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Range Expansion as a Response to Increasing Group Size in the Yunnan Snub-Nosed Monkey

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Key Words
Colobinae · Group size · Home range · Range expansion · *Rhinopithecus bieti*

Abstract

The Yunnan snub-nosed monkey *(Rhinopithecus bieti)* is characterized by a larger home range and group size than other colobine species. We investigated variations in home range size of a free-ranging group of *R. bieti* from 1998 to 2007 in the Baimaxueshan National Nature Reserve in Yunnan, China. Group size increased from 160 to 450 over the 10 years. Results also showed a home range shift and yearly home range expansion, although this expansion was very limited. The study group covered a 33.78-km^2 area during the 10-year period, with some areas abandoned and others used repeatedly. The yearly home range increase stopped in 2004 and decreased thereafter. Despite increasing group size usually being coupled with larger yearly home range (>30 km^2), the group confined itself within a relatively small and stable area (<18 km^2) during 2005–2007, with a significant portion of their accessible home range discarded. Consequently, the study group showed the highest recorded population density among extant groups of *R. bieti*. Reasons why the group settled into a substantially smaller home range area remain unclear.

D.L. and B.R. contributed equally to the paper.

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Introduction

Although Burt [1943] defined the home range of an animal as 'that area traversed by the individual in its normal activities of food gathering, mating and caring for young', operational estimates of home range are based on the entire area occupied by a social group each year [Ren et al., 2009]. Home range size in primates is significantly affected by group size [Clutton-Brock and Harvey, 1977]. For most primate species, larger groups exploit larger habitat areas due to greater food requirements [Isbell, 1991; Chapman et al., 1995], while under natural conditions limited suitable habitat restricts overpopulation [van Schaik, 1983; Dunbar, 1984; Crockett and Janson, 2000]. As such, studies on home range size and group size are helpful for estimating essential living conditions, group development and even extinction risk.

Colobine monkeys generally have smaller home ranges (<1 km^2) than sympatric macaques and apes [Clutton-Brock and Harvey, 1977; Chapman and Chapman, 2000], which is likely related to ubiquitous food resources in their habitats [Dasilva, 1992; Kay and Davies, 1994]. Exceptionally, Chinese snub-nosed monkeys (*Rhinopithecus* spp.) in harsh temperate montane areas occupy a substantially larger (>20 km^2) home range [Kirkpatrick et al., 1998; Li et al., 2000; Tan et al., 2007; Grueter et al., 2008; Ren et al., 2009] than other colobine species.

The Yunnan snub-nosed monkey *(Rhinopithecus bieti)*, a highly endangered colobine species, continues to experience intense habitat loss [Xiao et al., 2003] and localized extinction of groups with less than 50 individuals [Long et al., 1994]. Currently, only 17 groups of *R. bieti* remain in the wild [Long and Wu, 2008]. Previous studies have estimated home range size of *R. bieti* based on 1- or 2-year-long investigations [Kirkpatrick, 1996; Yang, 2000; Cui, 2003; Grueter et al., 2008; Ren et al., 2009], which confirmed a large home range (>20 km^2) and group size (>100 individuals). To date, however, no study has focused on the relationship between home range and group size in *R. bieti*. The main goals of this study were to investigate a wild *R. bieti* group over a 10-year period to determine (1) variations in yearly home range and (2) correlations between group size and home range size.

Methods

Study Site

Our study was carried out on a single *R. bieti* troop from Xiangguqing (27°37′ N, 99°22′ E; fig. 1), a 90 km^2 area of Samage Forest in the Baimaxueshan Nature Reserve, Yunnan, China [Li et al., 2008]. The reserve covers 281,640 ha, with a total *R. bieti* population of 1,200–1,400 individuals [Li, 2010]. The study site ranges from 2,500 to 4,100 m in elevation and consists of a mosaic of primary and secondary vegetation zones, including cattle pastures, mixed coniferous and deciduous broadleaf forest, high-elevation *Abies* forest, evergreen oak forest and pine forest [Li et al., 2008]. The region experiences significant seasonal variation in annual temperature and precipitation [Li et al., 2008], with an average annual temperature of 9.8°C and temperature ranges from –9.3°C in winter to 27.7°C in summer [Li, 2010]. Although certain areas of the forest were selectively logged a decade ago and livestock grazing and non-timber product harvesting by local communities continues, the study group still entered these areas. Group habituation commenced in 1998, with the group well habituated by 2006.

