat fragmentation on langur behavior has prevented a comprehensive understanding of their ranging behavior and the development of effective langur conservation strategies. We collected comparative data on time budgets, daily path lengths, home range and diets of four langur groups inhabiting the lightly fragmented Fusui forest (G1, G2) and the more heavily fragmented Chongzuo forest (G3, G4). The aim was to explore the effect of this fragmentation on langur ranging behavior. Our results showed that the Fusui groups spent more time on moving and less time on feeding and playing than the Chongzuo groups. Daily path lengths were 472.4–536.1 m for the Fusui groups and 449.6–480.7 m for the Chongzuo groups, indicating no marked inter-site variation. The Fusui groups occupied much larger home ranges (23.8–33.8 ha) than the Chongzuo groups (14.5–15.8 ha). However, all groups had similar monthly home ranges. Diets significantly differed among langur groups. The Fusui groups consumed more young leaves and had much lower diet diversity compared with the

Chongzuo groups. Our findings indicate that habitat fragmentation is one of the crucial determinants of white-headed langur ranging behavior because fragmentation reduces and restricts the home range. Langurs in fragmented habitat adopt an energy conservation strategy characterized by devoting more time to feeding and less time to moving, with a smaller home range and consumption of more plant species. We argue that linking fragmented forests with corridors should be considered a priority in a wider and comprehensive longer term langur population conservation and habitat management strategy.

Keywords *Trachypithecus leucocephalus* · Habitat loss · Isolation · Conservation · Home range

Introduction

Habitat loss and fragmentation have been linked to the decline of global biodiversity and are a significant threat to successful animal conservation. This is particularly true for primates that are highly susceptible to the effects of forest fragmentation (Cowlshaw and Dunbar 2000; Huang et al. 2002; Fahrig 2003; Marsh 2003; Chapman et al. 2010). Indeed, the survival and persistence of many forest-dwelling primates largely depends on their capacity to cope with these modified environments (Marsh 2003; Wong and Sicotte 2007). Thus, documenting primate behavioral response patterns to fragmented forests not only contributes to our understanding of the minimum requirements for species survival in the short term, but also informs the effectiveness of longer term species conservation and management in fragmented forests (Wong and Sicotte 2007; Chapman et al. 2010).

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Fragmentation often influences primates by reducing their habitat patch area (Fahrig 2003), increasing their isolation (Marsh 2003), and decreasing their habitat quality (Marsh 2003; Arroyo-Rodríguez and Mandujano 2006). The consequence of fragmentation can lead to changes in forest structure and composition and may result in the decline of species abundance and diversity (Arroyo-Rodríguez and Mandujano 2006). Therefore, primates living in smaller forest patches are usually expected to have smaller home ranges than those living in continuous forest (Shaffer 2013; Campera et al. 2014). For example, bearded sakis (*Chiropotes sagulatus*) living in continuous forest in Guyana ranged over a larger area than those living in fragmented forests (Shaffer 2013).

Primate responses to fragmentation vary. Some primates leave patches in fragmented forests, while others persist in them despite having a lower population and group size (Estrada and Coates-Estrada 1996; Onderdonk and Chapman 2000). For some primates, lower availability of food in fragmented forest typically requires them to reduce energy expenditure (Richard, 1985). They are likely to adopt an energy conservation strategy characterized by shorter daily range length, smaller home range size, less time spent moving and more time spent resting (Milton 1998; Wong and Sicotte 2007; Irwin 2008; Boyle and Smith 2010; Zhou et al. 2011a, b; Shaffer 2013). However, the effects of fragmentation on other species appear neutral or can be beneficial (Onderdonk and Chapman 2000; Lehmann et al. 2006). Species' response patterns to fragmentation are therefore not clear cut, but rather vary considerably across forest types and according to the extent of fragmentation. It is therefore difficult to make generalizations about primate responses when they cope with forest fragmentation.

The white-headed langur (*Trachypitecus leuccephalus*) is restricted to a 200-km² area of limestone hills in the southern Guangxi Province of China (Huang et al. 2002, 2008). According to the latest research, these critically endangered langurs only survive in three separated karst forest fragments: the Nongshan area of the Nonggang Nature Reserve, and the Chongzuo area and Fusui area of the Chongzuo White-headed Langur National Nature Reserve (Guangxi Forestry Bureau 2011). Karst forests in Guangxi Province suffer habitat degradation and fragmentation (Huang 2002; Huang et al. 2002, 2008; Chen et al. 2008). According to Huang et al. (2008), the Nongshan area was the best conserved fragment, followed by the Fusui and Chongzuo forest areas, respectively. Most ecological studies on these wild langurs have focused on the groups inhabiting the Fusui area, and investigated activity budgets (Huang et al. 2003; Li and Rogers 2004), diet (Huang et al. 2000a; Li et al. 2003; Tang 2004; Li and Rogers 2006; Zhou et al. 2013; Lu 2014), habitat use

(Huang et al. 2000b; Li and Rogers 2005a; Li et al. 2011) and ranging behavior (Li and Rogers 2005b; Zhou et al. 2011b). Few studies have been conducted in Chongzuo (Yin et al. 2011; Dayong et al. 2016). Information on the effects of habitat fragmentation on behaviors is not yet available, which prevents a full understanding of langur behavior and subsequently the species' conservation.

In this paper, we present quantitative data on the activity budgets, home ranges, and diets of four white-headed langur groups collected over 12 consecutive months in the fragmented limestone forests of the Chongzuo White-headed Langur National Nature Reserve. We first summarize inter-site differences in activity time budgets, daily path length, home ranges and diets, then examine how the white-headed langurs have adjusted their behaviors to living in a fragmented limestone forest. Finally, based on our results, we argue for the establishment of inter-forest corridors as a promising conservation strategy for langur habitats.

