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Censusing populations of white-headed langurs on limestone hills: problems and solutions

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ABSTRACT: Endangered white-headed langurs *Trachypithecus leucocephalus* (leaf monkeys) live on limestone hills in southwestern Guangxi, China. This terrain is unsuitable for using published census techniques to estimate langur population density, and the precision of unpublished techniques used in the past is unproven; yet reliable estimates are crucial for conservation planning. In this paper, we discuss existing censusing techniques in the context of their potential suitability for estimating the population of white-headed langurs; we introduce methods for partition-spot surveys and modified line-transect sampling; we validate the resulting data and recommend 2 techniques for future use. We show that partition-spot surveys provide accurate information on the number of langurs and their locations, but that modified line-transect sampling is more time-efficient. While validating our techniques, we documented an increase in the langur population of one hill cluster between 1998 and 2003.

KEY WORDS: Censusing · China · Conservation · Limestone hills · White-headed langurs

INTRODUCTION

White-headed langurs live on limestone hills in 3 nature reserves (Fusui, Chongzuo and Longgang) in southwestern Guangxi, China (Li et al. 2003), where they are highly endangered due to small population size, habitat fragmentation and restricted distribution (Huang et al. 2002, Li et al. 2003). They are currently included as a subspecies of *Trachypithecus poliocephalus* (*T. p. leucocephalus*), and are regarded by Conservation International and the International Primatological Society as one of the 25 most endangered primate species in the world (Mittermeier et al. 2005). The crucial importance of efforts to conserve them has been stressed by Huang et al. (2002), who estimated that the current world population is about 600, confined to 200 km^2 of habitat. However, the precision of existing techniques for conducting population censuses in limestone hill terrains is untested, so reliable population monitoring has so far been impossible.

A variety of systematic techniques have been developed for censusing primate populations (SCNP 1981, Brockelman & Ali 1987, Whitesides et al. 1988, Buckland et al. 1993, Plumptre 2000, White & Edwards 2000, Davies 2002, Plumptre & Cox 2006), of which line-transect sampling is by far the most widely used. Population density is estimated using data on the area sampled, the mean frequency of encounters with animals or indirect signs, and the mean number encountered. Because of the time and cost of doing detailed line transect sampling, a simplified procedure, known as 'recce' walks, has recently been proposed for censusing large mammals (White & Edwards 2000). This field procedure is similar to line transect sampling, except that surveyors walk along pre-existing paths or follow a path of least resistance, instead of cutting straight lines, and do not measure perpendicular distance. This technique yields indices of population density, but not the population density per se; however, data from recce walks and line transect sampling in the same area are significantly correlated (White & Edwards 2000, Plumptre & Cox 2006). Another variant of line transect sampling – sweep surveys – involves a number of surveyors working simultaneously along parallel transects, who record

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the position and time of all sightings of primates and their calls. This method is useful in small, known survey areas, where a total count is feasible, but it is very labour intensive (White & Edwards 2000).

Applying existing systematic techniques to white-headed langurs has been problematic, because of the vertical cliffs on which they live. Accordingly, different estimates of population size have emerged from data collected at the same time but using different techniques (Huang et al. 2003a), such as cave counts (W. S. Pan pers. comm.), observations and interviews (Huang et al. 2002), partition-spot surveys (PSS), and modified line-transect sampling (MLTS) (Li 2003). The problem with using line-transect sampling for censusing the cliff-dwelling langurs is that the theory behind it depends on randomising the position of the transect line, which is impossible since much of the habitat is inaccessible. However, during fieldwork over the past 10 yr, we have developed a way to modify the technique, so that it is applicable to the langurs in this unusual landscape. In this paper, we validate 2 techniques for censusing langurs using data we collected in the field, and recommend them for future censusing of langurs and other primates in limestone hill habitat. We also document an increase in the white-headed langur population, and discuss the likely reasons for it.