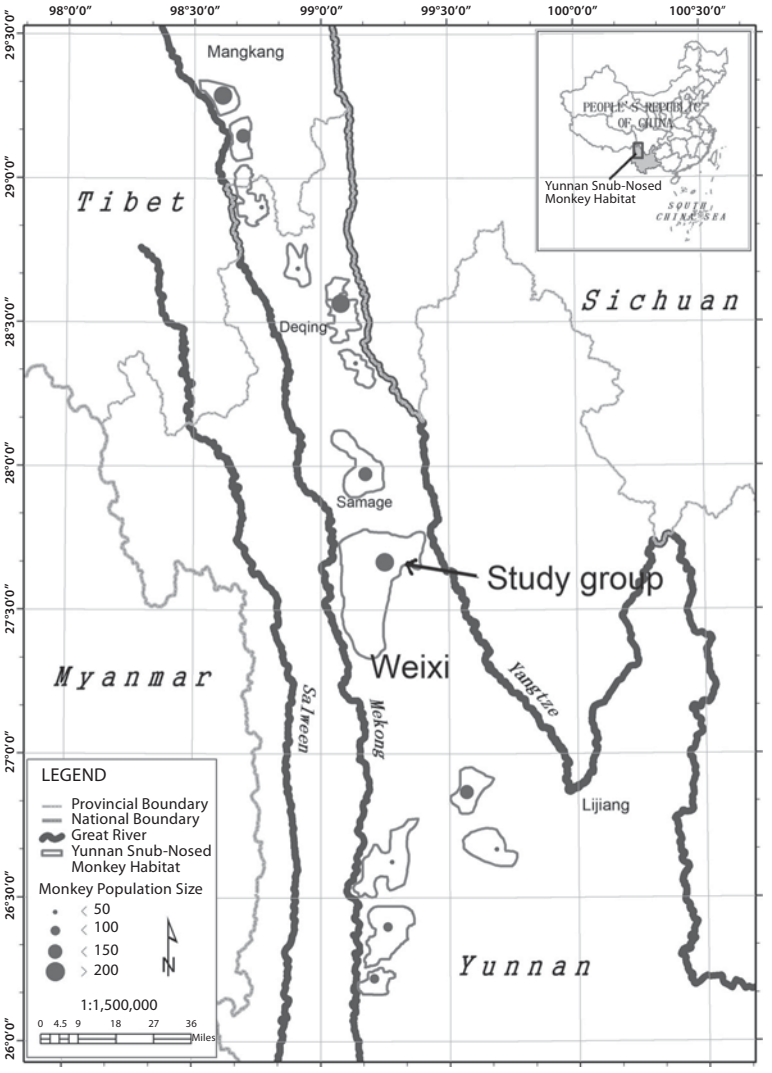


Fig. 1. Map of the study site and the location of groups of *R. bieti*.

Data Collection

Yunnan snub-nosed monkeys use multiple layers of the canopy and often travel long distances terrestrially [Kirkpatrick and Long, 1994; Xiang et al., 2009]. When terrestrial movement was observed for the study group, such as crossing grasslands or mountain ridges or visiting a forest water hole, the number of individuals was counted and recorded. Data on group size were collected by Baimaxueshan Nature Reserve staff between 1998 and 2003 and by our researchers between 2004 and 2007. To guarantee data consistency for home range and group sizes, the same reserve field worker (Mr. Jianhua Yu) assisted in data collection throughout the entire study period and provided reports at the end of each year.

Table 1. Data on the Xiangguqing group of *R. bieti* from 1998 to 2007

Year	Recording days	GPS locations	Group size	Total cells	New cells	Home range km^2	Population density individuals/km^2
1998	180	85	160	94	94	7.67	20.9
1999	180	145	180	149	55	12.16	14.8
2000	180	240	210	143	40	11.67	18.0
2001	180	320	250	178	35	14.52	17.2
2002	180	400	300	183	31	14.93	20.1
2003	180	546	331	211	28	17.22	19.2
2004	240	450	360	230	131	18.77	19.2
2005	265	500	395	215	0	17.54	22.5
2006	284	552	420	200	0	16.32	25.7
2007	300	1,003	450	210	0	17.14	26.3
In total	2,169	4,241	–	414	–	33.78	–
Average	217 ± 50	424 ± 261	306 ± 103	181 ± 42	41 ± 43	14.79 ± 3.41	20.4 ± 3.6

'–' indicates no data, and average data are presented as means ± SD.

Table 2. Population density, group size and home range size of the other studied groups of *R. bieti*

Field site	Group size	Home range km^2	Population density individuals/km^2	Geographical distribution	Reference
Fuhe	80	10.7	7.5	south	Liu et al. [2004]
Jinsichang	180	17.3	10.4	south	Ren et al. [2008]
Longma	80	9.56	8.4	south	Huo [2005]
Gehuaqing	410	24.75	16.6	middle	Grueter et al. [2008]
Wuyapiya	175	25.25	6.9	north	Kirkpatrick et al. [1998]
Xiaochangdu	210	21.25	9.9	north	Xiang [2005]

'South' indicates the monkey groups in Lijiang and Lanping, 'middle' those in Weixi and 'north' those in Tibet and Deqing, Yunnan province.

Group location data have been collected since 1998 via global positioning system (GPS) receivers. Local peak and valley names were also marked in a notebook when the GPS receiver located a site. The GPS data points represented geographical sites where the group was seen or fresh faeces (<3 days) were found. Locations of the study group were recorded by a GPS receiver once every 2 days by reserve staff (15 working days per month) from 1998 to 2004. We tracked the group and recorded locations by GPS receiver at least twice per day from 2004 to 2007, except during poor weather or in inaccessible terrain (table 1).