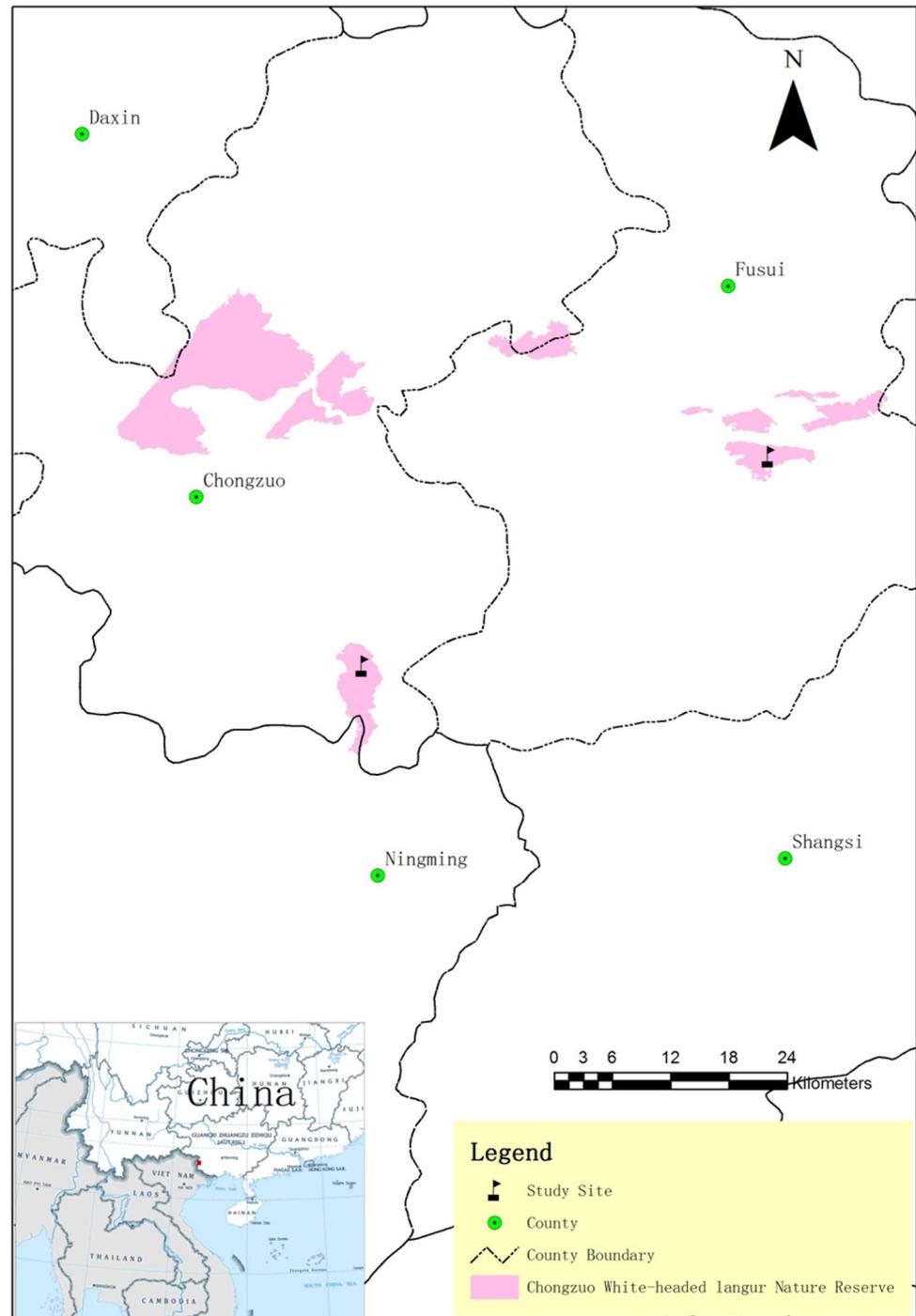
Methods

Study site and study subjects

We conducted our study at the Chongzuo White-headed Langur National Nature Reserve, in Southwest Guangxi Province, China (22°24'–22°46'N, 107°22'–107°42'E; Fig. 1). The reserve is characterized by limestone seasonal rainforests with an altitude range of 400–600 m a.s.l. (Guangxi Forestry Department 1993). The study site was located in Banli town of Chongzuo County (hereafter “Chongzuo”) and Bapen town of Fusui county (hereafter “Fusui”) (Fig. 1). The reserve is partly surrounded by large-scale agricultural sugarcane plantations (Li and Rogers 2005a, b).

This study was carried out in two separate periods: a first period from August 2007 to July 2008 in Fusui, and a second period between August 2011 and July 2012 in Chongzuo. We collected climatic data, including minimum temperature and maximum temperature, using a maximum and minimum thermometer, and rainfall via a rain gauge. The lowest mean monthly minimum temperature was 6.2 °C in January 2008 for Fusui and 8.1 °C in January 2012 for Chongzuo, whereas the highest mean monthly maximum temperature was 34.9 °C in August 2007 for Fusui and 34 °C in August 2011 for Chongzuo. The total rainfall was 1035 mm for Fusui and 1240 mm for Chongzuo during each study period. Based on monthly rainfall, the study period was roughly divided into two seasons: a dry season with <60 mm monthly rainfall from October 2007 to March 2008 for Fusui and November 2011 to April 2012 for Chongzuo, and a rainy season in the remainder of the period with >60 mm monthly rainfall.