STUDY SITE AND METHODS

Limestone topography. The limestone in South China was formed in the Devonian by deposition of calcium and magnesium carbonate in the ancient ocean (Guangxi Provincial Forestry Department 1993). Water has eroded the limestone blocks into clusters of hills, each cluster coinciding with a limestone block, with distance between the blocks varying from 1 to 10s of kilometres. Erosion has cut the blocks to different depths, forming cliffs and V-shaped valleys from 100 to 420 m deep (Li 2000). Soil developed in the Mesozoic has been deposited in the deeper valleys between the hills. This process has formed 2 typical landscapes: in Type I, hills are largely interconnected at a high level (Fig. 1), so that the landscape looks like a honeycomb from above with the valleys as comb cells; in Type II, hills are interspersed by flat ground. Accordingly, most areas in Type I are not accessible by humans and only a few paths reach the valleys inside the hill clusters. Valleys in Type II are accessible, with a slope at the foot of most hills, and cliffs from about halfway up. Foothills can be 10s of meters from one side to the other, but hilltops are in most cases only 1 to 2 m wide. Both landscape types appear in different proportions in different hill clusters.

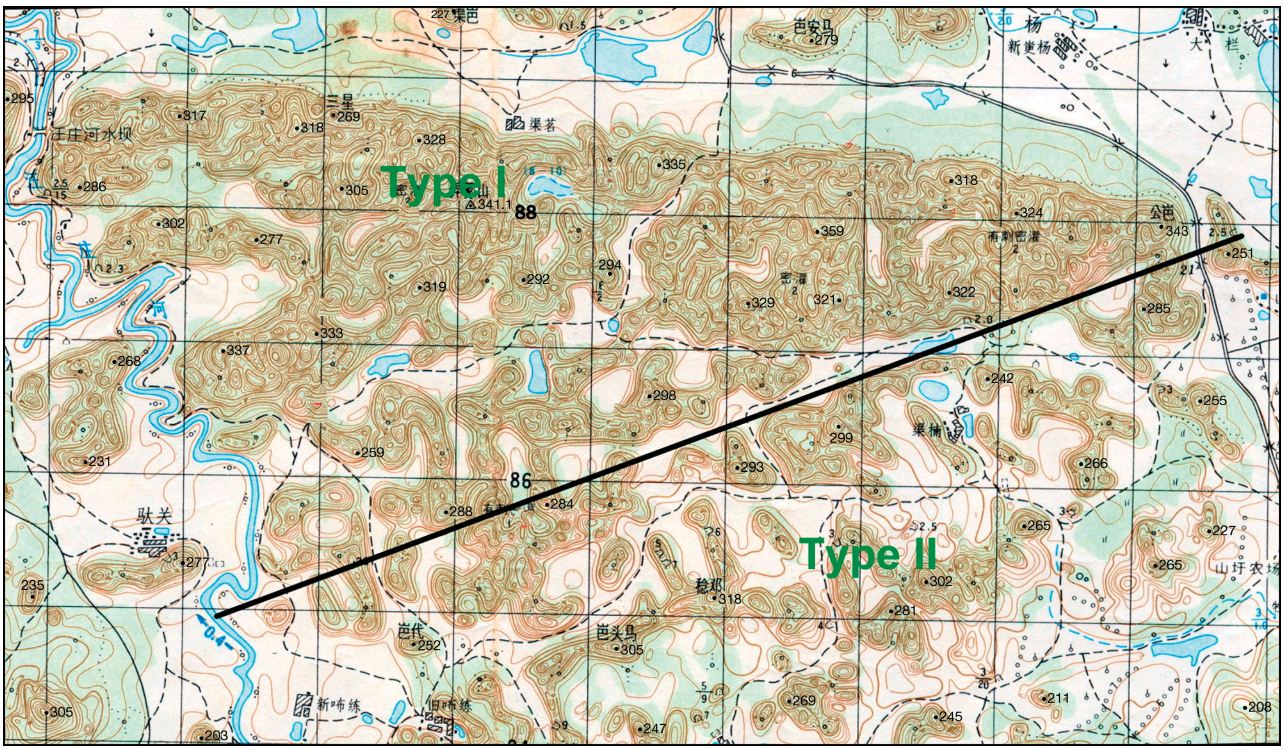

Fig. 1. Topographic map of limestone hills in the LGS cluster (19.8 km^2) in the Fusui Nature Reserve, southwestern Guangxi, China. A typical Type II landscape is shown below the black diagonal line; a largely Type I landscape, with less (about 1/6) of Type II, shown above the black line. Grid cells are 1 km^2; dashed lines are paths. For description of landscape types, see 'Study site and methods'