Data Analysis

All GPS locations of the study group were transferred onto a map (scale 1:50,000). As suggested by previous studies [Grueter et al., 2009; Ren et al., 2009] and annual group size of our study group, we selected a 250 m × 250 m grid to estimate annual home range sizes and total

home range size (table 1; fig. 2, 3). We measured and corrected home range sizes using the formula: A = (number of cells entered) × (0.0625)/cos (40°), where cos (40°) represents the approximate average angle of slope [Grueter et al., 2008]. Isolated grid cells were linked via the minimum number of intervening cells of suitable habitat [Grueter et al., 2009]. Furthermore, we used the local peak and valley names for the GPS locations to reduce estimation differences of home range in different years.

Linear correlation analysis was employed to determine the relationship between home range size and group size each year. The Mann-Whitney U test was used to compare the average population density of our study group over the 10-year period with 6 previously studied groups (table 2). Statistical tests were performed using SPSS® 12.0 software (SPSS Inc., Chicago, Ill., USA). All statistical analyses were 2-tailed, and the maximum significance level was set at 0.05.

Results

Home Range Size

The number of locations recorded by GPS differed each year, ranging from 180 days in 1998 to 300 days in 2007 (table 1). No significant correlation between the number of days the group was located each year and yearly home range size was detected (Spearman rank correlation, $r_s = 0.601$, $p = 0.066$, $n = 10$ years), although the number of times the group was located varied significantly each year (χ^2 test: $\chi^2 = 1{,}440.63$, d.f. = 9, $p < 0.001$). This suggests that the increase in working days from 2004 increased the precision in recording home range use, although the uneven sampling effort only marginally affected data comparability and interpretation.

Over the decade of study, the *R. bieti* group entered 414 grid cells, which corresponded to a total area of 33.78 km^2 (corrected by local site names and terrain traits; fig. 3).

The cumulative number of grid cells visited by the focal group from 1998 to 2007 is shown in table 1. The group continually added grid cells from 1998 to 2004, after which time the curve became asymptotic. The number of newly used grid cells varied from year to year, with a maximum of 131 cells in 2004 and a minimum of 28 in 2003. No new grid cells were used after 2005, and the home range did not markedly change thereafter (table 1; fig. 2).

Home Range Shifted Once

The group changed its home range core over time, ranging to the west of Xiangguqing in the late 1990s before including the area to the east in its home range in 1998. By the end of the study period, the group occupied the eastern part exclusively (fig. 2 and 3). The total home range was divided into 2 different areas A and B (fig. 2 and 3) throughout the 10 years. The group used mainly area A between 1998 and 2000, with area B first used in 2001 and expanded into until 2003. By 2004, area A was almost completely abandoned and only area B was inhabited (fig. 2 and 3).

Group Size and Home Range Size

Group size grew more or less continually during the study, from 160 individuals in 1998 to 450 individuals in 2007. The extent of the group's home range increased accordingly, from 7.67 km^2 in 1998 to 17.14 km^2 in 2007 (table 1). A significant positive correlation between group size and home range size was found for this group (linear regression test: $F_{1,9} = 23.39$, $p = 0.001$; fig. 4).

