Int J Primatol (2008) 29:783–794
DOI 10.1007/s10764-008-9251-z

Measuring Daily Ranging Distances of *Rhinopithecus bieti* via a Global Positioning System Collar at Jinsichang, China: A Methodological Consideration

Baoping Ren · Ming Li · Yongcheng Long · Cyril C. Grüter · Fuwen Wei

Received: 16 January 2007 / Accepted: 5 October 2007 /
Published online: 23 April 2008

Abstract There are few data on the daily ranging distances of Yunnan snub-nosed monkeys (*Rhinopithecus bieti*). We fitted 1 adult male from a natural group at Jinsichang in China's Yunnan Province with a global positioning system (GPS) collar and tracked him from December 2003 to October 2004 to estimate the daily ranging distances of the group. The total acquisition rate of the GPS collar was 82.2%, which indicates that one can use GPS collars to track the species efficiently in high-altitude, temperate, coniferous forest. We obtained group locations or fixes at 5 predetermined times during the day. The sleeping sites of the subjects are the key points to estimate the day range. We compared 2 measures of day range: the 2-point straight-line displacement and the multipoint cumulative daily ranging distance. Straight-line displacement between 2 consecutive mornings or 2 consecutive evenings can substitute for that between the morning sleeping site and the evening sleeping site. In general, the group does not move at night. The 2 measures of day range yielded different results. The multipoint cumulative daily ranging distance was the method of choice to measure their daily travel costs. The minimum required

B. Ren · M. Li · F. Wei (✉)
Key Laboratory of Animal Ecology and Conservation Biology, Institute of Zoology,
Chinese Academy of Sciences, Beijing 100101, China
e-mail: weifw@ioz.ac.cn

Y. Long
The Nature Conservancy, China Program, Kunming, Yunnan 650034, China

C. C. Grüter
Anthropological Institute, University of Zürich, 8057 Zürich, Switzerland

F. Wei
Institute of Zoology, Chinese Academy of Sciences, Datunlu, Chaoyang District, Beijing 100101,
China

number of fixes per day was 3. Per statistical evidence, the number of full-day group follows per month influences the estimate of day range of the group and ≥10 d is required to obtain a reliable estimate; 5 d per month might not be enough. We dealt mainly with the methodologic aspects of day range calculations. We did not address functional aspects on the estimate of day range, viz. the influence of vegetation, food distribution patterns, climate change, seasonality, and the monkey group itself.

Keywords day range · efficacy of GPS collar · *Rhinopithecus bieti*

Introduction

The length that a group of primates covers during its daily foraging is determined mainly by its travel costs (Steudel 2000). Proper measurement of day range is required to calculate the proximal travel costs of the group. One cannot always obtain the actual distance traveled under wild conditions. Many factors hamper efficiency of tracking and hence influence the measurement of daily ranging of a primate group, e.g., weather (Li 2002; McKey and Waterman 1982; Su *et al.* 1998), habituation of the individuals (Bennett 1986; Sigg and Stolba 1981), structure of the terrain (Gautier-Hion *et al.* 1981), density of the forest (Goodall 1977; Liu *et al.* 2004; Phillips *et al.* 1998), and moving velocity of the tracked group (Kirkpatrick 1996; Li 2002).

Researchers have applied various methods to collect data on day range of nonhuman primates: making marks on a topographic map on dislocation of the group (Koenig *et al.* 1997; Li 2002; Stevenson *et al.* 1994), carrying global positioning system (GPS) devices and georeferencing the group's successive positions (Sprague *et al.* 2004), or directly pacing the distance the group travels (Bennett 1986; Fossey and Harcourt 1977; Goodall 1977; Shimooka 2005; Yamagiwa and Mwanza 1994). Researchers commonly used 2 measures of day range: 1) 2-point methods, i.e., measures based on straight-line displacement between 2 sleeping sites ≤24 h (Hu *et al.* 1980; Shi *et al.* 1982) or 12 h (DeVore and Hall 1965; Isbell *et al.* 1999; Kirkpatrick 1996; Koenig *et al.* 1997; Stevenson *et al.* 1994) and 2) multipoint methods, i.e., all the locations of the tracked group, are plotted on maps at time intervals as the group moves, and then one calculates the total distance as the sum of the distances between successive chronologic points (Isbell *et al.* 1999). Straight-line distance between 2 geographical sites, e.g., between adjacent mornings (Su *et al.* 1998) or between 2 consecutive night nests (Goodall 1977), is habitually used as a substitute for the actual pathway traveled to measure the travel costs of free-ranging primate groups (Altmann and Altmann 1970; Isbell 1983; Kirkpatrick 1996; Li 2002; Olupot *et al.* 1994). Johnson *et al.* (2003), Muoria *et al.* (2003), and Tarnaud (2006) studied demographic management via a GPS collar and tested feasibility of using GPS collars in free-ranging nonhuman primates (Phillips *et al.* 1998; Sprague *et al.* 2004), but no research team had employed a GPS collar to estimate the daily travel length in free-ranging primates until our study.