At the bottom of the valleys, deep soil has been deposited and is suitable for agricultural use, but on the foothill slopes the soil is thin, and unsuitable for agriculture. Higher up there are only occasional pockets of soil. Only the flat ground and foothills hold surface water. Because of the distribution pattern of soil and surface water, large trees grow on the low flat ground, and medium-sized trees on the slopes. Cliffs and hilltops are sparsely vegetated with small bushes. Humans have been cultivating the ground in southwestern Guangxi for at least 2000 yr. All the flat ground in the Type II landscape has been cultivated for subsistence agriculture. Natural habitat is available only on the limestone hills, including the foothill slopes, cliffs, and hilltops, but the foothill slopes are the major habitat for white-headed langurs and other wildlife (Li & Rogers 2005a). Because of the disappearance of natural vegetation on the flat ground, the habitat of white-headed langurs, especially in landscape Type II, has been highly fragmented. It is naturally patchy in landscape Type I. Access for censusing is via paths along the edges between arable land and natural habitat and across the U-shaped connections between hills.

Censusing methods. Techniques previously used for censusing populations of white-headed langurs have included MLTS (Li 2003), PSS (Li & Shen 1982), observations and interviews (Huang et al. 2002), sweep surveys (Li 2000), and cave counts (W. S. Pan pers. comm.). The latter 3 techniques proved unsatisfactory in practice because: (1) Huang et al. (2002) gave no details of their methods or data precision, so we could not test their procedures. (2) Sweep surveys involved moving slowly along hilltops and on both sides of the section under survey. However, moving along hilltops is dangerous, so it is difficult to implement this technique routinely and, because of the practical difficulties of repeating surveys, the precision of the data could not be assessed. (3) Cave counts are derived from visible use of caves on cliffs by langur groups (Huang et al. 2003b), as determined by the presence of dung and urine on the rock at the cave entrance. This method suffers from severe observer bias, as observers differed greatly in their ability to distinguish caves used recently from unused caves, or those used long ago. Also, the number of caves varies greatly between the ranges of different langur groups. Thus, cave counts cannot be recommended unless they are based on more accurate and reproducible criteria.

Here, we detail the field methodology for PSS and MLTS. Our techniques were developed without use of GPS technology or sophisticated mapping and statistical software, a situation common to most wildlife managers in China.

PSS: In January and February 2003, we conducted population surveys in Fusui Nature Reserve (Li 2003), where there are 7 clusters of limestone hills (Fig. 1 in Li & Rogers 2005a). We used the PSS method in one cluster, LGS (19.8 km^2), where a total count was possible.

The survey area was first divided into 22 compartments on a topographic map (Fig. 2). The size of each compartment was determined by the range of a