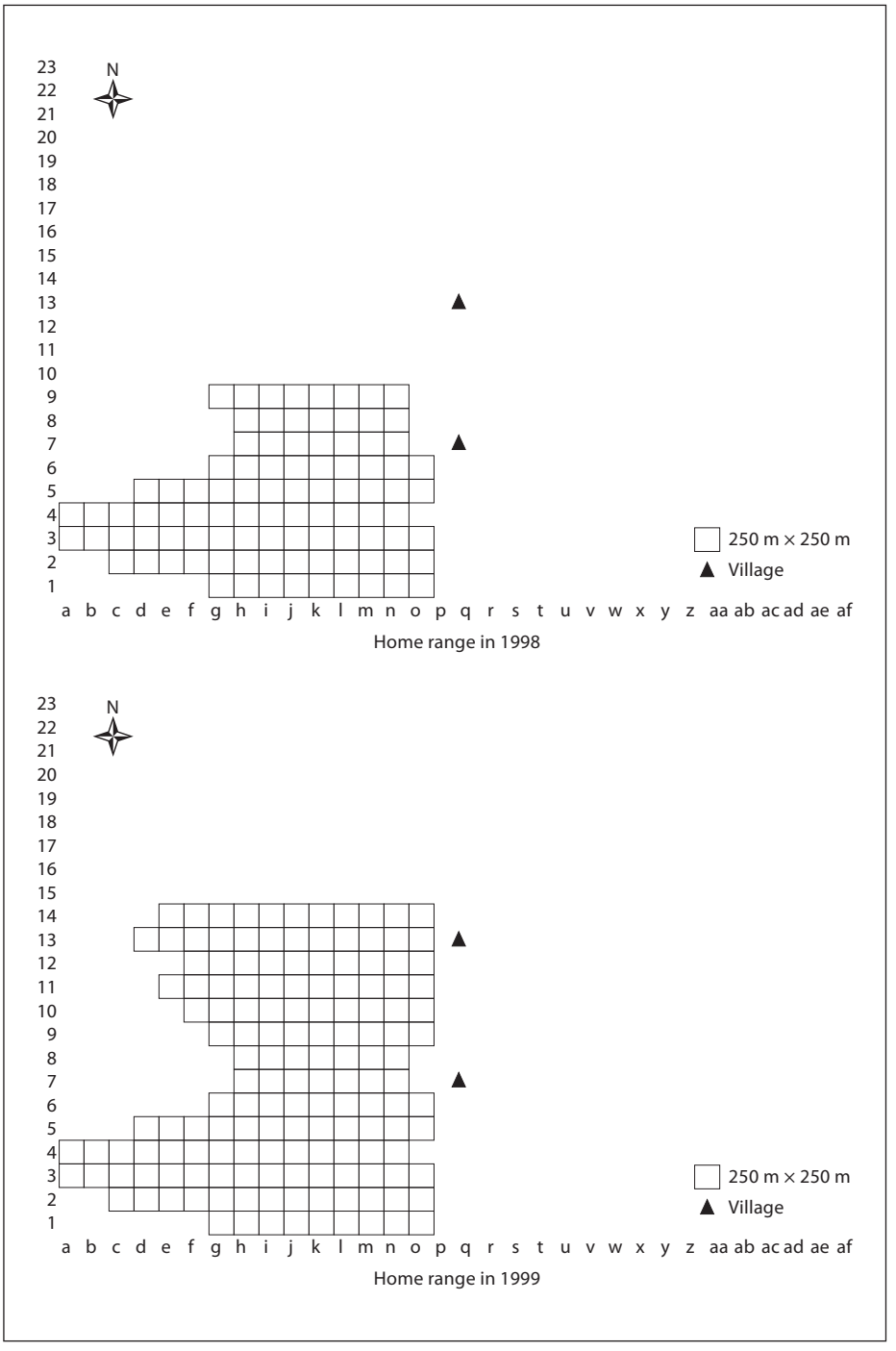
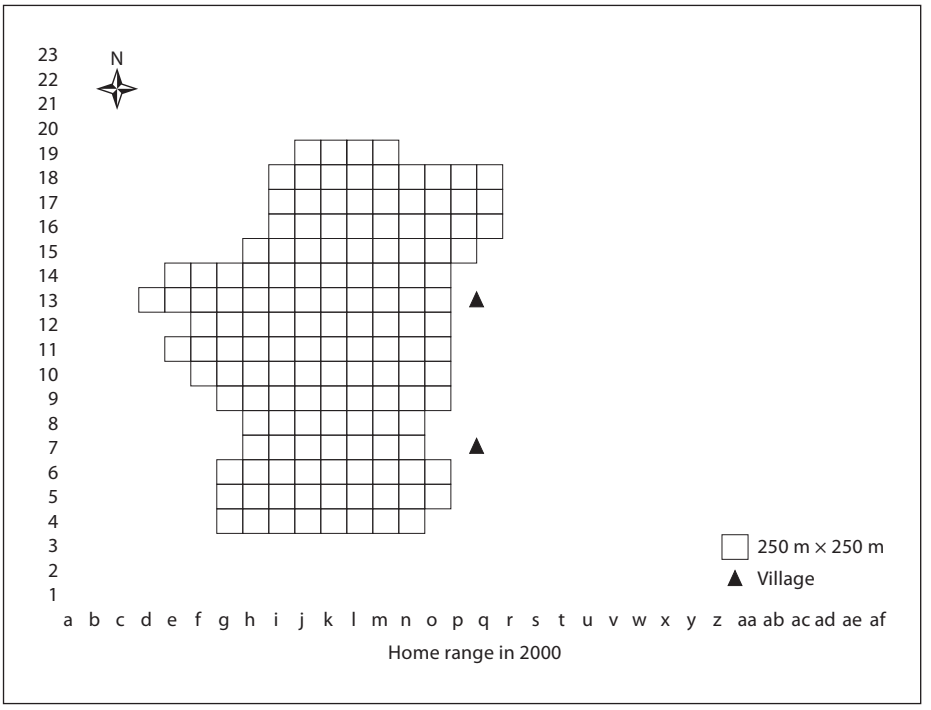


Fig. 2. Annual home range used by the Xiangguqing group of *R. bieti* from 1998 to 2007 (Figure continues on subsequent pages).