Measurements of day range raise several practical problems: How does one choose an appropriate method? How many fixes of the group are needed to estimate daily ranging distance reliably? At least how many monthly full-day follows are required?

Most diurnal, forest-dwelling, nonhuman primates exhibit a typical daily traveling and foraging pattern: After leaving the sleeping site in the morning, the primates head toward the first feeding site, then to the resting site for a routine siesta, then to the second feeding site, and finally to the sleeping site in the evening (Jolly 1985). Snub-nosed monkeys follow similar traveling patterns (Bai *et al.* 1988; Chen *et al.* 1983; Ding and Zhao 2004; Hu *et al.* 1980; Liu 1959; Long *et al.* 1998).

Only 13 semi-isolated natural groups of Yunnan snub-nosed monkeys inhabit northwestern Yunnan and southeastern Tibet (Long *et al.* 1996; Xiao *et al.* 2003). The rugged topography and dense forests make tracking them difficult (Wu 1991). Published data on day range of wild groups of *Rhinopithecus bieti* are scarce, and sample sizes were limited (Kirkpatrick 1996; Liu *et al.* 2004).

We employed GPS collar technology to monitor a free-ranging group of *Rhinopithecus bieti* on Mt. Laojunshan, Yunnan Province, China, from December 2003 to October 2004. Our objectives were 1) to calculate their daily ranging distances, 2) to compare day-range estimates calculated via different methods, and 3) to find a standard to measure day range of *Rhinopithecus bieti*.

Methods

Study Site and Subjects

Jinsichang (99°37′ E, 26°53′ N) lies in the eastern part of the geographic distribution of *Rhinopithecus bieti* (Xiao *et al.* 2003). The vegetation is continuous primary coniferous forests with fir (*Abies* spp.), larch (*Larix* spp.), spruce (*Picea* spp.), and alpine rhododendra (*Rhododendron* spp.) as the dominant species. The group confined its ranging to the forest belt between 3000 m and 3800 m above sea level (asl), an area densely covered with bamboo (*Fargesia* spp.).

Yang (2000) estimated that in 1997 and 1998, the group of *Rhinopithecus bieti* at Jinsichang contained 51 individuals We relocated the same group in July 2003 and found it contained *ca.* 180 individuals (Long *et al.* 1996). In most cases, the group moved and rested unobtrusively.

Subject Capture and Release

We used 2 types of collars (Telonics Inc., Mesa, AZ). One is a store-on-board GPS collar (type: TGW-3800; mass: 890 g) with a VHF beacon. The other is an ST-20 (mass: 740 g) Argos collar with a VHF beacon. Each collar has an autorelease function.

On December 17, 2003, we captured 2 healthy adult males at 1632 h with big tuck nets, fitted them with collars, and released them at 16:43, ≤11 min after capture. The subjects then immediately ran back to the group. We later noted the collared male with GPS transmitter to be the breeding male of a 1-male unit.

Data Collection

Data stored in the GPS collar included horizontal geographic positions of the individual, altitude, date, time, number of satellite signals, dilution of precision

(DOP), programmed timetable to obtain a fix, and ambient temperatures when we positioned a fix. The GPS collar acted in auto 2D/3D mode, i.e., when ≥4 satellite signals were available, we obtained a 3D fix —horizontal position and altitude; if we detected only 3 satellite signals, the collar recorded a 2D fix (horizontal position only). After transferring the fixes to a computer, we refined the elevation of each 2D fix via the elevation of spatial adjacent 3D fixes. We then adjusted 2D fixes into a reliable 3D fix (Rempel *et al.* 1995).

We programmed the collar to attempt GPS readings (fixes) at the following times daily: 0800, 1000, 1500, 1700, and 1900 h. The times roughly correspond to the first sleeping site, morning feeding site, resting site, afternoon feeding site, and second sleeping site, respectively (Ding and Zhao 2004; Long *et al.* 1998). We attempted no fix around noon because of the known propensity for the species to take a midday siesta. We programmed both collars to fall off at specific dates and times. Based on the expected power lifetime, we set the GPS collar to release at 0800 h on October 22, 2004. We obtained fixes via the GPS collar over 310 running days. The total number of attempted fixes is 1550.

The GPS collar also provided several values of the DOP. DOP represents the geometric configuration of satellites with respect to the GPS collar. A greater angle between the satellites lowers the DOP value —which ranges from 1 to infinity— and provides a more accurate measurement. A higher DOP value indicates poor satellite geometry and an inferior measurement configuration (Phillips *et al.* 1998). We set the maximum DOP value at 6. We discarded fixes if their DOP values were >6.

Statistical Analysis

We downloaded fixes saved by the GPS collar and mapped them via ArcView® 3.2a (ESRI, Redlands, CA). We had previously digitized a map of the study area (1:50,000) via the ArcView 3.2a platform. We took a SPOT5 satellite image in November 2004 —60 km×60 km, resolution: 2.5 m, unified the georeference of subjects via the projection of WGS_1984_UTM_ZONE_47N. Accordingly, we converted all GPS positions from latitude-longitude coordinates to UTM map coordinates. We calculated interfix distances in ArcView 3.2a via the Animal Movement Extension V.1.1 (Hooge and Eichenlaub 1997). We then imported the data into Microsoft Excel®, and performed statistical analyses in SPSS 11. Distances (m) of day range are means ± standard deviation (SD).