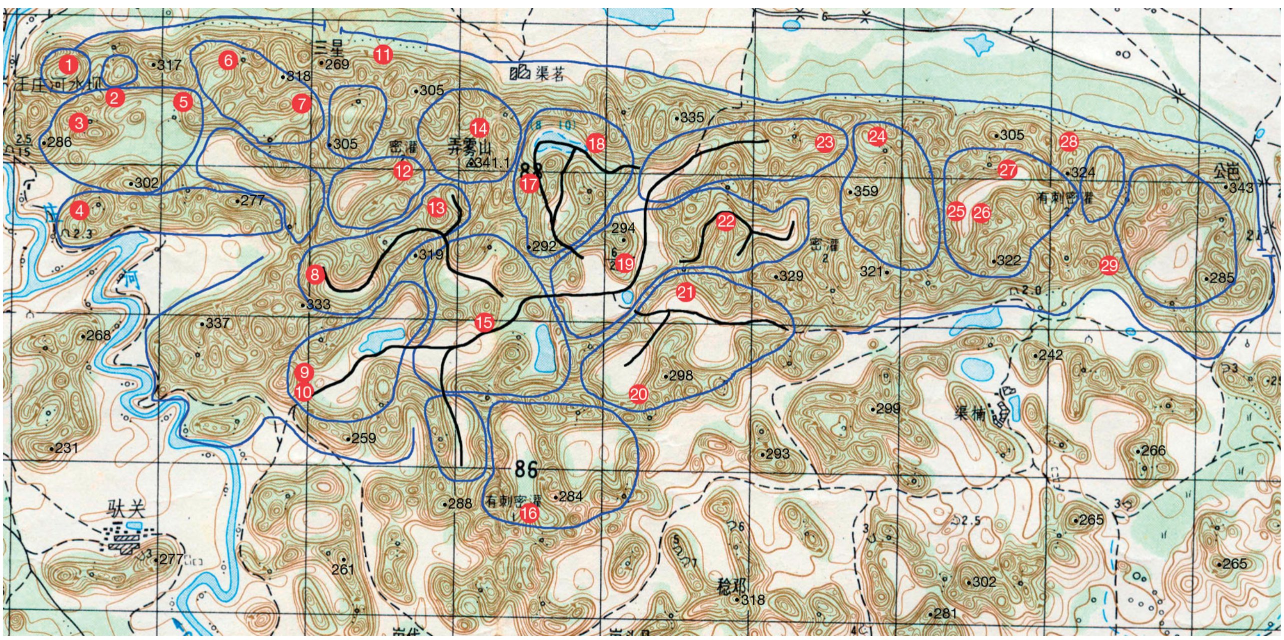

Fig. 2. Location of compartments for partition-spot surveys (PSS) in the LGS cluster in the Fusui Nature Reserve (blue lines), and the transect lines for modified line-transect sampling (MLTS) (bold lines). Grid cells are 1 km^2; dashed lines are paths. Red dots indicate the locations of langur *Trachypithecus leucocephalus* groups

field researcher's vision within it, accessibility, and distance between it and neighbouring compartments. Several surveyors worked together in the field, starting between 06:00 and 08:00 and finishing between 18:00 and 19:30 h. Each working group stayed all day in a compartment, moving around regularly within it and recording all langurs seen, any identifying features, time, and position. Some working groups also surveyed the outer sides of the hill cluster to avoid missing langurs invisible from inside the valleys. Neighbouring compartments were surveyed on the same day to avoid repeat counts of langur groups moving across the compartments. Field records were compared each night to identify the langur groups seen, and their positions were plotted on maps (scale 1/10 000). Several neighbouring compartments made up a section. A neighbouring section was surveyed on the next day until the whole study area was surveyed. This technique yielded data on the localities and number of langur groups, and group size, but data precision cannot be assessed if only one survey is conducted (see 'Discussion'). However, the technique does involve considerations of repeat counting and missed groups, which are the factors most often resulting in over- or underestimates of population size with non-systematic techniques.

MLTS: Two modifications to line-transect sampling were made: first, the transect lines were not placed randomly; instead, existing paths were used to traverse the area being sampled. In this respect, the technique was similar to recce walks (White & Edwards 2000). Second, transect width was not measured during sampling, because it was restricted by cliffs on both sides of valleys, but the width sampled could be determined post hoc on a map by the horizontal distance from the hilltop on one side to that on the other, and the area remained constant between transects. Therefore, this technique differed from recce walks, because it yielded data on the area surveyed and population density.

Fieldwork was conducted in the central area (5.32 km^2) of the limestone cluster LGS (Fig. 2) in March to September 1998 and January to February 2003. There were 5 paths available to cover the whole study site, which were used as transect lines. Surveyors were instructed to walk slowly along these, stopping every 200 m to search visually for langurs, and to listen for calls or the noise of movements in the trees. Each stop lasted for 20 min, because most langur groups could be detected in this time. Resting quietly for longer than 20 min tended to occur between 12:00 and 15:00 h, so we did not survey during this time (Li 2000). Langur groups on hilltops can be seen by surveyors on either side, so neighbouring areas were not covered at the same time, to minimize repeat counts of the same group. Upon detecting langurs, surveyors recorded the time of detection and the locations of the animals, thus further minimizing repeat counts on a single transect. A langur group often moved to a different site in the afternoon. Thus, 2 consecutive surveys on the same line were arranged on the same day, but one survey was completed in the morning and the other in the afternoon. Transects were repeated along the same paths at different times, and data precision depended on the number of repeats. The start and end points of a transect line were predetermined on a map, and these were not varied between replicate transects.