Fig. 1 Location of the study site in Chongzuo White-headed Langur National Nature Reserve, Guangxi, Southwest China



We followed four groups of white-headed langurs: G1 and G2 in Fusui (hereafter “Fusui groups”) and G3 and G4 in Chongzuo (hereafter “Chongzuo groups”). Group 1 initially consisted of 14 individuals (one adult male, eight adult females, two juveniles, and three infants), and increased to 18 individuals following the birth of four infants. Group 2 included 11 individuals (one adult male, five adult females,

three juveniles, and two infants) throughout the study period. Group 3 was composed of 12 individuals (one adult male and 11 adult females) at the beginning of the study, and increased to 22 individuals with the birth of ten infants by the end of the study period. Group 4 consisted of 16 individuals (one adult male, eight adult females, and seven infants) throughout the study period.

Vegetation composition

We investigated the vegetation composition for the Chongzuo groups, and cite data for the Fusui groups from Lu (2014) who recently conducted vegetation studies there. In Chongzuo, we randomly set up 18 quadrats (10 m × 10 m) across the main study site. In Fusui, Lu (2014) set up six quadrats: one 20 m × 20 m quadrat, two 15 m × 20 m quadrats, one 15 m × 15 m quadrat, and two 40 m × 10 m quadrats, respectively. We recorded trees, shrubs and woody lianas with diameter at breast height (DBH) ≥ 2 cm within quadrats, as did Lu (2014), and present plant dominance using relative density (RD), where $RD = \text{number of individuals of species } i / \text{total number of individuals in all quadrats}$ (Burton et al. 2005). We express forest plant diversity using the Shannon–Weaver diversity index: $H' = -\sum_{i=1}^n P_i \ln P_i$, where P_i is the percentage of plant species i in all quadrats.

Behavioral data collection

We followed langurs after 2 months' habituation with the assistance of a field guide. During full-day following from dawn until nightfall, we detected and observed the langur group near their previous night's sleeping site, without losing the langur signals for more than 30 min. During partial-day following, we began data collecting whenever we located the langurs, and stopped when we lost contact with the group for over 30 min or when the focal group entered a sleeping site. Over the periods of study, we completed 211 full-day observations, comprising 54 days for G1, 39 days for G2, 60 days for G3, and 58 days for G4 (Table 1).

We collected behavioral data using instantaneous scan sampling (Altmann 1974). Each scan began every 15 min and lasted for 5 min. To avoid sampling bias towards certain individuals or particular age-sex classes, we scanned the group from left to right or in a clockwise direction. We collected behavioral records on as many different individuals as possible during a scan so that all individuals in the focal group were included, but no individual was recorded more than once. During each scan, we recorded the predominant behavior of each individual after observing it for 5 s. We categorized behaviors into six classes: resting, moving, feeding, grooming, playing, and others, respectively. "Resting" included any inactive posture (mainly sitting and lying) and self-grooming. "Moving" referred to any locomotor behavior resulting in a spatial position change (mainly walking, leaping, and climbing). "Feeding" referred to manually or orally manipulating a food item. "Grooming" referred to either manipulating, stroking, or picking through the hair of another individual or a lemur having its own fur cleaned or explored by another individual. "Playing" referred to social play between two or more individuals, including chasing, hitting, wrestling that clearly showed interaction in a nonaggressive manner. The rest of the behaviors and unidentified activities were recorded as "other." When an individual fed, we noted the plant species and part eaten. Finally, we obtained a total of 7692 scans, comprising 2332, 1582, 2575, and 2603, respectively, for G1, G2, G3 and G4 (Table 1).

Following previous studies (Huang 2002; Zhou et al. 2007; Li et al. 2014), we used a grid cell method to estimate home range size and daily path length. During data collection, we plotted the center location of the focal langur group at half-hourly interval on a topographic map (scale

Table 1 Sample sizes of four white-headed langur groups

Month ^a	Total sample days				Full-day sample days				Total scans				Total location records			
	G1	G2	G3	G4	G1	G2	G3	G4	G1	G2	G3	G4	G1	G2	G3	G4
August	6	3	7	8	4	2	5	5	134	52	245	281	84	50	130	164
September	10	3	6	6	9	2	5	5	407	48	212	223	209	52	116	120
October	5	7	7	5	5	5	5	5	233	227	227	247	129	126	122	111
November	4	5	6	7	4	4	5	5	167	185	210	212	90	98	113	117
December	5	3	6	4	4	3	5	4	275	43	203	149	119	69	112	79
January	3	3	5	4	2	2	5	4	44	108	186	202	45	57	104	78
February	4	5	5	5	4	5	5	5	227	135	200	214	96	129	109	112
March	6	4	5	5	4	3	5	5	97	188	204	221	106	100	109	116
April	5	4	6	5	5	4	5	5	245	206	224	215	124	108	120	115
May	4	6	7	6	4	5	5	5	215	232	222	215	58	146	116	116
June	4	3	6	5	4	2	5	5	37	126	229	199	108	73	121	105
July	6	2	5	6	5	2	5	5	251	32	213	225	140	51	116	122
Total	62	48	71	66	54	39	60	58	2332	1582	2575	2603	1308	1059	1388	1355

^a Study period between August 2007 and July 2008 for G1 and G2, and between August 2011 and July 2012 for G3 and G4

1:10,000) divided into several 50 m × 50 m (0.25 ha) grid cells. We recorded the cells entered by any individual of the focal group, and then estimated the distance between the two consecutive locations. In total, for G1, G2, G3 and G4, we recorded 1308, 1059, 1388, and 1355 locations, respectively, of which more than 95% records were from the full-day observations (Table 1).