To conform to the calculating formulae of 2-point straight-line day ranges, we constructed 2-point distances from component time intervals available in the total data set. The constructed distances D-h-h are in Fig. 1: h-h is the time interval between the former and the latter hour, and D is the displacement from the point at the former hour to the point at the latter hour. For instance, we marked the straight-line distances between 2 consecutive morning (sleeping) sites at 0800 h as D08–08. We used a 24-h day scale and a ≤12-h day scale to compare differences between distances calculated within the 2 time intervals of a day scale.

D08-10-19 and D08-15-19 are 3-point cumulative distances, constructed from time intervals available in the total data set for a further comparison between the raw multipoint cumulative distances and the constructed 2-point straight-line distances.

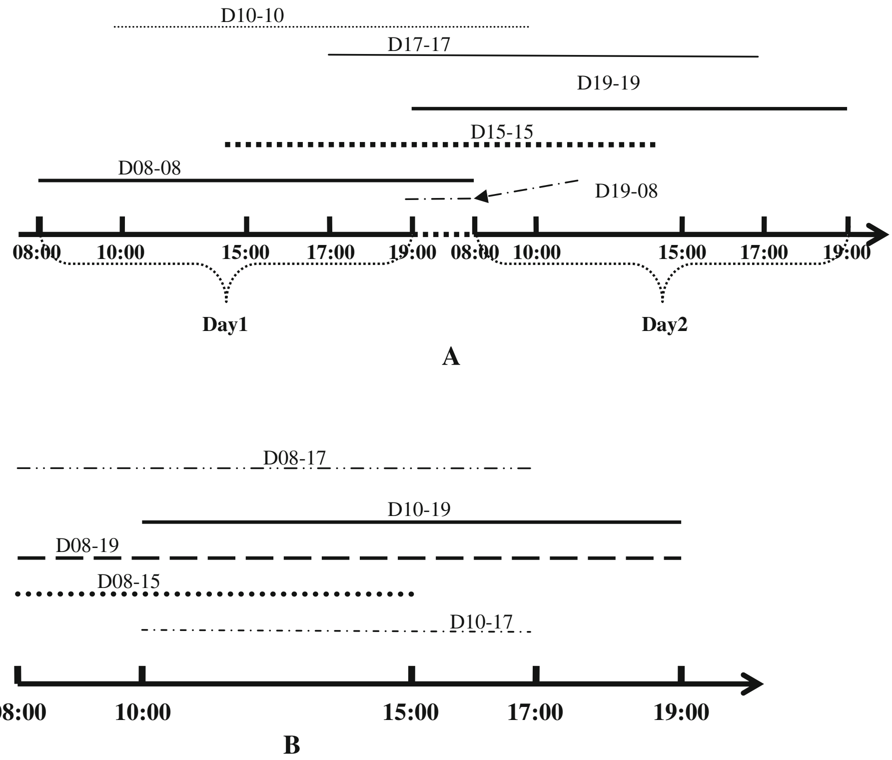

Fig. 1 All the different time intervals used to calculate two-point straight-line distances are illustrated and the labeling for each constructed distance is given above each line. Two consecutive days are sketched in the top figure (A), and the dotted line on the X axis indicates the night time between day 1 and day 2. A 12-hour day is illustrated in the figure at the bottom (B).

We calculated multipoint cumulative daily ranging distances with varying numbers of locations, depending on the number of fixes on any given day. D-x corresponds to the days on which we obtained *x* fixes. D-5, D-4, and D-3 are the raw sums of the fixes obtained via the GPS collar on each day. D-2 is the 2-point displacement on days with only 2 fixes.

We used independent samples *t*-test and 1-way ANOVA to compare differences between and among the means of daily ranging distances computed from different criteria. All tests are 2-tailed with a default significance level at $p=0.05$.

Results

Positions of the Group via the GPS Collar

We excluded 276 fixes because of a DOP value >6. In total, we obtained 1274 valid geographic locations of the group: the number of days with 5 fixes is 127; 4 fixes on 112 d, 3 fixes on 51 d, and 2 fixes on 19 d. The average number of satellites is 3.7, with a range: 3–6, $n=1274$). We acquired 763 2-dimensional (2D) fixes and 511 3-

dimensional (3D) fixes. 2D fixes account for 59.9% of the total 1274 fixes, and 3D fixes make up 40.1%. 2D fixes and 3D fixes do not randomly distribute among the various temporal intervals: $\chi^2=49.8$, df=1, $p=.000$. The total acquisition rate —number of locations obtained/number of locations attempted— of the GPS collar is 82.2% (1274/1550).