Based on the above field method, langur population density in the hill group LGS was estimated using the following calculations (SCNP 1981):

(1) The standard deviation of encounter frequency for langur groups (s):

$$s = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n-1}}$$

where x was the number of langur groups encountered on a single transect, n was the number of repeat surveys along a transect line, and n–1 the degrees of freedom.

(2) The mean frequency of encounters with langur groups (m):

$$m = \frac{x_1 + x_2 + \ldots + x_i}{n}$$

where i ranged from 1 to n.

(3) 95 % confidence limits (CL):

$$\mathrm{CL} = t_{0.05(n-1)} \times \frac{s}{\sqrt{n}}$$

where $t_{0.05(n-1)}$ was the 2-tailed value of t in Student's distribution when $p \leq 0.05$ and the degrees of freedom were n–1.

(4) Precision index for measuring the precision of population estimates; SCNP (1981) recommended the equation:

$$\%\ \text{precision} = \frac{\mathrm{CL}}{m} \times 100$$

This results in decreasing % precision with increasing precision of the estimates of population size. During fieldwork, the precision index was calculated daily and plotted against the cumulative number of repeats to determine a cut-off point for completion of sufficient repeat transects to achieve adequate precision.

(5) Estimate of group density (D_g):

$$D_g = \frac{m \pm \mathrm{CL}}{a}$$

where a was the area being sampled.

(6) Estimate of the total number of langur groups in the whole study area (G):

$$G = D_g \times A$$

where A was the size of the whole study area.

(7) Estimate of the population size in the whole LGS study area (N):

$$N = G \times mg$$

where mg was the mean group size. Mean group size was calculated from records obtained during MLTS, PSS, and from opportunistic observations. As data from the first source may result in over- or under-estimates of population size (see 'Discussion'), we used data collected in PSS.

RESULTS

PSS

We spent 6 d on the survey, with a team of 14 surveyors working full or part time in the field; thus, a total of 84 worker-days were invested. The survey was combined with a capacity building project to train reserve staff, so we assigned 2 people to each working group and each group stayed in one compartment each day. We recorded 30 langur groups plus 2 solitary males, numbering 233 langurs (Fig. 2; one small langur group not shown). The group density was 1.5 groups km^{-2}. Group size ranged from 2 to 20 langurs per group, with a mean of 7.8 langurs per group.

MLTS

During March to September 1998, each line was surveyed twice a month, so a total of 13 repeats were made along each line in the 6.5 mo. Table 1 shows that the data precision for each transect line was less than the precision overall (see 'Overall' column). However, there was no significant relationship between the area sampled and the precision index (Spearman rank correlation coefficient $r_S = 0.7714$, n = 6, 2-tailed, $p > 0.05$). The contribution of the area sampled to the variation of the data precision (= r_S^2) was 59.5%. Based on the overall data, we obtained an estimate of 19 ± 7 (i.e. 12 to 26) langur groups in LGS and 129 ± 48 (81 to 177) langurs, with a group density of 0.9 group km^{-2} and a precision index of 39.4%. The precision index decreased, and precision of the estimates increased, with the cumulative number of repeat transects (Fig. 3).

Table 1. *Trachypithecus leucocephalus.* Estimates of the population size of white-headed langurs in the LGS hill cluster, Fusui Nature Reserve, based on data from modified line transect sampling in 1998 and 2003. Overall: pooled data from single transect lines. s: standard deviation of encounter frequency for langur groups; m: mean frequency of encounters with langur groups; CL: confidence limits; % precision: precision of population estimates; D_g: group density; mg: mean group size; G: total number of langur groups in the whole study area; N: population size in the whole study area