Data analysis

Records for dependent infants were excluded from the analysis. We expressed the activity budgets based on monthly scan records that comprised four samplings each hour. We first divided the number of individuals engaged in activities for each scan by the total number of individuals recorded in that scan, then determined the hourly time budgets by averaging the values from four scans. We averaged the data for each hour to correct for potential bias introduced by uneven scan records across the day, before we averaged these percentages to calculate monthly time budgets. Annual time budgets were obtained by averaging all monthly percentages. We calculated the percentage of different plant parts and species in the monthly diet of each study group using monthly total individual feeding records (Li and Rogers 2006; Dayong et al. 2016). Annual dietary composition was obtained by averaging the monthly percentage. We expressed diet diversity using the Shannon–Weaver diversity index: $H' = -\sum_{i=1}^n P_i \ln P_i$, where P_i is the percentage of parts i in monthly feeding records.

Following Di Fiore (2003), we calculated the monthly home range by counting the grid cells entered by langurs and those linking isolated cells, and then determined the overall and seasonal home ranges by merging records from related months. To examine the home range usage patterns,

we compared the percentages of core cells in the total records of the rainy season to those from the dry season. The core cells are those with $\geq 1\%$ of the total records. We measured daily path length by summing the distances between successive chronological locations for focal groups (Di Fiore 2003; Zhou et al. 2007; Li et al. 2014).

We tested all variables with a one-sample Kolmogorov–Smirnov test to examine normality. All variables were normally distributed except for the frequency of grid cells entered. We therefore used a χ^2 -test to examine whether the langurs used the different grid cells with the same intensity, and used a Mann–Whitney U -test to compare the seasonal variation in core cells. We constructed generalized linear mixed models (GLMMs) to explain activity budgets, ranging patterns, and diets. We set the study sites as fixed factors and groups as random factors in the models. Further, we compared the models with and without the factor Site using ANOVA to examine the effects of Site on each dependent variable. Site was considered as a factor that markedly influenced the goodness-of-fit of the model when the P -value was < 0.05 . We used the lme4 package for GLMM in R 3.3.2. All tests were two-tailed, with significance levels of 0.05.

Results

Forest composition

We recorded 112 plant species belonging to 49 families in the Fusui groups, with a species diversity of 5.49. The RD of the ten most important species ranged from 2.88 to 10.42%, cumulatively contributing 54.5% of the total stems. We recorded 69 plant species from 32 families of the Chongzuo groups, with a species diversity of 3.44. The

Table 2 Dominance of the ten most common plant species in the quadrats

Chongzuo			Fusui ^a		
Species	Family	Relative density (%)	Species	Family	Relative density (%)
<i>Mallotus philippinensis</i>	Euphorbiaceae	13.32	<i>Lepionurus sylvestris</i>	Opiliaceae	10.42
<i>Cipadessa baccifera</i>	Meliaceae	10.25	<i>Sterculia monosperma</i>	Sterculiaceae	9.01
<i>Croton euryphyllus</i>	Euphorbiaceae	6.59	<i>Malaisia scandens</i>	Moraceae	8.17
<i>Sageretia thea</i>	Rhamnaceae	6	<i>Abelia uniflora</i>	Caprifoliaceae	6.2
<i>Boehmeria nivea</i> var. <i>tenacissima</i>	Urticaceae	5.12	<i>Strophoblachia fimbrialyx</i>	Euphorbiaceae	4.37
<i>Sterculia monosperma</i>	Sterculiaceae	4.39	<i>Desmos chinensis</i>	Annonaceae	3.8
<i>Cansjera rheedei</i>	Opiliaceae	4.1	<i>Murraya exotica</i>	Rutaceae	3.38
<i>Litsea glutinosa</i>	Lauraceae	3.51	<i>Oreocnide frutescens</i>	Urticaceae	3.31
<i>Alchornea trewioides</i>	Euphorbiaceae	3.37	<i>Delavaya toxocarpa</i>	Sapindaceae	2.96
<i>Maclura cochinchinensis</i>	Moraceae	3.22	<i>Pterospermum heterophyllum</i>	Sterculiaceae	2.89

Species are ranked by descending relative density

^a Cited from Lu (2014)

Table 3 Group compositions, time budgets and daily path lengths of focal white-headed langurs

Group	Group composition					Time budgets (% of total activity time, mean \pm SD)					Daily path lengths (m; mean \pm SD)			
	Adult males	Adult females	Juveniles	Infants	Total	Moving	Resting	Feeding	Playing	Grooming	Others			
G1	1	8	2	3–7	14–18	24.9 \pm 4.1	54.5 \pm 7.5	14 \pm 3.7	2.4 \pm 1.8	4.2 \pm 4.2	0.1 \pm 0.1	472.4 \pm 100		
G2	1	5	3	2	11	29 \pm 12.6	39.9 \pm 13.5	20.3 \pm 4.7	2.8 \pm 4.1	6.6 \pm 5.6	1.5 \pm 3.4	536.1 \pm 160.2		
G3	1	11	0	0–10	22	17.5 \pm 2.9	42.8 \pm 6.1	24.4 \pm 4.0	10.8 \pm 9.0	3.7 \pm 2.5	0.8 \pm 1.1	449.6 \pm 76.8		
G4	1	8	0	7	16	19.2 \pm 3.1	37.7 \pm 5.9	23.9 \pm 5.8	15.9 \pm 4.1	1.8 \pm 0.9	1.6 \pm 1.7	480.7 \pm 80.8		

RD of the ten most important species varied from 3.22 to 13.32%, together accounting for 59.88% of the total stems (Table 2).

Time budgets and daily path lengths

The Fusui groups spent more time on moving ($\chi^2 = 8.15$, $df = 1$, $P = 0.004$) and less time on feeding ($\chi^2 = 5.03$, $df = 1$, $P = 0.025$) and playing ($\chi^2 = 9.24$, $df = 1$, $P = 0.002$) than the Chongzuo groups (Tables 3, 4). The Chongzuo and Fusui groups devoted a similar amount of time to the rest of the activities, such as resting ($\chi^2 = 1.36$, $df = 1$, $P = 0.244$), grooming ($\chi^2 = 3.72$, $df = 1$, $P = 0.054$) and others ($\chi^2 = 0.43$, $df = 1$, $P = 0.511$). Inter-site differences in daily path lengths were not significant ($\chi^2 = 1.55$, $df = 1$, $P = 0.213$; Tables 3, 4).