Daily Ranging Distance Calculated with Different Criteria

A 100-m distance is the minimum to judge whether the group has moved. With the exception of distances <100 m, all 2-point straight-line displacements in 24 h —e.g., D08–08— 2-point straight-line distances —e.g., D08–19, D-2— and multipoint cumulative daily ranging distances —e.g., D–5, D–4, and D–3— in ≤12 h are in Table I. We provide standard deviation (SD), sample size *n*, minimum, maximum, and breakdown of the time intervals (in h) of each mean distance.

Statistical results of the day range comparisons for the 24-h interval, ≤12-h interval, and all other intervals, are in Table II. There is no significant difference among D08–08, D–15–15, D–10–10, D–17–17, and D–19–19 —1-way ANOVA: $F_{4,\ 1008}=0.762$, $p=0.550$— and among D–5, D–4, and D–3: 1-way ANOVA: $F_{2,\ 285}=0.973$, $p=0.379$). D08–08, D–10–10, D–15–15, D–17–17, and D–19–19 comprise 1 whole data

Table I Estimates of mean daily ranging distances of *Rhinopithecus bieti* at Jinsichang based on different time intervals and measures[a]

Category	Distances	Mean ± SD (m)	n (d)	Min (m)	Max (m)	Breakdown of the intervals (h)
Two-point, straight-line displacement ≤24 h	D08–08	553±417	186	104	2699	24
	D–10–10	548±378	236	101	2663	24
	D–15–15	522±326	158	103	1562	24
	D–17–17	549±357	196	112	2233	24
	D–19–19	545±393	237	100	2886	24
	D–19–08[b]	127±109	213	4	592	13
Two-point straight-line distance ≤ 12 h	D08–19	539±372	210	101	2602	11
	D08–15	388±278	168	104	2786	7
	D08–17	301±207	158	104	1138	9
	D–10–19	448±309	173	101	2405	9
	D–2	553±339	17[c]	120	1103	4.8 (range: 2–9)
Multipoint cumulative daily ranging distance ≤ 12 h	D–3	880±497	51[c]	280	3271	4.26 (range: 2–9)
	D–4	889±459	110	249	2594	3.43 (range: 2–7)
	D–5	962±454	127	383	3626	2.75 (range: 2–5)
	D08–10–19	863±364	193	104	2984	11
	D08–15–19	895±374	161	129	3000	11

[a] That is, 2-point, straight-line displacement ≤24 h and multipoint cumulative daily ranging distance within 12 h. D–5, D–4, and D–3 denote the multisite cumulative daily ranging distances based on 5, 4, and 3 locations during the daytime. D–2 is the 2-point displacement on days with only 2 available fixes. The other distances were constructed from time intervals available in the data set (Fig. 1).

[b] D–19–08 is an overnight interval.

[c] Sample sizes are very small compared with the others.

5 h was the time interval between the GPS fixes at 1000 and 1500 h; the remaining adjacent scheduled fixes were broken down by 2 h.

Table II Comparisons of daily ranging distances (mean ± SD in m) calculated with different time intervals[a]

Category		Ranging distances ≤24 h				
		D08–08	D–10–10	D–15–15	D–17–17	D–19–19
Ranging distances within 12 h	D08–19	p=0.191	p=0.798	p=0.652	p=0.769	P=0.869
	D08–17	p=0.000	p=0.000	p=0.000	p=0.000	P=0.000
	D08–15	p=0.000	p=0.000	p=0.000	p=0.000	P=0.000
	D–10–19	p=0.001	p=0.013	p=0.035	p=0.012	P=0.019
	D08–10–19	p=0.000	p=0.000	p=0.000	p=0.000	P=0.000
	D08–15–19	p=0.000	p=0.000	p=0.000	p=0.000	P=0.000
	D–2	p=0.068	p=0.125	p=0.153	p=0.104	P=0.149
	D–3	p=0.000	p=0.000	p=0.000	p=0.000	P=0.000
	D–4	p=0.000	p=0.000	p=0.000	p=0.000	P=0.000
	D–5	p=0.000	p=0.000	p=0.000	p=0.000	P=0.000

Note that D–5, D–4, and D–3 denote the multisite cumulative daily ranging distances based on 5, 4, and 3 locations during the daytime. D–2 is the 2-point displacement on days with only 2 available fixes. The other distances were constructed from time intervals available in the data set (Fig. 1).

[a] Reflecting 24-h two-point, straight line distance, and ≤12 h 2-point, straight-line distance. We used an independent t-test to compare the means between different data sets.

set, and D–5, D–4, and D–3 another. There are significant differences between 24-h 2-point straight-line distances, e.g., D08–08, and ≤12-h multipoint cumulative distance, e.g., D–5; Table II).

Comparisons of daily ranging distances ≤12 h are in Table III. D08–08 approximates to D08–19 (*t* test: $t=1.311$, df=394, $p=0.191$). When a valid GPS fix is added between the 2 sleeping sites, D08–19 is changed to a 3-site cumulative distance, either D08–10–19 or D08–15–19. There is no significant difference between D08–10–19 and D08–15–19 (*t*-test: $t=-1.820$, df=354, $p=0.195$). Further, D08–10–19 and D08–15–19 are not significantly different from D–5, D–4, and D–3 (Table III).