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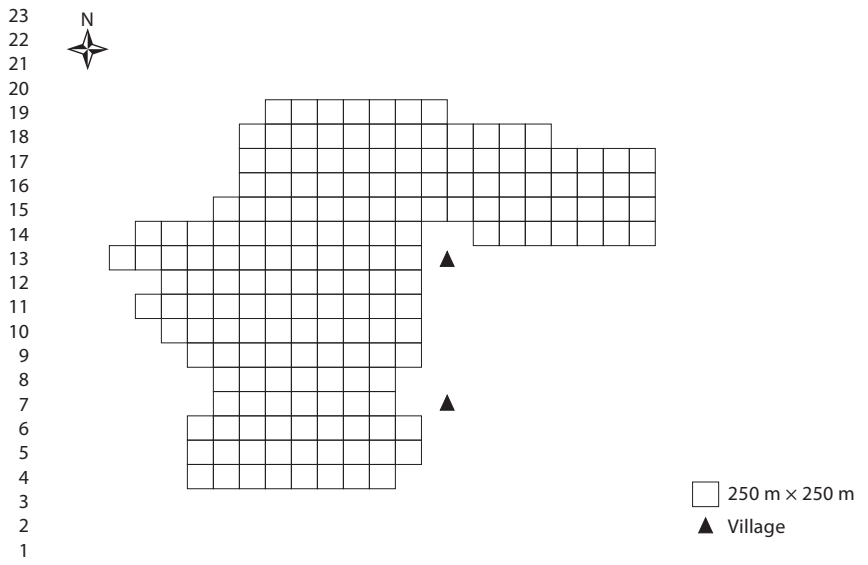
Population Density

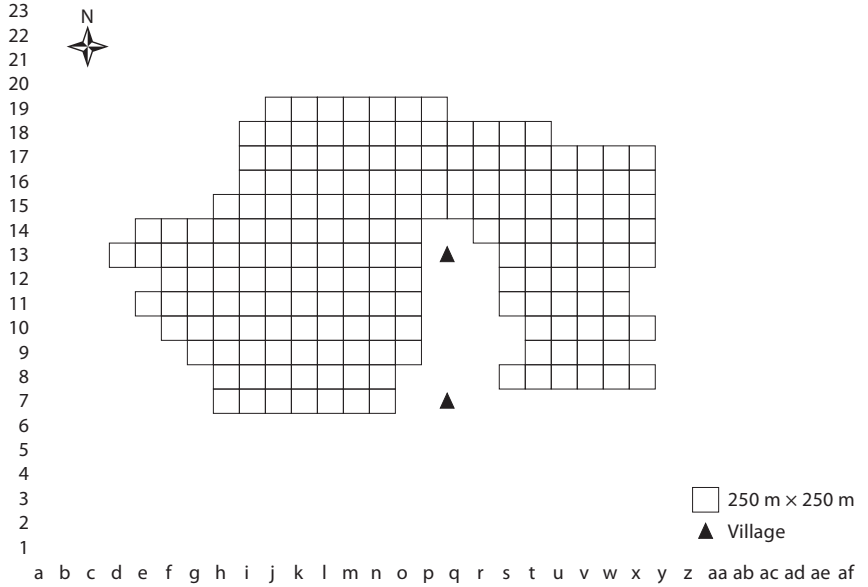
The average population density of our study group was the highest (20.4 individuals/km^2) observed in comparison to other wild groups of the same species (tables 1 and 2).

Discussion

R. bieti may cope with increasing group size and associated scramble competition by enlarging its yearly home range. Due to habitat reduction and restriction, however, this strategy cannot continue indefinitely [Xiao et al., 2003]. As seen in the present study, expansion was only observed for 7 of the 10 years (from 1998 to 2004), after which no new areas were used by the Xiangguqing group despite increasing group size (450 individuals by 2007). Conversely, 2 well-studied groups of Sichuan snub-nosed monkey *(R. roxellana)* from Yuhuangmiao in Zhouzhi Nature Reserve, Shaanxi, have maintained a relatively stable group size and stayed in the same home range since 1999 [Tan et al., 2007; Zhang et al., 2008]. This suggests that *R. bieti* should also exhibit only a small increase in group size when range expansion ceased. Our findings showed that the *R. bieti* group size not only continued to increase but had the highest population density in 2007 compared to all other studied groups (tables 1 and 2).