Home range

Home ranges of individual groups were completely separated by farmland. Overall, groups in Chongzuo had a smaller home range (58 cells for G3 and 63 for G4) than those in Fusui (95 cells for G1 and 135 for G2; Table 5). These differences were not significant for the monthly home ranges ($\chi^2 = 0.04$, $df = 1$, $P = 0.842$; Tables 4, 5). The total annual home range reached an asymptote by the end of the study suggesting that home range was reliable (Fig. 2). There was a clear distinction between the frequency with which different grid cells were used by the different groups (G1, $\chi^2 = 874.03$, $P < 0.001$, $df = 93$; G2, $\chi^2 = 2663.04$, $P < 0.001$, $df = 123$; G3, $\chi^2 = 115.46$, $df = 57$, $P < 0.001$; G4, $\chi^2 = 193.939$, $df = 62$, $P < 0.001$; Fig. 3). The Fusui used 24–43 cells as their core cells (17.8–24.2% of the total home range), while the Chongzuo groups covered a 22–31-cell core area (34.9–53.4% of the total home range). The seasonal variation in the percentage of core cells in the total records was significant for the Fusui groups (G1, $Z = -3.094$, $n = 62$, $P = 0.002$; G2, $Z = -1.982$, $n = 54$, $P = 0.047$) but not for the Chongzuo groups (G3, $Z = -1.341$, $n = 66$, $P = 0.180$; G4, $Z = -0.812$, $n = 40$, $P = 0.417$).

Diets

Diets of langurs indicated significant inter-site variation (Fig. 4; Table 4). The Fusui groups consumed more young leaves ($\chi^2 = 4.00$, $df = 1$, $P = 0.046$), but they had much lower diet diversity than the Chongzuo groups (Shannon–Weaver diversity index, 2.3 ± 0.3 vs 4.1 ± 0.5) ($\chi^2 = 17.24$, $df = 1$, $P < 0.001$). Consumption of the other food items was similar (mature leaves, $\chi^2 = 0.28$, $df = 1$, $P = 0.596$; flowers, $\chi^2 = 1.73$, $df = 1$,

Table 4 Best-fit models for activity budget, ranging pattern, and diet of the white-headed langur across the study sites

Item	Response variable	Explanatory variable	Estimate	SE	<i>t</i>	
Activity budget	Moving	(Intercept)	0.27	0.02	17.11	
		Site Chongzuo	−0.09	0.02	−3.86	
	Resting	(Intercept)	0.47	0.05	8.63	
		Site Chongzuo	−0.07	0.08	−0.90	
	Feeding	(Intercept)	0.17	0.02	7.76	
		Site Chongzuo	0.07	0.03	2.25	
	Playing	(Intercept)	0.03	0.02	1.44	
		Site Chongzuo	0.11	0.03	4.26	
	Grooming	(Intercept)	0.05	0.01	5.06	
		Site Chongzuo	−0.03	0.02	−1.75	
	Other	(Intercept)	0.01	0.01	1.33	
		Site Chongzuo	0.00	0.01	0.48	
	Ranging pattern	Daily path length	(Intercept)	504.25	25.09	20.10
			Site Chongzuo	−39.09	35.48	−1.10
Monthly home range		(Intercept)	29.46	2.22	13.30	
		Site Chongzuo	−0.50	3.13	−0.16	
Diet	Young leaves	(Intercept)	0.74	0.05	16.31	
		Site Chongzuo	−0.13	0.06	−2.08	
	Mature leaves	(Intercept)	0.13	0.04	3.48	
		Site Chongzuo	0.03	0.05	0.52	
	Flowers	(Intercept)	0.02	0.01	1.97	
		Site Chongzuo	0.02	0.02	1.20	
	Fruits	(Intercept)	0.08	0.04	1.80	
		Site Chongzuo	0.09	0.06	1.53	
	Others	(Intercept)	0.03	0.01	3.37	
		Site Chongzuo	−0.01	0.01	−0.57	
	Diversity	(Intercept)	2.32	0.10	23.05	
		Site Chongzuo	1.79	0.14	12.61	

$P = 0.189$; fruits, $\chi^2 = 3.09$, $df = 1$, $P = 0.079$; others, $\chi^2 = 0.34$, $df = 1$, $P = 0.562$). We recorded 107 species consumed by the Fusui groups and 134 species by the Chongzuo groups. Both groups shared 38 plant species, which accounted for 71.8% of the diet of the Fusui groups and 46.1% of the diet of the Chongzuo groups (Table 6).

Discussion

The Chongzuo groups spent more time feeding and less time moving. This could have been due to relatively lower food abundance in their forest fragments. As mentioned above, fragmented or degraded forests typically provide fewer food resources (Campera et al. 2014). Primates living in lower food abundance habitat tend to devote more time to feeding (Hanya 2004; Li and Rogers 2004). The Chongzuo groups have suffered heavier forest fragmentation, and the fragments contain fewer plant species and smaller average path sizes (Table 5). This implies lower

food abundance for these groups. Langurs spent more time feeding to maximize their energy intake as a response to reduced food resources in the more fragmented forest. Moreover, increasing feeding and decreasing moving could offset energy expenditure in the smaller fragmented forests (Huang et al. 2003; Wong and Sicotte 2007). Sympatric white-headed langurs adopted a similar strategy when facing low quality habitats (Li and Rogers 2004), by increasing their feeding time during the food-lean periods of the year (Huang et al. 2003).