The distances D08–19, D08–15, and D–10–19 are highly significantly different from one another (*t*-test, $p<0.05$, Table III). Both D08–15 and D–10–19 are very significantly different from D08–08 (*t*-test, $p<0.01$, Table II) and D08–19 (*t*-test, $p<0.05$, Table III).

We also calculated the overnight distance between the group's location at 1900 and 0800 h (D–19–08 in Fig. 1: the mean of D–19–08 is 127±109 m: range: 4–592 m; $n=213$.

Estimates of daily ranging distances vary depending on the number of fixes obtained via the GPS collar per day. Estimates of day range based on > 2 fixes are longer than those based on 2 fixes (*t*-test, $p=0.000$).

The sample size of D–3 is relatively small ($n=-51$). D–3 does not significantly differ from other multipoint cumulative distances, regardless of whether the distances are raw data, e.g., D–4 or D–5, or constructed distances, e.g., D08–10–19 and D08–15–19; Table III). On 19 positioning days, only 2 sites are fixed via the GPS collar: 17 d after excluding distances <100 m. This 2-site distance is marked as D–2. There is no significant difference between D–2 and D08–19, D08–15, D08–17, and D–10–19 (Table III). D08–08 does not differ significantly from D–2.

Table III Comparisons of ranging distances calculated with different time intervals and measures within 12 h by independent t-test (p-value)

	D08–15	D08–17	D–10–19	D08–10–19	D08–15–19	D–2	D–3	D–4	D–5
D08–19	p=0.000	p=0.000	p=0.029	p=0.000	p=0.000	p=0.146	p=0.000	p=0.000	p=0.000
D08–15		p=0.002	p=0.010	p=0.000	p=0.000	p=0.825	p=0.000	p=0.000	p=0.000
D08–17			p=0.000	p=0.000	p=0.000	p=0.067	p=0.000	p=0.000	p=0.000
D–10–19				p=0.000	p=0.000	p=0.423	p=0.000	p=0.000	p=0.000
D08–10–19					p=0.195	p=0.000	p=0.896	p=0.973	p=0.204
D08–15–19						p=0.000	p=0.902	p=0.971	p=0.207
D–2							p=0.000	p=0.000	p=0.000
D–3								P=0.910	p=0.287
D–4									p=0.216

Note: D–5, D–4, and D–3 denote the multisite cumulative daily ranging distances based on 5, 4, and 3 locations during the daytime. D–2 is the 2-point displacement on days with only 2 available fixes. We constructed the other distances from time intervals available in the data set (Fig. 1).

Discussion

Suitability of GPS Collar in Yunnan Coniferous Forests

The choice of an appropriate set of tracking devices is of major concern. Becoming familiar with the applicability and shortcomings of the tracking instrument is essential before performing the study (White and Garrott 1990). We decided to apply GPS tracking primarily because of the enormous difficulty of following the unhabituated snub-nosed monkey group on foot. Satellite reception, and hence location accuracy, determines whether GPS technology is a suitable tool. The reception of the GPS collar is seriously attenuated by thick vegetation (Phillips *et al.* 1998; Sprague *et al.* 2004). We achieved a total acquisition rate of 82.2%, which is lower than that in a temperate forest at fixed locations at the James H. Barrow Field Station, Hiram College, OH (*ca.* 97%, Phillips *et al.* 1998). Acquisition rate in our study was higher than that in a study on Japanese macaques (20%: Sprague *et al.* 2004) and at fixed locations in neotropical forests of Costa Rica and Trinidad (34%: Phillips *et al.* 1998). We conclude that GPS collars are useful tools to track snub-nosed monkeys in their high-altitude habitat with complex terrain and dense conifer forests.

Estimating Daily Ranging Distances

Various methodologic factors have a pronounced effect on the estimate of daily ranging distance in *Rhinopithecus bieti*: definition of a day —12-h vs. 24-h day— time intervals, number of obtained fixes per day, and number of tracking days per mo.

The distances covered between 0800 h and 1900 h (D08–19) and between 0800 h and 1500 h (D08–15) are significantly different from each other. D–10–19 and D08–19 are also different. Hence, D–10–19 and D08–15 are not reliable estimates of day range. The variation was likely caused by extensive foraging or moving after 1500 h and before 1000 h, respectively (Ding and Zhao 2004; Long *et al.* 1998). However, in line with Bai *et al.* (1988) and Long *et al.* (1998), nighttime sleeping sites and daytime resting sites were rather fixed points in the daily activity cycle of *Rhinopithecus bieti*.