Home range in 2001



Home range in 2002

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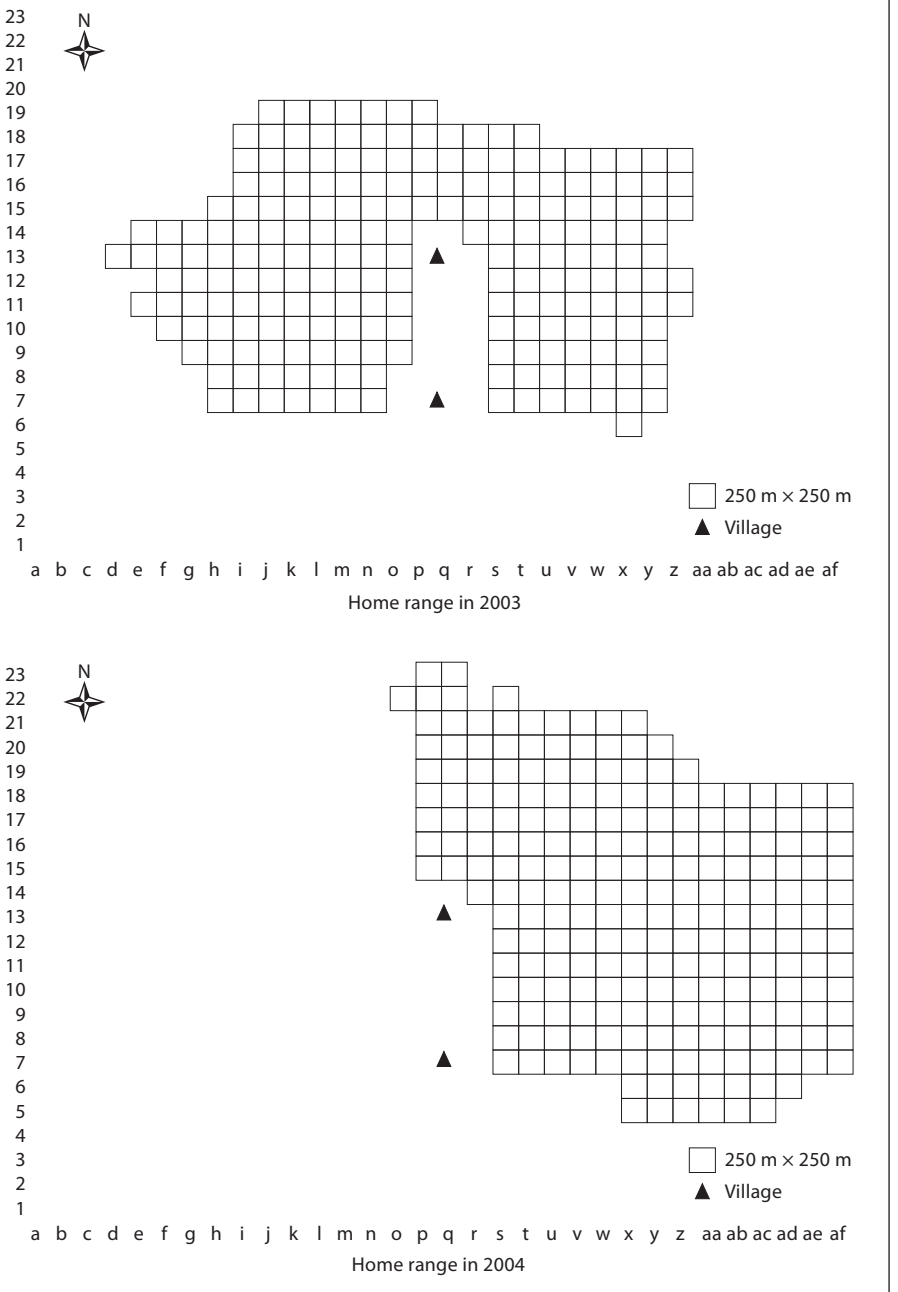

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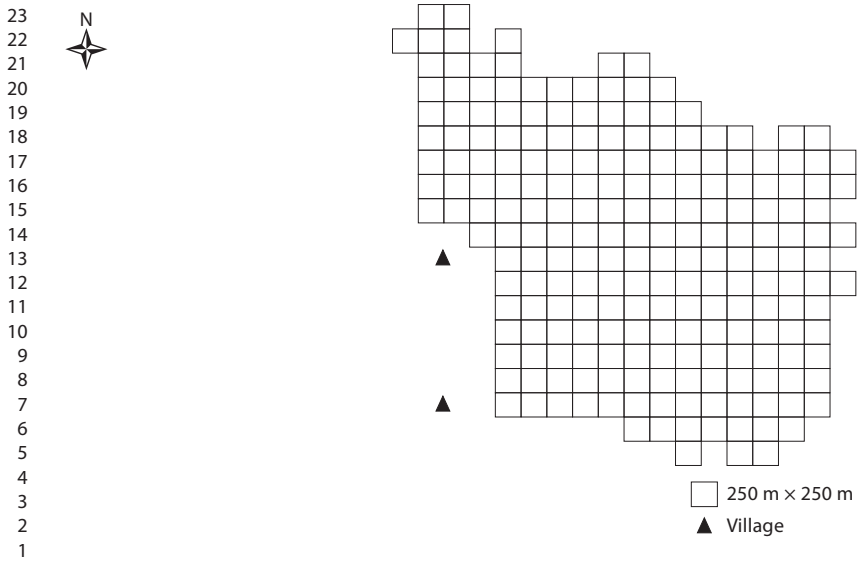
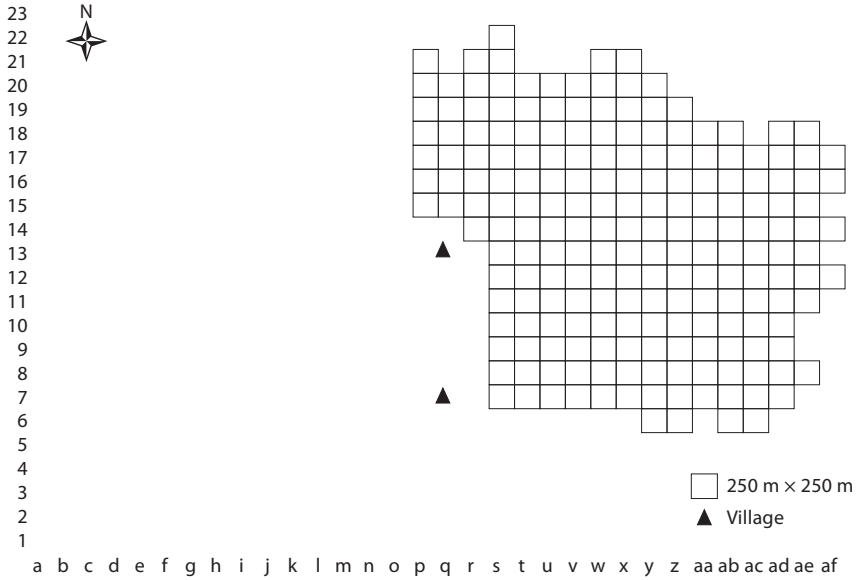