White-headed langurs predominantly consume young leaves and fruits supplemented with mature leaves (this study; Huang et al. 2000a; Li et al. 2003; Li and Rogers 2006; Zhou et al. 2013; Dayong et al. 2016). However, there were marked inter-site variations in diets in this study. This may be related to the differences in forest species composition. In general, the larger fragments had a greater abundance of large, primary trees, a lower density of small secondary species, and higher basal areas of species and families crucial for forest-dwelling primates,

Table 5 Comparison of diets, home ranges and habitat fragmentation of white-headed langur across study sites

Study site	Dietary composition (% of feeding time)				Home range (ha)	Monthly home range (ha; mean \pm SD)	Tree diversity ^b	Fragmentation index ^c	Average patch size (ha) ^c	References
	Leaves ^a	Flowers	Fruits	Others						
Fusui (G1)	83.4	3.5	12.4	0.7	23.8	8 \pm 2.4	5.49 ^e	2.65	36.81	This study
Fusui (G2)	91	1.3	6	1.7	33.8	6.7 \pm 3.1	5.49 ^e	2.65	36.81	This study
Fusui	89	2.7	6.1	2.2	28–48	– ^d	6.32 ^f	2.65	36.81	Li and Rogers 2005b, 2006
Fusui	75.3	2.3	22.5	0	53.5	2.4 \pm 1.9	6.15	3.18	31.05	Huang et al. 2000a; Huang 2002
Chongzuo (G3)	72.2	3.1	22.8	1.9	14.5	7.7 \pm 0.9	3.37	5.23	19.49	This study
Chongzuo (G4)	80.7	5.8	11.4	2.2	15.8	6.8 \pm 1.7	2.79	5.23	19.49	This study

^a Young leaves plus mature leaves, including leaves for which the phenophase was not clear

^b Shannon–Weaver diversity index

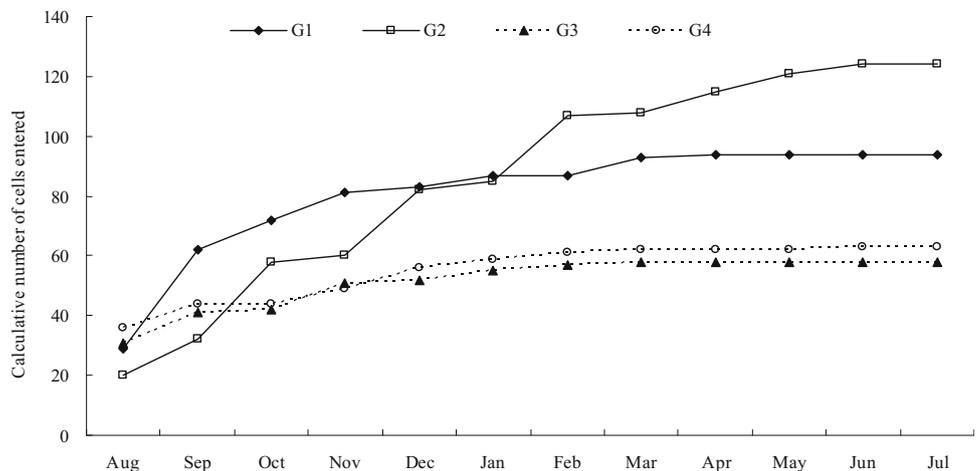
^c Cited from Chen et al. (2008)

^d Data were not available

^e Cited from Lu (2014)

^f Cited from Tang (2004)

Fig. 2 Relationship between the cumulative number of cells entered by the four focal white-headed langur groups [Fusui (G1, G2); Chongzuo (G3, G4)] and observation time



likely implying fewer food items such as young leaves (Arroyo-Rodríguez and Mandujano 2006). The white-headed langurs showed flexibility in their diet when coping with food reduction resulting from forest fragmentation. In the more fragmented forests, the Chongzuo groups fed on more plant species to maximize food intake, compared with the Fusui groups, such as lianas (23.8 vs. 9.1%; unpublished data). The most eaten liana (*Cansjera rheedei*) accounted for 9.1% of the annual feeding record for the Chongzuo groups, but was not consumed by the Fusui groups. There were possibly more lianas available in the Chongzuo forests, because lianas are abundant along forest edges, and the phenology of these species is less seasonal than those of trees (Chiarello 1994, 2003). In fact, more

than half of the food plants of the Chongzuo groups were not consumed by the Fusui groups. Lower food abundance, specific differences in food lists, and higher liana consumption by the Chongzuo groups likely accounted for their diets containing fewer young leaves and higher dietary diversity, despite there being lower tree diversity in the forests. This finding, however, requires further study with regards to resource abundance and phenology.

Most colobines often occupy a small home range (less than 100 ha) and use short daily path lengths (less than 1000 m) (see Kirkpatrick et al. 1998). In this study, white-headed langurs had a home range of 14.5–33.8 ha and a daily path length of 449.6–538.1 m, which are well within the range of variation previously reported for