Daily ranging distances, calculated from 2 consecutive points ≤24 h (D08–08), and from 2 points ≤12 h (D08–19), are not significantly different, confirming that the group of *Rhinopithecus bieti* did not move after sunset. After entering the sleeping site, groups of *Rhinopithecus* rarely change their positions, and they can be relocated at the same place the following morning (*R. roxellana*: Hu *et al.* 1980; Li *et al.* 2000; Liu 1959; Ren 1999; *R. brelichi*: Yang *et al.* 2002; *R. bieti*: Xiang 2005). Distances between 2 locations at the same hour ≤24 h, e.g., D08–08, D–10–10, D–15–15, D–17–17, and D–19–19, and distances between the morning and evening sleeping site in the daytime, e.g., D08–19, can substitute for one another. The observation that the group covered a short distance during the interval D–19–08 –<130 m— further confirms that points at 0800 h and 1900 h are sleeping sites. In case we are unable to locate the morning and evening sleeping site ≤12-h day (daytime), we can instead position the locations at the same hour on 2 adjacent days, e.g., D–17–17, to estimate day range.

Estimates of daily ranging distances based on 2-point straight-line displacements were 43% shorter than those based on cumulative multiple sites in *Rhinpoithecus bieti.* We thus conclude that the multipoint cumulative daily ranging distance is a far more reliable estimate of day range and associated travel costs (Isbell *et al.* 1999).

We employed a 5-point cumulative ranging distance as an estimate of day range. Ideally, we could have determined the daily travel distances via continuously recording GPS readings; however, the procedure requires enormous storage and battery power, which is not available in this application. As a result, we were limited to taking readings 5 times per day. Moreover, we attempted the 5 readings at times previously determined to be important in the monkeys' activity schedule, i.e., sleeping, resting, and feeding sites, as preliminarily evaluated (Ding and Zhao 2004; Long *et al.* 1998). We did not consider possible seasonal changes in activity budgets. Estimates of cumulative daily ranging distances based on 3, 4, and 5 fixes (D–3, D–4, and D–5) are not significantly different. Our results thus suggest that 3 fixes per day are sufficient to study day range of *Rhinopithecus bieti*: however, 5 fixes would be ideal.

The cumulative 3-point daily ranging distance based on the distance between morning sleeping site and daytime resting site, e.g., D08–15, plus distance between daytime resting site and evening sleeping site, e.g., D–15–19, can be an economic method to estimate the day range of *Rhinopithecus bieti*. If one cannot locate the study group at the fixed hours e.g., punctually at 0800 or 1500 h, etc.— then one can alter the schedule; if the resting site had been recorded, then one can also use 1 geographic position in the morning, before 12:00, and another in the evening to estimate the day range.

On some days, the study group stayed in 1 valley for a whole day and did not engage in long-distance movement. Nevertheless, we recorded traveled distances from the collared individual on those days. The day ranges of individuals and of the group can be very different in some nonhuman primates (Isbell *et al.* 1999). Thus it is necessary to set a minimum distance to judge whether the group has moved. We set the minimum distance at 100 m. Based on our observations, a group member seldom moved >50 m horizontally when the group was resting. When an individual moved >100 m, this usually resulted in the departure of the whole group. Thus we did not include distances <100 m in the calculation of day range.

Another problem concerns the number of days that should be spent each month tracking the study group to achieve a reliable estimate of the group's mean day range. Some earlier studies adopted a 5-d observation period per mo to record the locations of the study group (Defler 1996; Harrison 1983), yielding a total sample size of 60 d in 12 mo. We obtained 1 data set (D–3) whose sample size was below 60 d (n=51 d) with higher S.D. (497 m). There is no significant difference among the mean cumulative day ranges, e.g., D–5, D–4, and D–3. We expected that the small sample size of D–3 would make the ranges not significantly different among D–5, D–4, and D–3. In addition, D–2 showed no significant difference from D08–19 and other 24-h, 2-point straight-line displacements. Long investigation days on the day range are needed to clarify suspicions about the effect of small sample size on ranges. We therefore speculate that 5 d/mo might not be enough time to obtain a sample size large enough to measure the day range accurately. We suggest that 10 tracking days per mo is the minimum requirement to obtain a total annual sample size of >100 d ranges.

Acknowledgments A grant from TNC China Program and funding from the National Natural Science Foundation of China (No. 30470310) and the Key Project of Natural Science Foundation of China (No. 30630016) supported our research. We thank our field assistants, Z. M. Zhang, Y. J. Zhang, and X. R. Yang, and R. D. Wu for the integration of many data sets into the ArcView system. We also appreciate R. D. Wu's help in calculating some basic parameters for our final analysis. The State Forestry Administration of China and the Forestry Bureau of Yulong County also supported the field work. We acknowledge the 2 anonymous reviewers and Daniel White for valuable comments and language editing.

References

Altmann, S. A., & Altmann, J. (1970). *Baboon Ecology: African Field Research*. Chicago, IL: University of Chicago Press.

Bai, S. C., Zou, S. Q., Lin, S., Tuo, D., Zhong, T., & Wang, X. H. (1988). An investigation of distribution, number and food habit of *Rhinopithecus bieti*. *Zoological Research*, *9*(Suppl.), 67–75.

Bennett, E. L. (1986). Environmental correlates of ranging behaviour in the banded langur, *Presbytis melalophos*. *Folia Primatologica*, *47*, 26–38.