Transect	1998						Transect	2003					
	Line I	Line II	Line III	Line IV	Line V	Overall		Line I	Line II	Line III	Line IV	Line V	Overall
1	0	0	0	0	0	0	1	2	1	1	1	2	7
2	0	1	1	0	0	2	2	1	1	3	1	4	10
3	0	1	2	0	0	3	3	1	2	2	2	3	10
4	0	1	0	1	1	3	4	3	3	1	1	2	10
5	0	1	2	1	1	5	5	1	1	5	0	2	9
6	1	5	2	0	2	10							
7	3	4	1	1	1	10							
8	1	3	1	1	0	6							
9	3	3	1	0	1	8							
10	0	0	0	1	0	1							
11	0	3	1	0	1	5							
12	1	2	4	1	0	8							
13	0	2	1	1	0	4							
Variable													
Area (km^2)	0.57	1.01	2.41	0.48	0.85	5.32		0.57	1.01	2.41	0.48	0.85	5.32
s	1.11	1.53	1.09	0.52	0.66	3.27		0.89	0.89	1.67	0.71	0.89	1.30
m	0.7	2.0	1.2	0.5	0.5	5.0		1.6	1.6	2.4	1.0	2.6	9.2
CL	0.7	0.9	0.7	0.3	0.4	1.97		1.1	1.1	2.1	0.9	1.1	1.6
% precision	97.2	46.2	53.6	50.1	73.9	39.4		69.4	69.4	86.3	88.0	42.7	17.4
D_g (g km^{-2})	1.2	2.0	0.5	1.0	0.6	0.9		2.8	1.6	1.0	2.1	3.1	1.7
mg (ind. g^{-1})					6.8[a]							7.8[b]	
G						19 ± 7[a]							34 ± 6
N						129 ± 48							265 ± 47

[a]Data from sweep surveys in December 1996 to April 1997 (Li et al. 2003)
[b]Data from the partition-spot surveys in January to February 2003

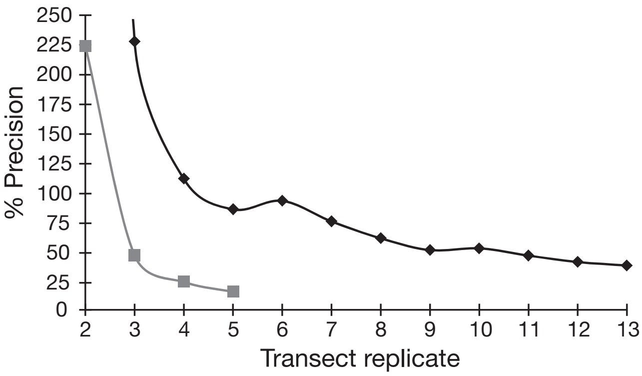

Fig. 3. Relationship between data precision using modified line-transect sampling (MLTS) and increasing number of transect replicates.% precision calculated from overall data in Table 1. 2003 data (■);1998 data (◆)

In January and February 2003, there were 7 surveyors. Each of them surveyed one transect line every half day, with 5 repeats in 2.5 d along each path. Thus, a total of 17.5 worker-days were invested. We obtained an estimate of 34 ± 6 (i.e. 28 to 40) langur groups in LGS and 265 ± 47 (218 to 312) langurs using the overall data, with a group density of 1.7 groups km^{-2} and a precision index of 17.4 % (Table 1). The data precision similarly increased with more replicates of each transect (Fig. 3), but no significant correlation was found between the area sampled and the precision index (Spearman rank correlation coefficient test, $r_S = 0.4857$, n = 6, 2-tailed, p > 0.5). The contribution of the area sampled to the variation of precision index was 23.6 %.

DISCUSSION

In January and February 2003, we obtained 2 different data sets on the population size of white-headed langurs in hill cluster LGS using the techniques of PSS and MLTS, which we could then compare. The PSS yielded a population size of 30 langur groups and 233 individuals, and the MLTS yielded an estimate of 28 to 40 langur groups and 218 to 312 ind. Thus, results from the 2 data sets overlapped. With further replicates, the data precision in the latter technique would increase. One more replicate of each transect would decrease the CL to 1.0, and thus the precision index would decrease to 10.9 %. This would give population estimates ranging from 30 to 38 langur groups and 234 to 296 ind., so that the values from the PSS would be at the lower limit of the estimate from the MLTS method. This could be due to an underestimate of the size of langur groups in inaccessible areas. Previous data had shown that groups competed for areas less disturbed by humans (Li & Rogers 2004a, 2005b). Group size was also greater in less disturbed areas (Li & Rogers 2004a), and the groups had smaller home ranges and spent more time in the valleys inaccessible to humans (Li & Rogers 2005b). However, in a single PSS, we had fewer chances to encounter the larger langur groups. We can regard the results from the PSS as a conservative estimate of the population size of the langurs, and therefore as an indicator of minimum population size.