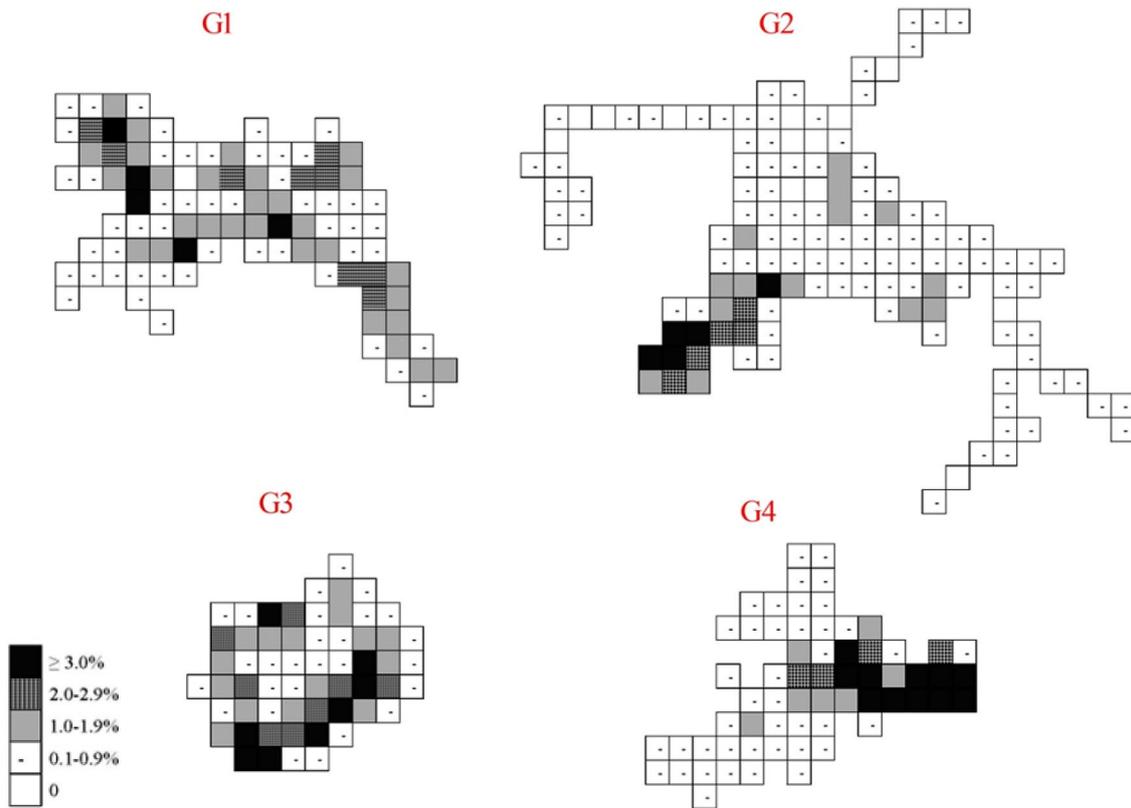
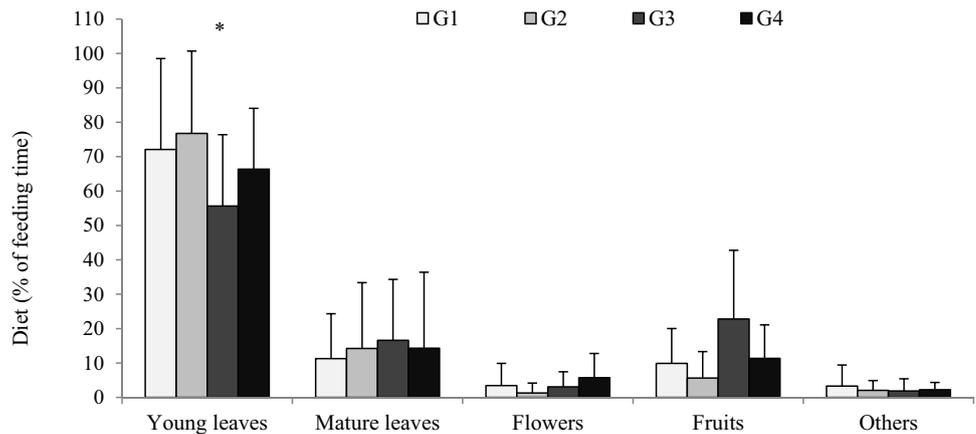


Fig. 3 Home range and use intensity for the four focal white-headed langur groups. For abbreviations, see Fig. 1

Fig. 4 Inter-site comparison of dietary composition between Fusui and Chongzuo groups. *Asterisks* represent a significant difference. For abbreviations, see Fig. 1



Trachypithecus sp. (see Zhou et al. 2011b). However, differences between the home ranges of the Chongzuo and Fusui groups were significant. The Chongzuo groups occupied a much smaller home range than the Fusui groups. This characteristic may indicate a response to food resource scarcity and habitat fragmentation. Previous studies have shown that the size of the home range is mainly affected by the abundance of food resources (Li et al. 2014). An increased or decreased home range indicates a primate’s positive behavior or coping mechanism in periods of food scarcity (Zhou et al. 2011b; Shaffer 2013; Campera et al.

2014; Li et al. 2014). Covering a smaller home range could reduce energy expended in the search for food (Richard 1985). The more fragmented forests in Chongzuo, with their consequent lower food availability, could create smaller home ranges for langurs. Besides food abundance, smaller available fragments in Chongzuo also contributed to inter-site variation in the langur home range. In our study sites, limestone fragments were completely separated by farmland, and langurs did not dare cross this farmland to expand their home range. They were confined to smaller fragments, and therefore covered a smaller home range. Our results are