Chen, F. G., Min, Z. L., Luo, S. Y., & Xie, W. Z. (1983). An observation on the behavior and some ecological habits of the golden monkey (*Rhinopithecus roxellana*) in Qinling Mountains. *Acta Theriologica Sinica*, *3*, 141–146.

Defler, T. R. (1996). Aspects of the ranging pattern in a group of wild wooly monkeys (*Lagothrix lagothricha*). *American Journal of Primatology*, *38*, 289–302.

DeVore, I., & Hall, K. R. L. (1965). Baboon ecology. In I. DeVore (Ed.) *Primate behavior: Field studies of monkeys and apes* (pp. 20–52). Boston: Harvard University Press.

Ding, W., & Zhao, Q. K. (2004). *Rhinopithecus bieti* at Tacheng, Yunnan: Diet and daytime activities. *International Journal of Primatology*, *25*, 583–589.

Fossey, D., & Harcourt, A. H. (1977). Feeding ecology of free-ranging mountain gorilla (*Gorilla gorilla beringei*).. In T. H. Clutton-Brock (Ed.) *Primate ecology: Studies of feeding and ranging behaviour in Lemurs, Monkeys and Apes* (pp. 415–447). London: Academic Press.

Gautier-Hion, A., Gautier, J. P., & Quris, R. (1981). Forest structure and fruit availability as complementary factors influencing habitat use by a troop of monkeys (*Cercophithecus cephus*). *Revue D Ecologie*, *35*, 511–536.

Goodall, A. G. (1977). Feeding and ranging behaviour of a mountain gorilla group (*Gorilla gorilla beringei*) in the Tshibinda-Kahuzi region (Zaïre). In T. H. Clutton-Brock (Ed.) *Primate Ecology: Studies of Feeding and Ranging Behaviour in Lemurs, Monkeys and Apes* (pp. 449–479). London: Academic Press.

Harrison, M. J. S. (1983). Patterns of range use by the green monkey, *Cercopithecus sabaeus*, at Mt. Assirik, Senegal. *Folia Primatologica*, *41*, 157–179.

Hooge, P. N., & Eichenlaub, B. (1997). *Animal movement extension to Arcview. Ver. 1.1., Alaska Science Center—Biological Science Office*. Anchorage, AK: U.S. Geological Survey.

Hu, J. C., Deng, Q. X., Yu, Z. W., Zhou, S. D., & Tian, Z. X. (1980). Ecological and biological research of the giant panda and golden-haired monkey. *Journal of Nanchong Teacher's College*, *2*, 1–29.

Isbell, L. A. (1983). Daily ranging behavior of red colobus (*Colobus badius tephrosceles*) in Kible forest, Uganda. *Folia Primatologica*, *41*, 34–48.

Isbell, L. A., Pruetz, J. D., Nzuma, B. M., & Young, T. P. (1999). Comparing measures of travel distances in primates: Methodological considerations and socioecological implications. *American Journal of Primatology*, *48*, 87–98.

Johnson, A., Singh, S., Doungdala, M., Chanthasone, B., Namsombath, T., & Hedemark, M. (2003). *A preliminary survey for gibbon and other primates in the Nam Ha National Protected Areas, Lao PDR, February 2004*. Vientiane, Laos: Wildlife Conservation Society.

Jolly, A. (1985). *Evolution of primate behavior* pp. 87–114. New York: Macmillan Publishing Company.

Kirkpatrick, R. C. (1996). Ecology and behavior of the Yunnan snub-nosed langur (*Rhinopithecus bieti*, Colobinae). Dissertation, University of California, Davis, pp. 39–67.

Koenig, A., Borries, C., Chalise, M. K., & Winkler, P. (1997). Ecology, nutrition, and timing of reproductive events in an Asian primate: Hanuman langur (*Prestybis entellus*). *Journal of Zoology, London*, *243*, 215–235.

Li, B. G., Chen, C., Ji, W. H., & Ren, B. P. (2000). Seasonal home range changes of the Sichuan snub-nosed monkey (*Rhinopithecus roxellana*) in the Qinling Mountains of China. *Folia Primatologica*, *71*, 375–386.

Li, Y. M. (2002). The seasonal daily travel in a group of Sichuan snub-nosed monkey (*Pygathrix roxellana*) in Shennongjia Nature Reserve, China. *Primates*, *43*, 271–276.

Liu, S. F. (1959). A preliminary investigation of the golden monkey in Qinling Mountains (in Chinese with English abstract). *Journal of Northwest University*, *3*, 19–26.

Liu, Z. H., Ding, W., & Grüter, C. C. (2004). Seasonal variation in ranging patterns of Yunnan snub-nosed monkeys *Rhinopithecus bieti* at Mt. Fuhe, China. *Acta Zoologica Sinica*, *50*, 691–696.

Long, Y. C., Kirkpatrick, C. A., Xiao, L., & Zhong, T. (1998). Time budgets of the Yunnan snub-nosed monkey (*Rhinopithecus* (*Rhinopithecus*) *bieti*). In N. G. Jablonski (Ed.) *The natural history of the Doucs and Snub-nosed Monkeys* (pp. 279–289). Singapore: World Scientific Publishing.