Home range in 2005



Home range in 2006

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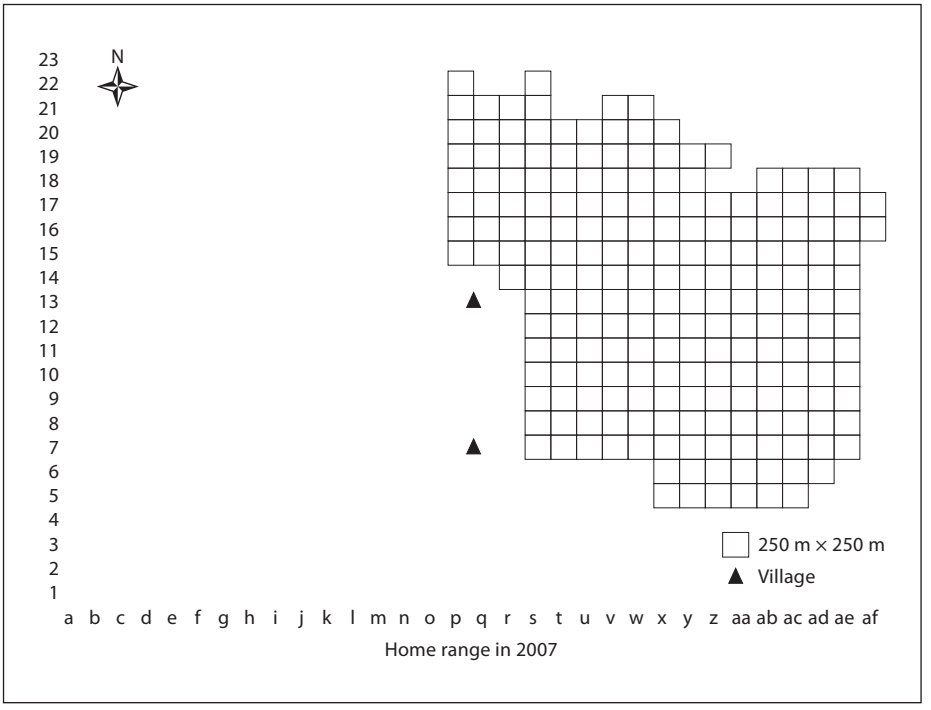

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Our study group also had the largest group size (450 individuals by 2007) and home range area (33.78 km^2) in the wild compared with previously studied *R. bieti* groups [Kirkpatrick et al., 1998; Xiang, 2005; Grueter et al., 2008; Ren et al., 2009]. However, increasing human population pressure [Xiao et al., 2003] made it difficult for the study group to enlarge its range area after 2004. Although such habitat restrictions should see a reduction in group size, the study group showed an unusual and unsustainable strategy of increasing group size in a very confined area (area B). A smaller home range represents reduced food supply, which frequently translates to smaller group size in many non-human primates [Clutton-Brock and Harvey, 1977; Bennett, 1986; Oates, 1987; Barton et al., 1992; Kaplin, 2001; Palacios and Rodriguez, 2001; Tan et al., 2007]. Based on such research, it would seem likely that the *R. bieti* study group will suffer from crowding due to its high population density.

The present study confirmed that *R. bieti* does expand its home range area with increasing group size, with the study group continuing to visit new grid cells from 1999 to 2004. As group size increased, the troop exploited new spatial habitat to compensate for increased resource competition [Clutton-Brock and Harvey, 1977; Dunbar, 1988]. Such range expansion was, however, very limited. Our study group abandoned its original home range and moved to a new area in 2004, a radical shift that has not been observed previously in other groups. Based on the data obtained, it is difficult to determine why such a home range shift occurred, although habitat deterioration, resource depletion and heavy human disturbance in area A may have been a factor. Additionally, the smaller home range observed from 2004 may initially have