Data from our MLT sampling (Table 1) show that data precision for single transect lines was less than that for the whole study site, probably due to sampling error. Langurs move around on the limestone hills, so their home ranges cover most parts of each hill (Li & Rogers 2005b), whereas surveyors sampled only visible areas, covering only a small part of the home range of any group. Thus, it is easy to miss langur groups during surveying. Using the overall data reduces biases and variance, because any langur group missed along one transect could be detected in other transect areas. Therefore, pooling data from single transect lines results in better data precision. Although no significant correlations were found from our studies to support the effect of sampling error, a comparison between data from 1998 and 2003 indicates this. In short-term fieldwork (2003), various factors may simultaneously influence variance within the data, which reduces the contribution of area sampled. However, this contribution should increase with more replicate transects (1998), because repetition will reduce the influence of chance factors. Our findings support this expectation.

Fig. 3 shows that precision of the overall data improved with increasing transect repeats, but the relationship was non-linear. The precision index decreased sharply initially, but the curve then levelled out, providing a cut-off point for the number of repeat transects required. Surveyors were all experienced, so non-detection and area sampled probably did not have a major influence on variations in the precision index. Instead, variation probably resulted only from the langurs' foraging and ranging behaviour, which can take them out of the study site (Li & Rogers 2004b, 2005b), or involve periods of concealment in vegetation (Li 2000).

There was a constant difference in data precision between 1998 and 2003 (Fig. 3), and the 2 curves are nearly the same shape. An obvious difference is that, in 1998, we had fewer trained surveyors in the field for longer (6.5 mo), whereas in 2003, we had many more trained surveyors working for only 2.5 d. In long-term fieldwork, climatic changes influence the langurs' behaviour (Li 1993, Huang et al. 2003b), which in turn alters the data precision. Also, there were frequent births and deaths, which changed the size of langur groups (Li & Rogers 2004a). These factors would not have influenced data precision in the short 2003 surveying period. Another factor may be sampling error, which was greater in 1998, because we surveyed a single transect line at a time, and could have missed langur groups outside the transect area at the time of sampling. In 2003, however, all 5 transect lines were sampled simultaneously, so a langur group missing from the area of one transect line during surveying could be detected on another line.

The final factor causing over- or underestimates is the mean group size (*mg*). Habitats of different quality supported langur groups of different sizes (Li & Rogers 2005b), and group size in the central area of the study site was greater than that in marginal habitat. Thus, when data from the central area were used for calculating the *mg* size, an overestimate of population size resulted, whereas data from marginal habitat gave an underestimate. Data from the whole study area (LGS in the case studies) obtained either in intensive surveys or from opportunistic observations may yield a better estimate.

In terms of conservation, the most interesting difference between the MLTS results in 1998 and 2003 is that the population size estimate for LGS in 2003 was significantly larger (34 ± 6 groups, 265 ± 47 langurs cf. 19 ± 7 groups and a total of 129 ± 48 langurs). More groups were counted and more infants seen, even though the area of the reserve had not changed. The most likely reason for this increase in langur numbers is that in 2000 the reserve headquarters changed their working practices. Throughout the 1990s, reserve staff did not patrol the limestone hills. Hunting was common and tree felling for cash income was not prohibited in the protected areas. In 2000, central government seized illegal guns and poaching stopped. In the same year, with a new scoring system imposed to assess annual achievement, and more funding from the state budget, reserve staff resumed daily patrols. We had fewer reports of poaching in 2001, and none in 2003. The natural vegetation had recovered to some extent by 2003, compared to its condition in the 1990s, because fewer trees had been cut. Therefore, the cessation of poaching and recovery of vegetation probably made major contributions to the increase in langur numbers. If these important changes to working practices could now be combined with essential habitat restoration, and establishment of existing reserves as secure refuges for langurs, then prospects for their conservation would improve.