Table 6 Plant species consumed by the Fusui and Chongzuo groups

Species	Family	Parts eaten	Percent of feeding record	
			Fusui groups	Chongzuo groups
<i>Aphananthe aspera</i>	Ulmaceae	YL, ML	16.15	0.21
<i>Ficus microcarpa</i>	Moraceae	YL, ML, FR	11.41	4.31
<i>Sinosideroxylon pedunculatum</i> var. <i>pubifolium</i>	Sapotaceae	YL, ML, ST	4.59	5
<i>Tetragium planicaule</i>	Vitaceae	YL, ML, FR	4.59	0.66
<i>Celtis biondii</i>	Ulmaceae	YL, ML, FR, FL	4.21	2.85
<i>Archidendron microsperma</i>	Mimosaceae	YL, ML, FR	3.94	0.21
<i>Mours alba</i>	Moraceae	YL, ML	3.36	0.03
<i>Sterculia nobilis</i>	Sterculiaceae	YL, FR, ST	2.62	3.99
<i>Broussonetia papyrifera</i>	Moraceae	YL, ML, FR, ST	2.47	2.81
<i>Capparis hainanensis</i>	Capparaceae	YL, ML, FL	2.27	0.36
<i>Ficus tinctoria</i>	Moraceae	YL, ML, FR	2.12	2.66
<i>Iodes cirrhosa</i>	Icacinaceae	YL, ML, ST	1.97	0.43
<i>Maclura cochinchinensis</i>	Moraceae	YL, ML, FR	1.79	1.68
<i>Cuscuta japonica</i>	Convolvulaceae	ST	1.69	0.65
<i>Albizia kalkora</i>	Mimosaceae	YL	1.29	0.39
<i>Rhus chinensis</i>	Anacardiaceae	YL, ML, FL	1.21	0.02
<i>Pteroceltis tatarinowii</i>	Ulmaceae	YL, ML	1.06	8.22
<i>Croton euryphyllus</i>	Euphorbiaceae	YL, P	0.93	0.25
<i>Malaisia scandens</i>	Moraceae	YL	0.71	0.02
<i>Canthium dicoccum</i>	Rubiaceae	YL, ML	0.4	3.64
<i>Pueraria lobata</i>	Papilionaceae	YL, ML, FL, ST	0.4	3.57
<i>Alchornea trewioides</i>	Euphorbiaceae	YL, ML, FR	0.3	0.11
<i>Paederia scandens</i>	Rubiaceae	YL, ML	0.3	0.06
<i>Cipadessa cinerascens</i>	Meliaceae	YL, ML, FR, FL	0.25	0.25
<i>Flueggea virosa</i>	Euphorbiaceae	YL, ML, FR	0.18	0.77
<i>Sageretia thea</i>	Rhamnaceae	YL, ML	0.18	0.11
<i>Millettia pachycarpa</i>	Leguminosae	YL, ML	0.18	0.1
<i>Desmos chinensis</i>	Annonaceae	YL	0.18	0.01
<i>Illigeria rhodantha</i>	Illigeraceae	YL	0.18	0.01
<i>Berchemia floribunda</i>	Rhamnaceae	YL, ML	0.15	0.35
<i>Psidium guajava</i>	Myrtaceae	YL	0.15	0.03
<i>Ficus virens</i>	Moraceae	YL, ML, FR	0.13	0.39
<i>Gouana javanica</i>	Rhamnaceae	YL, FR	0.13	0.33
<i>Oreocnide frutescens</i>	Urticaceae	YL	0.13	0.03
<i>Bombax malabaricum</i>	Bombacaceae	YL, ST	0.05	0.03
<i>Millettia reticulata</i>	Papilionaceae	YL, ML	0.03	0.91
<i>Zanthoxylum armatum</i>	Rutaceae	YL, ML, FL	0.03	0.39
<i>Chavdaia rubinervis</i>	Rhamnaceae	YL, ML	0.03	0.25

YL Young leaves, ML mature leaves, FL flowers, FR fruits, P petioles, ST stems

consistent with those of Shaffer (2013), who concluded that home ranges of bearded sakis were apparently confined by the size of forest fragments. François langurs (*Trachypithecus francoisi*), a close phylogenetic relative sympatric with the white-headed langur, also had larger home range in the continuous forest compared with those in fragmented forests (Zhou et al. 2007, 2011a; Li et al. 2014).

There were no observable differences in monthly home range and daily path length. This could be linked to the difference in home range use pattern. We found that the core areas represented a lower percentage of total home ranges of the Fusui groups. Moreover, the seasonal variations in core cells were significant for the Fusui groups but not for the Chongzuo groups. This might indicate that these

langurs changed the core areas of their home ranges periodically. Meanwhile, the Chongzuo groups, with less area to move in due to heavier forest fragmentation, could not shift their home ranges periodically. As a response to food scarcity, the Chongzuo groups therefore searched for food in a limited area and spent more time feeding, which consequently led to a smaller home range, but similar monthly home ranges and daily path lengths. To accurately estimate the influence of resources on ranging behavior, further study on the abundance and spatial distribution of food plants is required.

Primates' successful persistence in fragmented habitats is heavily dependent upon their abilities to adapt to habitat fragmentation (Cristóbal-Azkarate and Arroyo-Rodríguez 2007). White-headed langurs survive in the fragmented forests via behavioral and dietary flexibility (this study; Huang 2002; Li and Rogers 2006; Zhou et al. 2011b). In fact, white-headed langur population grew from 580 to 620 individuals in 1999 and to 937 individuals by 2010 (Huang et al. 2002; Guangxi Forestry Bureau 2011). This likely implies that food-related factors, such as food abundances, were not a substantial barrier to langurs, at least temporarily. Instead, habitat fragmentation has been the more dangerous threat to white-headed langurs (Huang et al. 2002). Even in the nature reserve studied here, the landscape structure between 1973 and 1999 dramatically changed due to an increase in agricultural land use (Chen et al. 2008). Due to land ownership, the reserve administrator can only control illegal hunting for langurs, but has no right to control habitat destruction such as tree cutting and cultivation on the flat land and valleys around the rocky hills of the reserve (Huang et al. 2002; Li and Rogers 2005b; Guangxi Forestry Bureau 2011). Thus these langur groups are separated by large cultivated areas and villages. The existing habitat of the white-headed langurs studied here was approximately equivalent to their potential habitat (Feng 2005). Thus, it is crucial to protect the size and intactness of the existing forest fragments. Linking these fragments by corridors should be considered a priority for habitat management here.

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