Long, Y. C., Kirkpatrick, C. R., Zhong, T., & Xiao, L. (1996). Status and conservation strategy of the Yunnan snub-nosed monkey (in Chinese). *Chinese Biodiversity*, *4*, 145–152.

McKey, D. B., & Waterman, P. G. (1982). Ranging behaviour of a group of black colobus (*Colobus satanus*) in the Douala-Edea Reserve, Cameroon. *Folia Primatologica*, *36*, 76–98.

Muoria, P. K., Karere, G. M., Moinde, N. N., & Suleman, M. A. (2003). Primate census and habitat evaluation in the Tana delta region, Kenya. *African Journal of Ecology*, *41*, 157–163.

Olupot, W., Chapman, C. A., Brown, C. H., & Waser, P. M. (1994). Mangabey (*Cercocebus albigena*) population density, group size, and ranging: A twenty-year comparison. *American Journal of Primatology*, *32*, 197–205.

Phillips, K. A., Elvey, C., & Abercrombie, C. L. (1998). Applying GPS to the study of primate ecology: A useful tool? *American Journal of Primotology*, *46*, 167–172.

Rempel, R. S., Rodgers, A. R., & Abraham, K. F. (1995). Performance of a GPS animal location system under boreal forest canopy. *Journal of Wildlife Management*, *59*, 543–551.

Shi, D. C., Li, G. H., & Hu, T. Q. (1982). Preliminary studies on the ecology of the golden-haired monkey. *Zoological Research*, *3*, 105–110.

Shimooka, Y. (2005). Sexual differences in ranging of *Atelis belzebuth belzebuth* at La Macarena, Colombia. *International Journal of Primatolology*, *26*, 385–406.

Sigg, H., & Stolba, A. (1981). Home range and daily march in a Hamadryas baboon troop. *Folia Primatologica*, *36*, 40–75.

Sprague, D. S., Kabaya, H., & Hagihara, K. (2004). Field testing a global system (GPS) collar on a Japanese monkey: Reliability of automatic GPS positioning in a Japanese forest. *Primates*, *45*, 151–154.

Steudel, K. (2000). The physiology and energetics of movement: Effects on individuals and groups. In S. Boinski, & P. A. Garber (Eds.) *On the move: How and why animals travel in groups* (pp. 11–23). Chicago: University of Chicago Press.

Stevenson, P. R., Quinones, M. J., & Ahumada, J. A. (1994). Ecological strategies of woolly monkeys (*Lagothrix lagotricha*) at Tinigua National Park, Colombia. *American Journal of Primatology*, *32*, 123–140.

Su, Y. J., Ren, R. M., Yan, K. H., Li, J. J., Zhou, Y., Zhu, Z. Q., et al. (1998). Preliminary survey of the home range and ranging behavior of golden monkeys (*Rhinopithecus* (*Rhinopithecus*) *roxellana*) in Shennongjia Natural Reserve, Hubei, China. In N. G. Jablonski (Ed.) *The natural history of the Doucs and Snub-nosed Monkeys* (pp. 255–268). Singapore: World Scientific Publishing.

Tarnaud, L. (2006). Cathemerality in the Mayotte Brown lemur (*Eulemur fulvus*): Seasonality and food quality. *Folia Primatologica*, *77*, 166–177.

White, G. G., & Garrott, R. A. (1990). *Analysis of wildlife radio-tracking data*. San Diego: Academic Press.

Wu, B. Q. (1991). Survey and analysis of feeding habits of *Rhinopithecus bieti* (in Chinese). *Acta Anthropologica Sinica*, *10*, 357–371.

Xiang, Z. F. (2005). *The Ecology and Behavior of Black-and-White Snub-nosed Monkeys* (*Rhinopithecus bieti*, Colobinae) *at Xiaochangdu in Honglaxueshan National Nature Reserve, Tibet, China* (dissertation). Kunming, China: Kunming Institute of Zoology, Chinese Academy of Sciences, pp.83–98.

Xiao, W., Ding, W., Cui, L. W., Zhou, R. L., & Zhao, Q. K. (2003). Habitat degradation of *Rhinopithecus bieti* in Yunnan, China. *International Journal of Primtatology*, *24*, 389–398.

Yamagiwa, J., & Mwanza, N. (1994). Day-journey length and daily diet of solitary male gorillas in lowland and highland habitats. *International Journal of Primatology*, *15*, 207–224.

Yang, S. J. (2000). *Habitat, diet, range use and Social Organization of Rhinopithecus bieti at Jinsichang* (dissertation in Chinese). Kunming, China: Kunming Institute of Zoology, Chinese Academy of Sciences.

Yang, Y. Q., Lei, X. P., & Yang, C. D. (2002). *Ecology of the wild Guizhou Snub-nosed Monkey* pp. 1–5. Guiyang: Guizhou Science and Technique Publishing House.