Practical application of survey methods

Our results have shown that PSS counts are very labour intensive, but yield good estimates of population size, and additional information on group size and composition. MLTS is very time-efficient, but may lead to some double counting, and yield limited information on group dynamics. MLTS is sensitive to sampling error and any clumped distribution of langur groups, leading to an overestimate of population size if groups preferred habitat near existing paths, and an underestimate if they tended to avoid the paths. Thus, MLTS would yield the best data if langur groups were evenly distributed. By contrast, the PSS does not require consideration of the distribution pattern of langur groups. Furthermore, the local conservation authority is more interested in information on the locations of langur groups, so it prefers this technique to MLTS. However, information on langur group locations is of less immediate use in conservation management, because the locality of home ranges often changes with social dynamics (Li & Rogers 2005b).

Although the distribution patterns of animals do not restrict use of the PSS, it is difficult to apply in the topography of landscape Type I (Fig.1), because it is logistically difficult to partition the study area in such terrain. For example, in Longgang National Nature Reserve, the topography is largely Type I (Li 2000), and only 10% of the area could be accessed in previous population surveys (Z. Li unpubl. data). This may be the reason why there are few reliable historical data from the reserve (Li et al. 2003).

PSS counts become prohibitively labour intensive when the costs of doing repeat surveys are considered. A single survey yields no data on variance; thus, data precision cannot be assessed without replicate surveys. Using PSS sampling to cover the LGS hill cluster on a routine basis, a minimum of one observer is required in each compartment, totalling 7 reserve staff. Then, it would take 42 worker-days (6 d; 7 surveyors) to complete a single survey in LGS. If 5 replicates are required to yield data with a precision index of 17.4%, as we obtained in 2003 using MLTS, then a total of 210 worker-days (30 d; 7 surveyors) would be needed, 12 times more than the investment needed using MLTS. If other hill clusters are involved, it will be impossible, due to financial, manpower and time constraints, for the reserve to conduct enough PS surveys. Therefore, MLTS is cheaper and faster, and more suitable for the rapid population surveys that are normally conducted in conservation management. In particular, this technique uses existing paths, and data can be collected during daily reconnaissance (White & Edwards 2000), so population monitoring involves little financial investment. From Fig. 3, a reasonable cut-off point for the number of replicate transects required to achieve an acceptable level of precision would be 2, assuming that the MLTS is applied according to our methods in 2003.

Some further comment is required on the applicability of sweep surveys (Li 2000; Li et al. 2003) for censusing white-headed langurs. Apart from the danger of doing such surveys in this terrain (see 'Censusing methods'), they have other disadvantages. Surveyors did not stay in compartments long enough to compensate for possible repeat counts or missed groups of langurs. Thus, variance between sweep surveys would probably be greater than with PSS. Although it was quicker, and therefore cheaper, to conduct a single sweep survey, more replicate surveys would be needed if data precision was to be similar to PSS. The large amount of investment (time, risk to participants, labour, and funds) restricts the practicality of conducting replicate surveys, making them less useful in practice than PSS.

Recommendations and application to other species

The optimal situation would be to compare data collected using conventional line-transect sampling with data from the MLTS. However, such comparisons cannot be made in limestone hills, because there is often no choice but to use existing paths. We currently recommend PSS and MLTS for counting populations of white-headed langurs. MLTS is recommended when one or more of the following conditions are met: (1) The survey area has low hunting pressure according to police records and villager interviews, or it is known that langur groups are evenly distributed. (2) The survey area is mainly landscape Type I, in which PSS cannot be done.

We especially recommend this technique for rapid population surveys in areas with high population density, such as LGS in Fusui NR (Li et al. 2003) and Longguanshan in Chongzuo NR (Huang et al. 2003a), because changes in population size in these areas significantly influence the survival status of the species as a whole. To obtain the best data precision, the fieldwork must be completed in a short period, as described for our surveys in 2003. The number of replicate transects required (hence time) depends on data precision. Surveyors should calculate the data precision index and plot it against the accumulative number of transect repeats every day. When the curve levels out, no further repeats are required (Fig. 3, 2003 curve). In other situations, we recommend PSS, especially when no previous surveys have been made in Type II landscapes.

In addition to white-headed langurs, François' langurs *Trachypithecus françoisi* are also found on limestone hills in South China (Li 1993, Li et al. 2007), and resemble white-headed langurs behaviourally (Gong 2006, Xiong 2006). Other colobine species are found on limestone landscape in Indochina and Thailand (Oates et al. 1994). If the behaviour of these species is similar to that of white-headed langurs, the 2 techniques recommended may be suitable for them also.

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