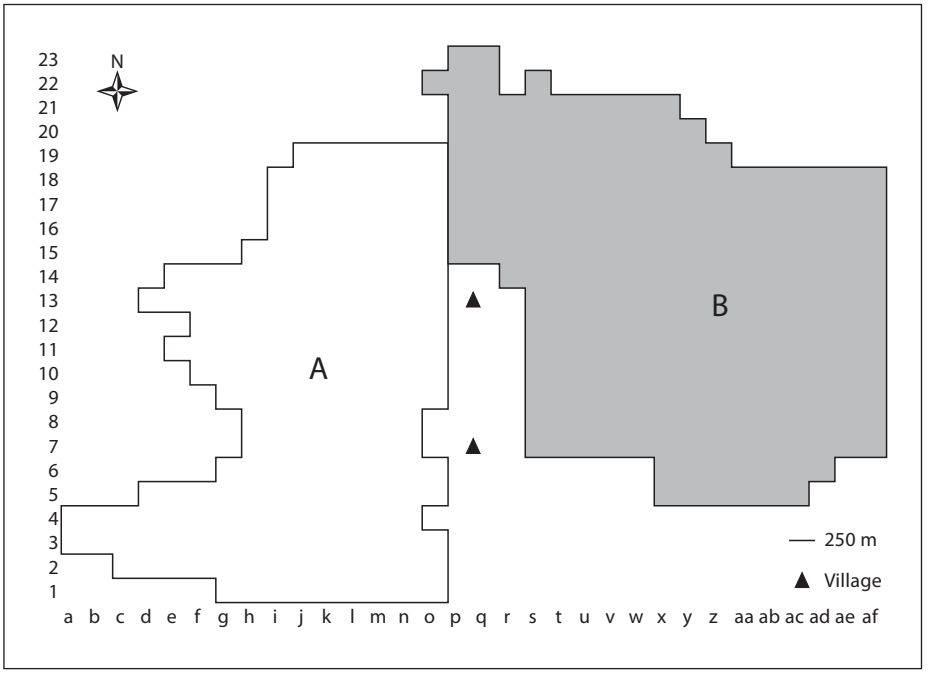

Fig. 3. Total ranging area estimate and home range shift from area A to area B of the Xiangguqing group of *R. bieti* from 1998 to 2007.

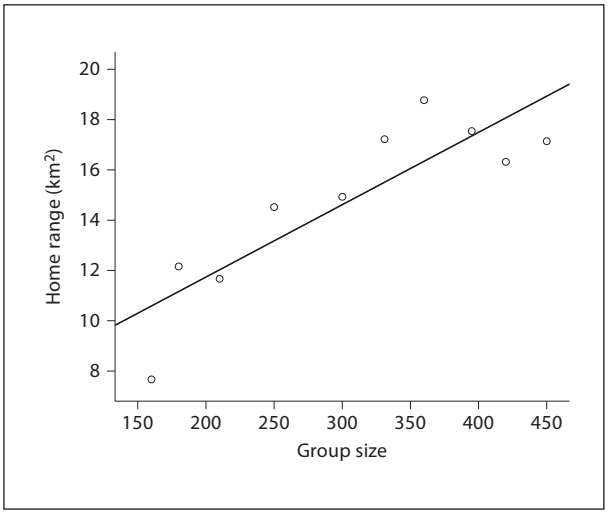

Fig. 4. Correlation between yearly group size and yearly home range size of the Xiangguqing group of *R. bieti* from 1998 to 2007.

provided adequate resources for a limited amount of time, allowing the group to remain in the smaller, and possibly more resource-rich, area B. Since lichens are the main food (>60% of feeding time) of *R. bieti* [Kirkpatrick et al., 1998; Ding and Zhao, 2004], it has been hypothesized that the slow growth of lichens forces *R. bieti* to shift its home range over years or decades to avoid lichen-depleted habitats [Kirkpatrick et al., 1998]. Although no current evidence is available to support this hypothesis, it may explain *R. bieti*'s home range shift away from the well-used area A into area B (fig. 3). Since *R. bieti* feeds on more than 100 plant species [Zhao et al., 2009], it may also shift home range to feed on more diversified dietary items rather than lichens only.

Population density was determined by home range and group size. High population density suggests probable intragroup food competition [Bishop, 1979]. While the population density of *R. bieti* has been low in most wild groups (<10 individuals/km^2 [Kirkpatrick et al., 1998]), it was much higher in the Xiangguqing group (table 1) and reached an average of 20.4 individuals/km^2 during 1998–2007. Based on 'normal' densities for *R. bieti*, it seems improbable that the new home range in area B will provide sufficient permanent support and the group may have to expand or shift its present home range in the future.

Analytical methods sharply influence home range estimates [Grueter et al., 2009]. Although home range estimation is sensitive to grid cell size, we used the grid cell method [Grueter et al., 2009; Ren et al., 2009] as it is effective for the typical spatial spread of a group in 2 dimensions [Ostro et al., 1999]. In this study, the 250 metre grid was selected because (1) the usual spatial spread of the study group was >200 m before 2003, (2) our study group was large and needed much more room to spread out after 2003 and (3) most previous studies used the 250 metre grid to estimate the home range of *R. bieti*, therefore allowing for comparisons between studies. As a result, annual home range sizes may be slightly overestimated before 2003 and underestimated after 2003 due to inherent limitations in the grid cell method.

From a conservation perspective, it is both impractical and risky to wait for clarity as to whether a study group contains too many individuals. If it does, translocation of some of the animals might be a viable solution for this group of *R. bieti* to save the group from over-exploiting the forest and, consequently, being unable to sustain all its members. Further research on habitat use and an assessment of the lichen biomass would help us to understand better the relationships between home range size and group size in *R. bieti*.

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